



Transcend

State of the Industry— Generative Design in Wastewater Treatment

October 2023



Water is an invaluable resource that supports life and various human activities.

However, as human settlements have grown, so has the need for effective water treatment methodologies. This report delves into the multifaceted world of wastewater treatment, outlining the importance, advancements, market dynamics, and various technological strategies employed in this critical sector.

From the challenges posed by phosphorous pollution and the innovative approaches in membrane technology to the foundational primary treatment processes, the report comprehensively discusses each segment's significance and current trends. Special emphasis is laid on the drivers pushing the evolution of wastewater treatment, the market opportunities they create, and the potential barriers in adoption.

By synthesizing a myriad of data and insights, this report aims to provide a holistic view of the wastewater treatment landscape. Whether it's the market value spurred by technological innovations or the transformative impact of wastewater reuse, every element is explored in detail, offering readers a cohesive understanding of current practices and future potential in wastewater management.

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Carbon accounting

Background

Carbon accounting, sometimes referred to as greenhouse gas accounting – is the process in which a company (or plant) measures the level of carbon dioxide emissions they are responsible for. The driving force of carbon accounting is the need to reduce global warming by trying to reduce carbon footprint and reach net-zero carbon emissions. Carbon accounting helps to serve as a quantifiable measure that a company or individual can be held accountable for and so that they may equally and fairly trade carbon credits between states, companies, and individuals in the carbon market.



Opportunity

The global carbon footprint management market is expanding due to increasing environmental consciousness and the topic's increased focus by regulatory bodies worldwide. Businesses across sectors are adopting carbon accounting software to comply with government mandates and industry standards like the US Green Deal and the EU's new taxonomy for sustainable activities. Penalties for non-compliance with carbon emission reduction mandates can be significant, and hence are being considered earlier in development planning.

Market size

The US market size for carbon management software has been estimated at approximately USD \$9 billion in 2022, with projected growth rates (CAGR) varying between 6.2% (Marketsandmarkets), 6.4% (Straits research), 13.3% (Mordor Intelligence) and 28.6% (Technavio) over the next 10 years, depending on the source.

Competitors

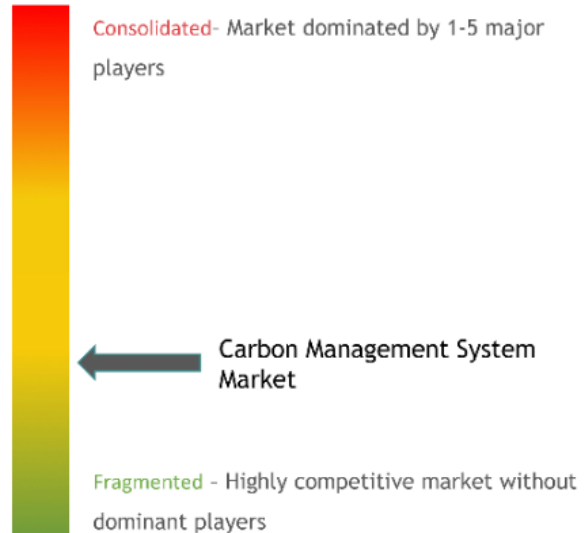
The market is tending towards fragmentation with an increase in the number of players offering software for monitoring and management, due to a rise in the adoption of cloud services. Meanwhile, carbon accounting consultation services show steady growth.

Carbon Management System Market Top Players

- 1 Simble Solutions Ltd
- 2 IBM Corporation
- 3 ENGIE Impact
- 4 GreenStep Solutions Inc.
- 5 SAP SE

*Disclaimer: Major Players sorted in no particular order

Market Concentration



Source: Mordor Intelligence



Figure 1: Top market players as competitors (Mordor Intelligence, 2022)

In July 2022, Gravity Climate launched its carbon management software “GRAVITY” for industrial businesses and their supply chain partners. The software focuses on industries with significant physical operations and infrastructure, such as construction, metals, and energy services.



Water sector

CONTEXT

Looking at the water sector, the following infographic by GWI summarizes the highest global carbon emissions by water industry sub-sectors, with water distribution and abstraction, wastewater treatment, and septic tanks playing significant roles.

Key emission hotspots

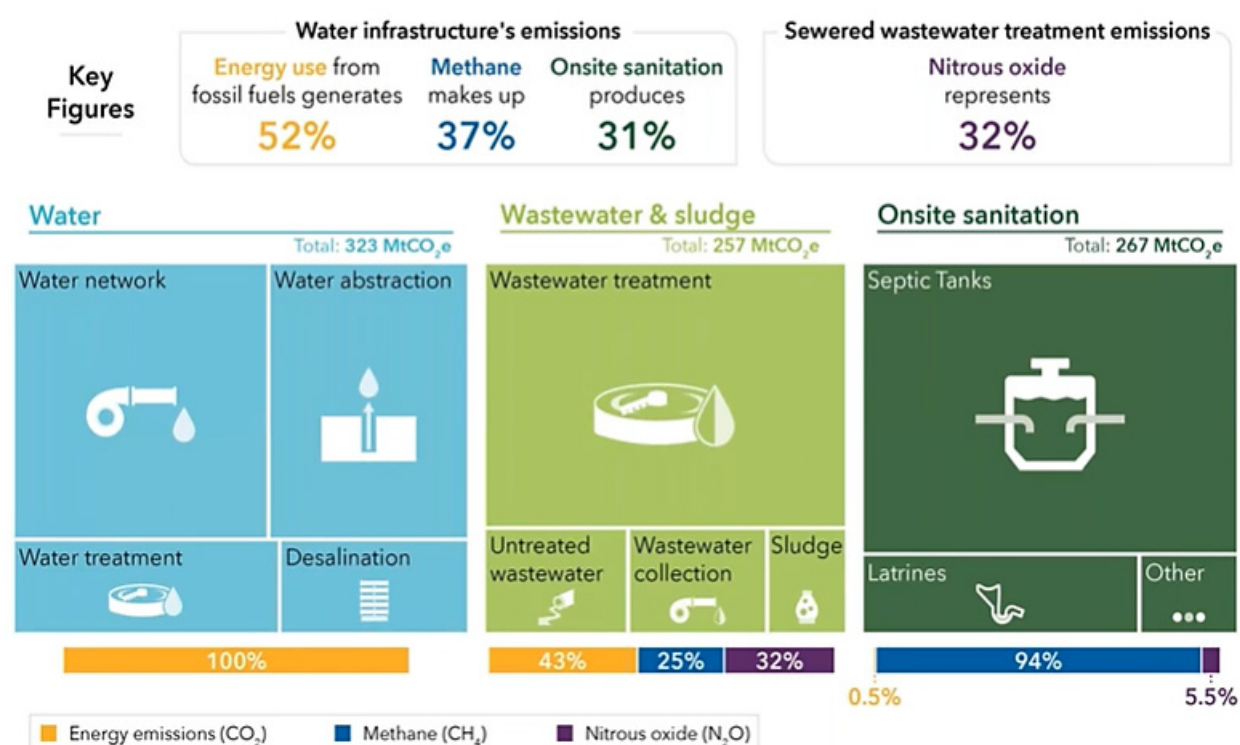


Figure 2: Global carbon emissions by water industry sub-sector—GWI's COP27 presentation Mapping water's carbon footprint (16 November 2022)

TECHNOLOGY OPPORTUNITIES

As the carbon accounting industry grows to bring more awareness of these significant contributors to carbon emissions, solutions are required to mitigate the industry's emissions. The following solutions were identified by GWI as key trends that will be driven by the growth in the carbon management market. The focus is currently on reducing energy consumption, but there are also indirect opportunities such as creating a greener energy supply mix.

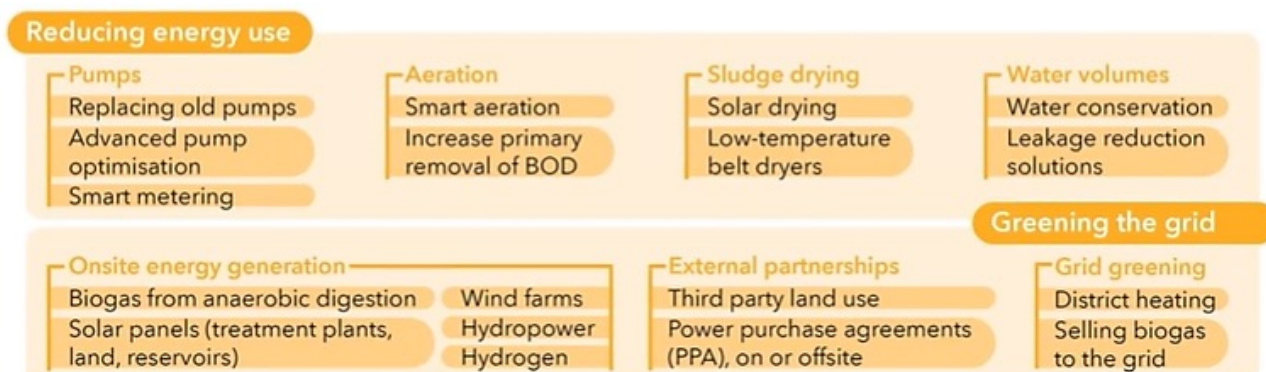


Figure 3: Popular solutions to reduce carbon emissions in the water industry–GWI’s COP27 presentation Mapping water’s carbon footprint (16 November 2022)

For some TDG clients, including Scottish Water and South West Water, older technologies may have a higher potential to reduce emissions. For example, trickling filters can be used as an alternative to activated sludge to remove carbon and some nutrients using only pumping, consuming less energy than activated sludge with aeration requirements.

DRIVER FOR FUTURE TECHNOLOGIES

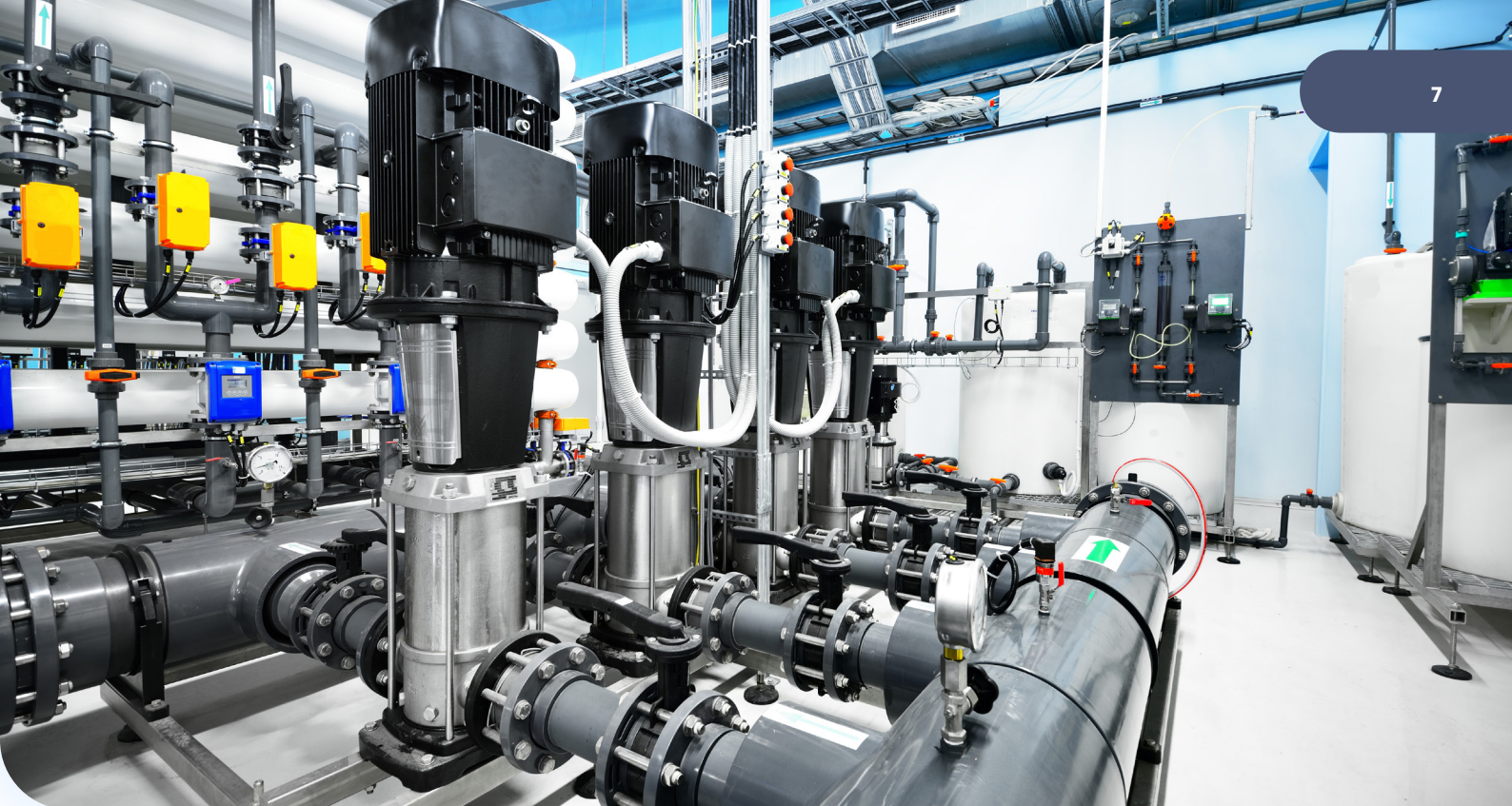
Nitrous oxide is a particular concern at wastewater treatment plants. It is 300 times more potent than carbon dioxide as a greenhouse gas. The triggers for its release are still being researched, but it is released during the activated sludge process and appears to increase in biological nutrient removal processes and in stressed systems (e.g. during seasonal peak loads or insufficient aeration conditions). Alongside the lowering of effluent nutrient limits by regulators, the production of nitrous oxide is set to increase.

MARKET RISKS

The value of the impact of carbon may not be growing fast enough to support carbon as a key driver in decision making in the water sector. Water is a primary human resource, the supply of which cannot cease to focus on the future impact of carbon emissions.

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Membrane innovation

Background

Membrane technology is established as a favourite choice for reclaiming water from different wastewater streams for reuse through separation of solids from liquid. Membrane separation is based on selective filtration through pores of different sizes and consists of four main membrane types: microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. A Membrane BioReactor (MBR), a widely used technology in both municipal and industrial wastewater treatment plants, is a process which combines a microfiltration or ultrafiltration membrane unit with a suspended growth bioreactor.

Innovation

Membrane application in wastewater treatment is expanding beyond solid-liquid phase separation systems with some innovative approaches. Membrane Aerated Biofilm Reactor (MABR) technology, for example, is a membrane that is porous to oxygen, separating liquid and gaseous phases in the biological reactor, for a higher efficiency transfer of oxygen to the growing biomass. This technology has demonstrated 50 to 75% savings in aeration energy costs.

Another example is ZwitterCo, who are producing innovative membranes that can separate high concentrations of fats, oil and grease from water, producing two valuable output streams. This type of waste stream would cause severe irreparable fouling to most conventional membranes.

NX Filtration have developed technology to precisely control their hollow fibre membrane's selectivity properties on a nanometre level based on a polyelectrolyte multilayer, achieving removal of micropollutants, medicine residues, pesticides, PFAS and other pollutants.

Market value

The global membranes market size was valued at USD \$6.4 billion in 2022 and is projected to reach USD \$10.1 billion by 2027, assuming a growth rate of 9.7% from 2022 to 2027. The market for membrane water and wastewater treatment is expected to grow at a rate of at least 7% for this period.

Market trends and drivers

The following market trends and drivers are contributing to the steadily growing membrane technology market:

- **Stringent Regulatory Standards:** Governments and regulatory bodies across the globe are imposing stringent effluent discharge standards, driving the adoption of advanced wastewater treatment technologies such as membrane systems.
- **Water Scarcity Concerns:** The increasing scarcity of freshwater resources is creating a pressing need for water reuse and recycling. Membrane technologies play a crucial role in wastewater reclamation and enabling the safe and sustainable reuse of water.
- **Industrial Applications:** Industries such as food and beverage, pharmaceuticals, chemicals, and power generation require efficient wastewater treatment solutions to comply with environmental regulations. Membrane technologies offer effective treatment options for these industries.
- **Technological Advancements:** Ongoing research and development efforts have led to continuous improvements in membrane technologies, including enhanced fouling resistance, higher flux rates, and reduced energy consumption, making them more cost-effective and efficient. This is one of the major factors driving the market, as the reduced energy consumption is associated with carbon emission reduction. Advancements are focusing on achieving lower pressure membrane technologies to achieve this.

Conclusion

In conclusion, the future of membrane technology looks promising, with continuous research and development paving the way for more efficient, cost-effective, and environmentally friendly solutions. The potential of membranes extends beyond traditional applications, with innovative approaches opening new avenues for enhanced efficiency and cost savings. The growing market value of membrane technology is a testament to its increasing adoption and acceptance worldwide. With a minimum projected growth rate of 7% in the coming years, membrane technology is poised to play an even more significant role in securing our water resources and safeguarding the environment.

Phosphorous removal

Background

Phosphorous is a major pollutant found in wastewater, primarily originating from domestic, industrial, and agricultural sources. High levels of phosphorous in water bodies can lead to eutrophication, algal blooms, and ecological imbalances. Consequently, governments and environmental agencies worldwide have implemented regulations to limit phosphorous discharge, creating a demand for effective removal technologies in wastewater treatment plants.

Market drivers

Factors such as increasing water pollution concerns, stringent environmental regulations, growing investment in wastewater infrastructure development, and phosphorous resource shortages are expected to drive market growth. We take a closer look at the following market drivers:

- 1. Stringent Regulatory Standards and Changing Regulations:** Governments worldwide are implementing stringent regulatory standards regarding phosphorous discharge limits, compelling wastewater treatment facilities to adopt effective removal technologies to mitigate the environmental impact of phosphorous pollution. Here are some notable changes in regulations that have contributed to this trend:
 - a. Water Quality Standards and Limits:** Regulatory bodies are establishing and revising water quality standards and limits, including specific thresholds for phosphorous concentration in water bodies. These standards aim to ensure the protection of aquatic ecosystems and public health. As scientific research advances and more data becomes available on the ecological impacts of phosphorous pollution, regulatory agencies are updating these standards to reflect the latest knowledge.
 - b. National and Regional Discharge Permits:** Authorities issue discharge permits to wastewater treatment plants, setting specific limits on the concentrations of pollutants, including phosphorous, that can be released into receiving water bodies.
 - c. Phosphorous Trading and Offset Programs:** Some regions have implemented phosphorous trading and offset programs, allowing wastewater treatment plants and industries to trade or offset their phosphorous loadings. These programs incentivize facilities to reduce phosphorous discharges below their permitted limits by installing advanced phosphorous removal technologies. Facilities that achieve lower phosphorous levels can earn credits that can be sold to other facilities exceeding their phosphorous limits.

- 2. Adoption of Advanced Technologies:** Wastewater treatment plants are increasingly adopting advanced technologies like biological phosphorous removal and membrane filtration, which offer more efficient and cost-effective phosphorous removal compared to conventional methods.
- 3. Growing Awareness and Education:** There is a growing awareness among the general public about the adverse effects of phosphorous pollution, which is driving the regulatory changes and hence also the demand for efficient phosphorous removal technologies.
- 4. Rising Investment in Wastewater Infrastructure:** Governments and private entities are investing significantly in upgrading existing wastewater treatment infrastructure and constructing new facilities, providing lucrative opportunities for the phosphorous removal market.
- 5. Phosphorous Resource Shortage:** There is a growing concern regarding the potential shortage of phosphorous worldwide. Phosphorous is a finite resource, primarily obtained from phosphate rock deposits, and it is an essential nutrient for agricultural productivity. As the global population grows and demand for food increases, the demand for phosphorous as a fertilizer also rises. Geopolitical factors, trade restrictions, and market dynamics can further impact the accessibility and cost of phosphorous resources. Consequently, there is a need for sustainable phosphorous management, including the reduction of phosphorous waste and the recovery of phosphorous from various sources, including wastewater. An estimated 22% of global phosphorus demand could be satisfied by recycling domestic wastewater worldwide.

Technologies

Phosphorous removal

The phosphorous removal market can be segmented based on technology including:

- 1. Chemical Precipitation:** Chemical precipitation is a widely used technology for phosphorous removal in wastewater treatment. It involves the addition of chemicals such as iron or aluminum salts to the wastewater, which react with phosphorous to form insoluble precipitates. The market value for chemical precipitation technologies is influenced by factors such as the scale of application, type of chemicals used, and the overall demand for phosphorous removal solutions. It is considered to be a mature technology, and the market value is typically stable.
- 2. Biological Phosphorous Removal:** Biological phosphorous removal relies on the use of specific microbial communities that can accumulate and remove phosphorous from wastewater. This technology has gained popularity due to its effectiveness and cost efficiency. The market value for biological phosphorous removal is influenced by factors such as the size of the wastewater treatment plant, the complexity of the treatment process, and the level of phosphorous removal required. It is considered to have a moderate to high market value.

- 3. Enhanced Biological Phosphorous Removal:** Enhanced biological phosphorous removal (EBPR) is an advanced variation of biological phosphorous removal that achieves higher removal efficiency through process optimization and control. EBPR typically involves additional steps, such as anaerobic conditions and alternating cycles, to enhance the phosphorous uptake by microbial organisms. The market value for EBPR technologies is influenced by factors such as the complexity of the process, the level of automation, and the demand for advanced phosphorous removal solutions. It is considered to have a moderate to high market value.
- 4. Adsorption:** Adsorption technologies involve the use of adsorbents, such as activated carbon or specialized media, to capture and remove phosphorous from wastewater. Adsorption is an effective method for phosphorous removal, especially for low concentrations and small-scale applications. The market value for adsorption technologies depends on factors such as the type and quality of adsorbents, the specific design of the system, and the overall demand for adsorption-based phosphorous removal solutions. It is considered to have a moderate market value.
- 5. Membrane Filtration:** Membrane filtration technologies, including microfiltration, ultrafiltration, and nanofiltration, can effectively remove phosphorous from wastewater by physically separating solids and dissolved substances. Membrane filtration is known for its high removal efficiency and ability to produce high-quality effluent. P effluent concentrations of 1 mg/L can be achieved by conventional gravity settling, however, stricter effluent standards will generally demand more sophisticated separation techniques. The market value for membrane filtration technologies depends on factors such as the membrane material, system design, membrane lifespan, and the scale of application. It is considered to have a high market value due to its advanced nature and high-performance capabilities.



SPOTLIGHT: NEREDA

The Nereda technology is an innovative wastewater treatment process that utilizes aerobic granular sludge to remove pollutants, including phosphorous, from wastewater. While the primary focus of the Nereda technology is biological nutrient removal (BNR), it can effectively target the removal of phosphorous as well.

The Nereda process operates on the principle of granular sludge formation, where dense aggregates of bacteria and other microorganisms form larger, compact structures called granules. These granules have excellent settling properties, allowing for enhanced separation of solids from the treated wastewater.

In the context of phosphorous removal, the Nereda process incorporates specific adaptations and process controls to optimize the phosphorous removal efficiency. Key mechanisms by which Nereda achieves phosphorous removal include:

- 1. Enhanced Uptake:** The granular sludge within the Nereda process contains microorganisms with high phosphorous uptake capabilities. These microorganisms can accumulate and store phosphorous within their cells, leading to efficient removal from the wastewater.
- 2. Anaerobic Conditions:** The Nereda process includes an anaerobic zone within the treatment cycle. This anaerobic phase creates favorable conditions for phosphorous release from the biomass, further enhancing its removal.
- 3. Denitrification:** The Nereda process also incorporates denitrification, which reduces the competition between nitrate and phosphorous uptake, allowing for improved phosphorous removal efficiency.

Overall, the Nereda technology offers an advanced and sustainable solution for wastewater treatment, combining biological nutrient removal with efficient phosphorous removal. Its unique granular sludge configuration and process controls enable high-performance treatment, energy efficiency, and a smaller footprint compared to conventional activated sludge systems.

Technologies in the Transcend Design Generator

The Transcend Design Generator (TDG) offers the following options for phosphorous removal:

- 1. Chemical Precipitation:** a selection can be made from 6 different chemicals, with dosing positions and primary and secondary phase separation units. An additional 2 chemicals and a further dosing point at the biological reactor will be added in Q3 to support the needs of our UK utility customers.

- 2. Biological Phosphorus Removal:** aerobic zones within all our biological reactor types take into account the phosphorus uptake to form biomass, removing it from the liquid stream.
- 3. Enhanced Biological Phosphorus Removal:** anaerobic zones can be incorporated into conventional activated sludge, MBBR and MBR reactors in TDG. SBR and **Nereda** technologies are also available, where phases of their cycles are optimized for anaerobic conditions.
- 4. Membrane Filtration:** MBR facilities can be selected in TDG, which involve an ultrafiltration step.

Phosphorus recovery

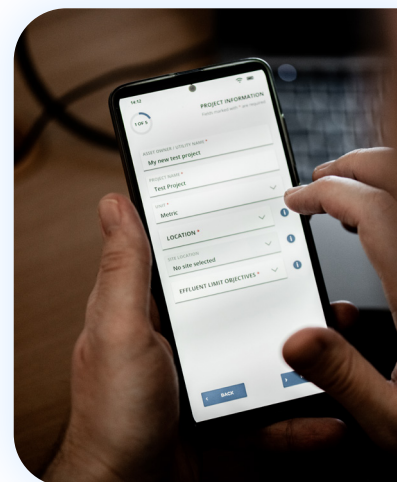
Phosphorous recovery technologies, which aim to extract and reuse phosphorous from wastewater, have gained attention in recent years. These technologies offer the dual benefit of mitigating phosphorous pollution while providing a valuable resource for agricultural or industrial applications. Phosphorous recovery technologies can include techniques such as struvite precipitation, thermal processes, and biological phosphorous recovery. The uptake of phosphorous removal technologies in wastewater treatment is driven by the need to minimize phosphorous pollution, protect water resources, and reduce the environmental impact of disposing of additional sludge produced by phosphorous removal technologies. Stringent environmental regulations are driving up the cost of sludge disposal from wastewater treatment plants.

While the adoption of phosphorous recovery technologies is growing, phosphorous removal technologies still dominate the market due to:

- Water regulatory requirements, with their established role in wastewater treatment, are a higher priority than waste and carbon regulatory requirements, and
- The economic balance between the higher capital cost of recovery technologies compared with the growing operational cost associated with disposing of additional sludge produced by removal processes.

Technology implementation impact

Implementing phosphorous removal or recovery technologies requires an overall treatment plant re-modelling, due to the integrated nature of the technologies. For enhanced biological phosphorus removal and membrane filtration, an additional anaerobic zone in a reactor or alternative phase separation units is a major reconfiguration of the secondary treatment and its recycled flows. Even for chemical phosphorous removal, which appears to be easier to retrofit, the additional sludge produced due to the chemical addition can increase the required sludge treatment and secondary treatment process units. These changes have major capital infrastructure cost and ongoing operating cost implications.



Market analysis

Market value estimate

The global phosphorous removal market is estimated at US \$59 billion. It is projected to be realized over a 20- to 25-year forecast period as the uptake of phosphorous removal and recovery technologies accelerate.

The phosphorus removal market value is based on a 50/50 market share between chemical and enhanced biological phosphorous removal technologies. While other technologies are already in the market, their market value is not as easily quantified due to proprietary solutions forming the majority, with limited costing data.

The enhanced biological phosphorous removal market cost increase of 12.75% compared to conventional aerobic systems is based on:

- An estimated 20% to 50% extra sludge is produced by biological nutrient removal processes (which include phosphorus removal) compared to conventional aerobic processes. Taking the average of 35% extra sludge, the sludge treatment process units, which constitute at least 15% of the total capital cost of a wastewater treatment plant, resulting in a 5.25% overall increase in plant capital cost.
- An estimated 10% to 50% extra reactor and clarifier capacity is required for biological nutrient removal plants compared to conventional aerobic reactors, to accommodate the recycled extra sludge flow and anaerobic zones. Taking the average of 30% extra capacity (reactor volume and clarifier surface area), the secondary treatment, which constitute approximately 25% of the total capital cost of a wastewater treatment plant, resulting in a 7.5% overall increase in plant capital cost.

The chemical phosphorus removal market cost increase of 15.13% compared to conventional aerobic systems is based on:

- An estimated 30% to 80% extra sludge is produced by adding chemical phosphorus removal to conventional aerobic processes. Taking the average of 55% extra sludge, the sludge treatment process units, which constitute at least 15% of the total capital cost of a wastewater treatment plant, resulting in an 8.25% overall increase in plant capital cost.
- Associated with the additional sludge production, the reactors and clarifiers can expect an estimated 27.5% increase in capacity (volume and surface area, respectively) at a return activated sludge recycle ratio of 1. The reactors and clarifiers, which constitute approximately 25% of the total capital cost of a wastewater treatment plant, require increased capacity, resulting in a 6.88% overall increase in plant capital cost.

The capital cost of wastewater treatment was estimated from a unit cost of US\$ 2 per m³/d of wastewater treatment capacity required, with 380 billion m³/d of wastewater requiring treatment globally, while only 56% is treated (UN Water), resulting in a cost of US\$ 426 billion for wastewater treatment infrastructure without phosphorous removal.

Note that these market values are based on averages, and values can vary significantly depending on the phosphorous load that requires removal, the other available nutrients in the wastewater to support phosphorous removal processes, the configuration of the treatment plant, peak and dynamic loading conditions, economic variations globally, the fraction of wastewater that is sewered and treated per region, the size of the treatment plant, etc.

Transcend market share

The potential Transcend market share for phosphorous removal in wastewater treatment can be estimated at \$1.2 billion over the next 20-years. The projected realization of this market value starts at \$370 million in the next 5 years as Global Water Intelligence estimates global spending on digital solutions to grow 8% annually.

The market share is based on preliminary design costs for water infrastructure projects ranging from around 1% to 5% of the total project cost. These costs typically cover activities such as feasibility studies, site assessments, data collection, preliminary engineering designs, and environmental impact assessments. The preliminary engineering designs is assumed to constitute approximately 2% of the total infrastructure cost.

Competitive landscape

The phosphorous removal market is highly competitive, with several key players operating globally. Some of the major companies in the market include:

- **Evoqua Water Technologies:** Evoqua offers a range of technologies for phosphorus removal, including chemical precipitation and enhanced biological phosphorus removal (EBPR) systems.
- **SUEZ Water Technologies & Solutions:** SUEZ provides various phosphorus removal solutions, including chemical precipitation systems, biological processes, and advanced filtration technologies.
- **Veolia Water Technologies:** Veolia offers a range of phosphorus removal technologies, including chemical precipitation, adsorption, and biological processes, tailored to specific wastewater treatment needs.
- **Ovivo:** Ovivo specializes in wastewater treatment solutions, including phosphorus removal technologies such as chemical precipitation, biological phosphorus removal, and membrane filtration.
- **Aqwise-Wise Water Technologies:** Aqwise provides innovative solutions for biological nutrient removal, including phosphorus removal. Their technologies, such as AGAR and AGAR MBBR, enhance the removal of nitrogen and phosphorus in wastewater treatment.
- **Kemira:** Kemira is a chemical company that offers various products and solutions for phosphorus removal, including coagulants and flocculants used in chemical precipitation processes.

- **HUBER Technology:** HUBER provides phosphorus removal technologies for wastewater treatment, including chemical precipitation systems and advanced filtration solutions.
- **Nijhuis Industries:** Nijhuis Industries offers sustainable wastewater treatment solutions, including phosphorus removal technologies like chemical precipitation, biological processes, and membrane filtration.
- **Siemens Water Solutions:** Siemens provides advanced phosphorus removal solutions, including chemical precipitation technologies, as well as membrane filtration systems for water and wastewater treatment.

These companies are focusing on research and development activities, strategic partnerships, and mergers and acquisitions to strengthen their market presence and expand their product portfolios.

Conclusion

The phosphorous removal market is experiencing steady growth due to increased environmental regulations, rising awareness about water pollution, and growing investments in wastewater infrastructure. Advanced technologies, such as biological phosphorous removal and membrane filtration, are gaining prominence due to their efficiency and cost-effectiveness. The market is expected to expand significantly in the coming years, providing lucrative opportunities for both established players and new entrants in the phosphorous removal industry.

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Primary treatment

Background

Primary wastewater treatment is the first of three treatment phases that follow pretreatment. The wastewater treatment process consists of three phases – primary treatment, secondary treatment and tertiary treatment. Primary treatment removes material that will settle with gravity or float. Primary treatment reduces the organic load and suspended solids in wastewater, reducing the load on the subsequent biological and chemical treatments, and hence also reducing the capacity and costs associated with secondary treatment.

Technologies

Some of the key technologies used for primary treatment of wastewater are:

- **Primary Clarifiers:** Primary clarifiers, also known as primary sedimentation tanks, are large tanks where wastewater flows slowly, allowing suspended solids and particulate matter to settle to the bottom due to gravity. The settled solids form a sludge layer, while clarified water is collected for further treatment.
- **Dissolved Air Flotation (DAF):** DAF systems are effective in primary phase separation. They introduce fine air bubbles into wastewater, which attach to suspended solids, oils, and greases, causing them to float to the surface. The floating material is then skimmed off, leaving behind clarified water.
- **Inclined Plate Settlers:** Inclined plate settlers, or lamella clarifiers, consist of a series of inclined plates that enhance settling by increasing the surface area for solids to settle. The inclined plates provide a longer path for wastewater flow, facilitating better separation of solids.
- **Primary Filtration:** The process of primary filtration involves passing the wastewater through a series of disks covered with pile cloth filtration media. The pile cloth, a specially woven fabric with a coarse texture, acts as a filter medium that effectively traps and retains solid particles, including debris, sediment, and larger organic matter. The disks are arranged in a parallel configuration, creating a filter bed that allows for efficient and continuous flow of wastewater. Greater solids removal efficiency can be achieved than in primary clarifiers, and the removal performance is more reliable during peak flows, causing a high uptake rate for this relatively new technology. Transcend supports clients with including this technology in their designs. Clients are using primary filters to guarantee primary treatment efficiency during rainfall events, increase primary solids diversion to digesters for energy recovery, and reduce the load on the secondary treatment plant, expanding overall treatment plant capacity.

SPOTLIGHT: PRIMARY EFFLUENT FILTRATION AS EMERGING TECHNOLOGY

Another application for primary filtration of the effluent from the primary phase separation step is emerging. Where existing wastewater treatment plants already have primary clarification systems, adding primary filters to the effluent of the clarifiers has been shown to be beneficial in solids diversion towards digestion and energy recovery, as well as reducing the organic loading to the secondary treatment process. A 2013 study funded by the California Energy Commission (CEC) found that primary effluent filtration can reduce TSS to the aeration basin by 50 to 60 percent.

Drivers

- **Stringent wastewater discharge regulations:** Several governments have implemented strict regulations and standards for wastewater management for both municipal and industrial sectors to prevent water pollution and ensure compliance with environmental norms. For instance, the U.S. EPA has established the National Pollutant Discharge Elimination System (NPDES) program that regulates the discharge of pollutants from point sources into waters of the United States. Similarly, the European Union has adopted the Urban Wastewater Treatment Directive (UWWTD) that sets minimum standards for the collection and treatment of urban wastewater. These regulations create a demand for primary treatment equipment to meet the effluent quality criteria.
- **Carbon emission reduction targets:** The wastewater sector is a significant source of greenhouse gas (GHG) emissions, mainly from the biological processes that generate methane and nitrous oxide. According to the Intergovernmental Panel on Climate Change (IPCC), the wastewater sector accounted for about 3% of the global GHG emissions in 2010. To mitigate the climate change impacts of the wastewater sector, several countries have set carbon emission reduction targets and implemented policies and measures to promote low-carbon technologies and practices in wastewater management. For instance, the European Union has adopted the Circular Economy Action Plan that aims to reduce GHG emissions from wastewater by 50% by 2030 and by 80% by 2050 compared to 1990 levels. These targets create a demand for primary treatment equipment that can reduce the organic load and energy consumption of downstream treatment processes. Furthermore, the production of primary sludge offers the opportunity to generate biogas for energy offsetting. IMESA research indicates that including primary clarifiers (without biogas) can reduce a wastewater treatment plant's lifecycle cost by 34% over a 30-year design horizon. Further including biogas and energy generation for offsetting can bring this value up to 78%, depending on the size and organic load of the plant.

- **Peak wastewater flow treatment**

- **regulations:**

Both combined and separate sewer systems experience high peak influent flows during wet weather events that can exceed the capacity of their biological treatment units. These occurrences are becoming increasingly frequent as storms grow larger with climate change. To prevent damage to the treatment plant and maintain effective operations, some plants divert a portion of the flow around these units. However, the U.S. EPA's bypass regulation prohibits the intentional diversion of waste streams from any portion of a treatment facility except where necessary for essential maintenance and the EPA has initiated a rulemaking process to address the issues associated with the management and treatment of peak flows to ensure the protection of water quality and public health. Therefore, the uptake of primary treatment technologies has seen growth to ensure that peak flows are at least passed through a primary treatment step before discharge to the environment to protect the receiving water body from spills and pollution.

- **Limited space at existing treatment facilities:** The compact nature of primary treatment processes allows for more efficient use of limited space available at existing wastewater treatment plants.



Barriers

- **Potentially detrimental to enhanced biological phosphorous removal:** One of the barriers for including primary treatment is the increasingly stringent phosphorous effluent limits set by regulators. While more stringent effluent limits are commonly seen as a driver for wastewater treatment technology adoption, the separation of primary sludge can reduce the performance of downstream enhanced biological phosphorus removal facilities. To control the organic load that enters the reactor, primary treatment units can be partially bypassed.
- **Primary sludge stabilization:** Primary treatment units produce primary sludge or backwash, which requires sludge stabilization process units. At smaller plants, which have basic sludge dewatering for secondary sludge, adding primary sludge treatment units is not often practical due to the low economic benefit at small scale.

Market analysis

Market value estimate

The global primary water and wastewater treatment equipment market size was valued at USD \$12.12 billion in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 3.5% to reach USD \$15.92 billion by 2027. The market growth is driven by the rising demand for clean water, the increasing number of wastewater and sludge treatment plants, and the increasingly stringent regulations and standards for wastewater management.

The primary clarifier led the market and accounted for 28.7% of the global revenue in 2019 on account of its ability to remove around 25% of the total BOD, 40% to 60% of the suspended solids, and 90% to 95% of the settleable solids in the wastewater.

Conclusion

Overall, the market's positive trajectory, driven by the need for clean water and stringent wastewater management regulations, presents a promising landscape for primary wastewater treatment solutions, with primary clarifiers leading the market while newer technologies, like primary filters, show potential for future growth and adoption.

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Wastewater reuse

Background

Wastewater reuse, also known as water recycling or water reclamation, refers to the process of treating and repurposing wastewater for various beneficial purposes instead of discharging it into the environment.

The concept of wastewater reuse revolves around the understanding that treated wastewater can be a valuable resource rather than a waste product. Through advanced treatment processes, contaminants are removed, making the water safe for reuse in different applications, such as irrigation, industrial processes, environmental restoration, and even drinking water production with appropriate treatment.

Wastewater reuse presents an innovative and sustainable approach to address water scarcity, promote water conservation, and support sustainable water management. By treating and repurposing wastewater, this practice offers a valuable alternative water source, contributing to environmental protection, economic efficiency, and water resource sustainability. While challenges exist, the growing recognition of the importance of water reuse and advancements in treatment technologies pave the way for expanding opportunities in this sector.

Opportunity

Overall, the motivations for wastewater reuse stem from the pressing need to address water scarcity, promote sustainable water management, and capitalize on the economic and regulatory drivers. The combination of these factors has created a growing market for wastewater reuse solutions, offering opportunities for businesses involved in water treatment, technology development, engineering, consulting, and related sectors.

Drivers

Reuse has gained significant attention and momentum in recent years due to a range of motivations and market opportunities. Here are some key factors driving the interest and growth in wastewater reuse:

- **Water Scarcity:** Water scarcity is a global challenge, with many regions facing limited freshwater resources. Wastewater reuse offers a solution by providing an alternative source of water that can supplement traditional freshwater supplies. This is particularly important in arid and water-stressed regions where water availability is a critical concern.



- **Sustainable Water Management:** Wastewater reuse supports sustainable water management practices by reducing the strain on freshwater resources and decreasing the reliance on groundwater or surface water. By treating and reusing wastewater, the demand for freshwater extraction is reduced, leading to long-term environmental and economic benefits.
- **Diverse Applications:** Wastewater reuse can serve various applications, such as agricultural irrigation, industrial processes, landscaping, and even potable water production with advanced treatment. This versatility opens up a wide range of market opportunities across different sectors, providing customized solutions to meet specific needs.
- **Cost Savings:** Implementing wastewater reuse systems can offer cost savings in several ways. Firstly, it reduces the need for investing in expensive infrastructure for freshwater extraction and distribution. Secondly, it can decrease the costs associated with wastewater treatment and disposal, as the treated wastewater can be reused instead of being discharged into the environment or water bodies.
- **Regulatory Drivers:** Regulatory frameworks are increasingly promoting and mandating wastewater reuse to optimize water resource management and conservation. Governments and environmental agencies around the world are implementing policies and regulations that encourage or require water recycling practices. This creates a favorable market environment and opportunities for companies operating in the wastewater reuse sector.
- **Technological Advancements:** Advances in water treatment technologies have improved the feasibility and efficiency of wastewater reuse. Innovative processes such as membrane filtration, reverse osmosis, and advanced oxidation enable the removal of contaminants from wastewater, making it safe for various applications. Technological developments continue to enhance the viability and attractiveness of wastewater reuse solutions.
- **Public Perception and Acceptance:** There has been a growing recognition of the importance of sustainable water management practices among the general public and stakeholders. This increased awareness and concern for the environment have led to a greater acceptance of wastewater reuse as a viable and responsible approach, creating market opportunities for companies operating in this sector.

Market size

According to a report by the International Water Association (IWA) and the Global Water Intelligence (GWI), the global market for wastewater reuse was valued at around \$14 billion in 2019. Assuming a conservative annual growth rate of around 10% (which aligns with the historical trends and the increasing emphasis on water reuse), we can project the future market size of wastewater reuse. Please note that this projection is based on broad assumptions and should be interpreted as a rough estimate.

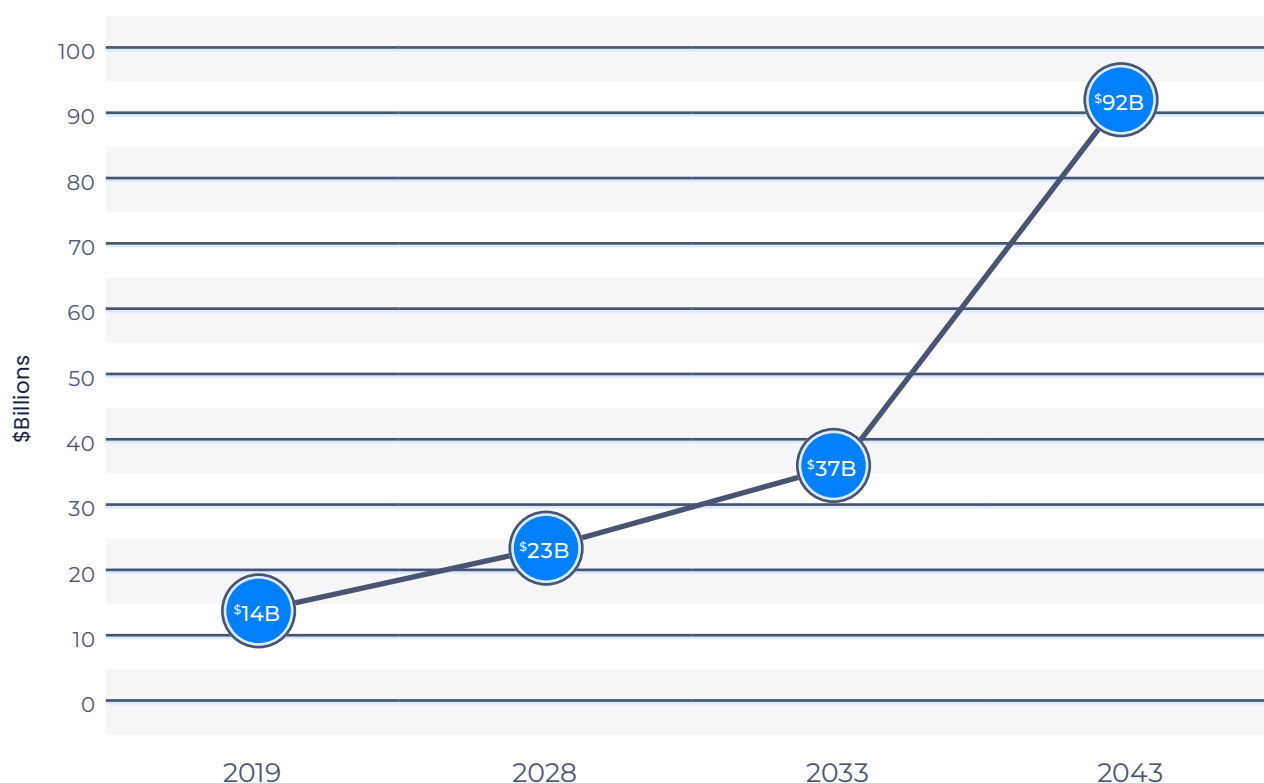


Figure 4: The projected future market size of wastewater reuse in billions of US\$. The market could reach approximately \$23 billion, \$37 billion, and \$92 billion in 5, 10 and 20 years (2028, 2033, 2043), respectively.

Regional variations will significantly impact the market size, as the demand and investment potential can vary across different countries and regions based on their water stress levels, economic development, and government policies regarding water management.

Transcend market share

In general, preliminary design costs for water infrastructure projects can range from around 1% to 5% of the total project cost. These costs typically cover activities such as feasibility studies, site assessments, data collection, preliminary engineering designs, and environmental impact assessments. Assuming that the preliminary engineering designs constitute approximately 2% of the total infrastructure cost, **the potential Transcend market share for wastewater reuse can be projected to reach approximately \$460 million, \$740 million, and \$1.84 billion in 5, 10 and 20 years (2028, 2033, 2043), respectively.**

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Wet weather flow

Background

In a context of continuous population growth contributing increasing volumes to existing sewer systems, the increase in rain and heavy downpours in recent decades – one of the ongoing impacts of climate change – continues to trigger wastewater overflows.

The increased volume of stormwater runoff combines with wastewater in combined sewers or infiltrates into leaks in separate sewers and results in the capacity of the wastewater treatment plant being exceeded. This situation results in emergency release of the stormwater runoff and untreated wastewater into receiving water bodies.

“... discharges can cause or contribute to water quality impairments and potentially expose people to untreated sewage. Sewer overflows can also back up into residential homes, public buildings and commercial facilities.”

Report to Congress on Combined Sewer Overflows to the Great Lakes Basin, 2016.

Climate models project that both overall precipitation and the amount of rain falling in heavy downpours, will continue to increase this century with continued climate change, which could cause even more overflows.

Opportunity

It may not be possible to design treatment plants for every potential overflow, however, steps are being taken to reduce the number and severity of sewage spills, to mitigate health and environmental impacts. With multiple studies (Risch et al., 2018; Sojobi et al., 2022; Kim et al., 2007; Tavakol-Davani et al., 2016) finding significant increased toxicology caused by wet weather overflow events, and the health of recreational facilities at risk, utilities are under pressure from the public to reduce wastewater overflow events worldwide.

The EPA lists interventions for reducing overflows, where the items in bold can be designed within Transcend Design Generator (TDG):

- Sewer system cleaning and maintenance.
- Reducing infiltration and inflow through system rehabilitation and repairing broken or leaking service lines.
- **Enlarging or upgrading sewer, pump station, or sewage treatment plant capacity and/or reliability.**
- Controls limiting fats, oils and grease (FOG) into the sewer systems.
- **Construction wet weather storage facilities.**
- **Expanding the capacity of the treatment works.**
- Educating the public on how FOG and certain household products can clog sewers.

Opportunity example

The opportunity to design for wet weather events in TDG has already been realized for the Trinity River Authority (TRA) Denton Creek Regional Wastewater System. TDG incorporated a flow bypassing design feature which allowed designs to consider multiple additional configurations for partial peak flow treatment. Incorporating additional technologies in primary treatment, and higher peak flow factors can provide further realization of the benefits of TDG for this opportunity.

Opportunity locator

News reports of sewage spills can be found in almost any country in the world. While not all of these are caused by wet weather overflows, many overflow issues can be solved by similar design concepts that apply to wet weather overflows. This international opportunity is driving the TDG improvements in equipment redundancy options and making customizable settings available to the user. Having backup equipment can reduce overflows and spills, but should be considered early when comparing options due to cost, carbon and footprint impacts.

Market size

The market sizing is multi-dimensional, as we can consider direct and various degrees of indirect market opportunities and impacts. Direct market opportunities include the planning, design and construction of wastewater treatment infrastructure upgrades. Indirect market opportunities can include the prevented cost of health, environmental, social and economic loss caused by wet weather sewage overflows.

Direct market size

Estimated at US \$1.7 billion for the Great Lakes District, of which US \$170 million for engineering design services.

Extrapolating to the rest of the world by sewer-connected population served, a global market of approximately US\$ 130 billion, of which US\$ 13 billion for engineering design services.

The market size is based on 22,000 MG of untreated wastewater reported in 2014 from combined sewer in the Great Lakes District. In Michigan it is estimated that rain falls for 155.3 days per year on average, therefore an additional wet weather treatment capacity of 142 MGD



would be required. At a design and construction cost of US\$ 12 million per MGD (Fehr Graham Engineering & Environmental, 2022), the estimated market value is US\$ 1.7 billion.

The true extent of sewage overflow is often undocumented and largely unknown. Therefore, the true market value can be much greater than estimated by these measured overflows.

Indirect market size

Estimating the potential losses caused by sewage spills may not be easily quantified, however, considering the economic contribution of an area at risk, can describe the order of magnitude of the market:

As many as 1.5 million jobs are supported by the Great Lakes, contributing to an estimated \$62 billion in annual wages (EPA 2016).

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Conclusion

The evolving landscape of wastewater management and treatment has been marked by rapid innovation, enhanced technological solutions, and a growing awareness of environmental sustainability. As the global community continues to grapple with challenges such as water scarcity, the urgency of phosphorous pollution, and the need to adhere to stringent regulatory mandates, the solutions and market potential explored in this report come to the forefront as vital responses.

The understanding and mitigation of phosphorous pollution, driven by advancements in removal technologies, have become increasingly important. This is particularly the case in regions with a history of eutrophication in freshwater bodies. The market drivers identified, especially the stringency in regulations and the growing awareness, highlight the collective global shift towards better water quality management.

Wastewater reuse, no longer seen merely as a 'back-up' source of water, is establishing its importance in the global water management strategy. As water becomes an increasingly scarce resource in many parts of the world, recycling and reusing wastewater becomes not just an environmentally conscious decision but also an economic and strategic one. The market potential in this sector is both promising and essential for sustainable future growth.

The realm of membrane innovation is a testament to how technology is pushing boundaries to ensure that water, an invaluable resource, is treated with the sophistication it demands. These innovative approaches, from MABR to the groundbreaking works of ZwitterCo and NX Filtration, highlight a market that is ripe with potential and driven by the need for efficiency and sustainability.

Lastly, the integral role of primary treatment in wastewater management is underscored by its evolution and the newer technologies in play. With its promise of efficient solid-liquid separation and the potential benefits it offers in the larger wastewater treatment context, primary treatment holds a pivotal place in the water treatment cycle.

In sum, the wastewater treatment and management sector is evolving at a pace that mirrors the urgency of global water challenges. With increasing innovation, a growing market, and the convergence of technology and environmental needs, the future of wastewater management is both promising and imperative. As we move forward, continued research, investment, and a holistic understanding of the entire water cycle will be essential to navigate the challenges and harness the opportunities that lie ahead.



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