Wastewater Treatment Plants of the Future: Current Trends Shape Future Plans

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The wastewater industry faces many new challenges that complicate near- and long-term planning decisions. Increasing energy costs, trace organic compounds, finite resources, water conservation, and inexorably more stringent regulations, must all be considered before investing in major facility improvements. While the future is never certain, inclusion of strategic exercises like scenario planning and future mapping during the planning process can help to define the boundaries of what the future might bring to treatment facilities.

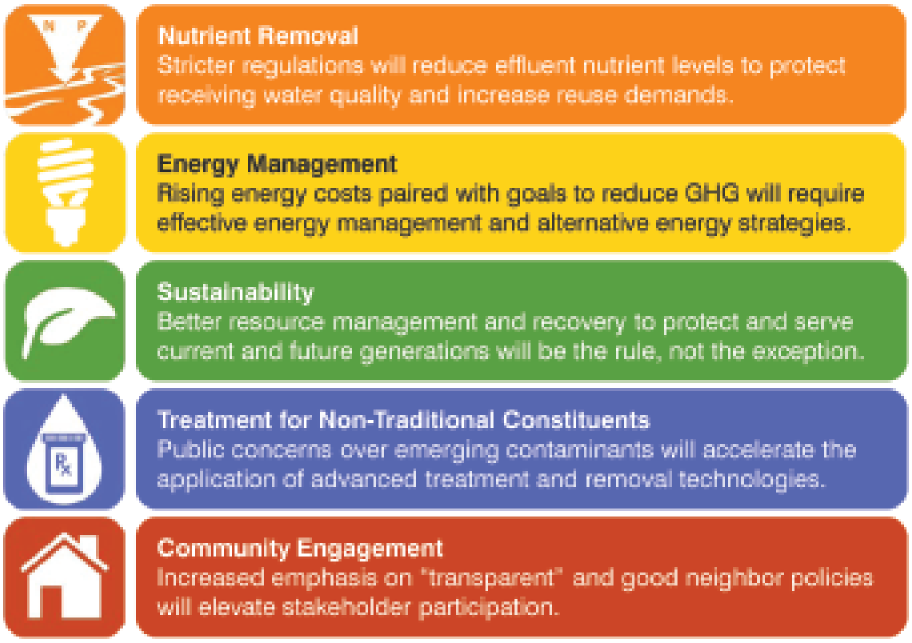
Futurists point out that the important trends in the future have their seeds in the present. On this basis, treatment technologies will evolve to address five major trends in wastewater treatment: 1) nutrient removal and recovery, 2) trace organic compounds, 3) energy conservation and production, 4) sustainability, and 5) community engagement.

The water industry has historically taken far longer than other business sectors to develop and implement new technologies. However, many innovations are now under development with benefits that could be compelling enough to shorten the length of the technology life cycle in the water sector. Implementation of these technologies would radically alter wastewater treatment plants in the future.

Current trends and highlights of some of today's technical innovations, including nutrient removal and recovery, fine sieves, nitritation-Anammox processes, anaerobic treatment, sludge pre-treatment, and thermal conversions, are discussed.

Background

Speculation on the future of wastewater treatment continues to be a recurring theme in the water industry. Predictably, the future will be shaped by events that cannot be predicted and that will influence the future in ways that are impossible to foresee. However, studying the trends and forces shaping current events, and using this knowledge to develop possible boundaries for future conditions, can result in better insights into what might occur.



Nutrient Removal
Stricter regulations will reduce effluent nutrient levels to protect receiving water quality and increase reuse demands.

Energy Management
Rising energy costs paired with goals to reduce GHG will require effective energy management and alternative energy strategies.

Sustainability
Better resource management and recovery to protect and serve current and future generations will be the rule, not the exception.

Treatment for Non-Traditional Constituents
Public concerns over emerging contaminants will accelerate the application of advanced treatment and removal technologies.

Community Engagement
Increased emphasis on "transparent" and good neighbor policies will elevate stakeholder participation.

Near-Term Trends Shaping the Future of Wastewater Treatment

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Strategic Planning

When the future is assumed to be like the past, forecasts can be made by simple, linear extrapolations. However, with greater degrees of uncertainty that conditions will continue as they are, forecasting becomes less useful. One structured method for evaluating these uncertainties is known as scenario planning, scenario thinking, or scenario analysis. With scenario planning, flexible plans for the future are prepared by evaluating alternative scenarios that could exist in the future. Future mapping is a more visually-based variation on scenario planning that attempts to examine a range of possible futures. Neither process attempts to predict the future, but rather develops an understanding of the forces and their relationships that could shape future conditions.

By creating several plausible, but distinctly different sets of future conditions, an organization can test the viability of current strategies under new circumstances. Ultimately, the goal is to be able to make better planning decisions that provide the flexibility to adapt to future changes.

Global Trends

Current trends (patterns of gradual change) often become the starting point for assessments of possible future conditions. Progressive changes in aspects of our society, businesses, and environment can be discerned and used to foresee the ultimate results of these changes over time. Past experience shows that most significant trends derive from underlying socio-cultural, economical, political, technical, ecological, demographic, organizational, and risk factors. Trends occur at all levels, with the largest, global changes affecting nearly everything, while localized trends will only affect specific regions, locations, or industries.

Key global trends with implications for the water industry include changes in population and demographics, increased urbanization, increasing living standards, climate change, and a scarcity of resources needed to sustain life, including land, water, and phosphorus. Regardless of the scale, utilities can benefit by being aware of the forces at work, and by being prepared to adapt to opportunities and threats that could significantly affect them.

A number of individuals and organizations have explored trends in the water industry including the Water Environment Research Foundation, or WERF (Crawford, G., 2010; Henderson, D., 2011), STOWA, the Dutch acronym for Stichting Toegepast Onderzoek Waterbeheer or Foundation for Applied Water Research (2010), the Water Research Foundation (Means, E.G., III et al., 2006), and the European Commission (Segrave, A. et al., 2007; Zuleeg, S. et al., 2006; and Rosén, L. and Lindhe–Chalmers, A., 2007). These different groups have expressed widely divergent views, as evidenced by the summary of selected studies in Table 1, although there is some commonality. Even though many of these studies were done within the context of potable water supplies, most of the identified trends apply equally to wastewater.

Wastewater Trends

From the perspective of the wastewater industry, five major trends, that encompass some of those in Table 1, are evident. These include nutrient removal and recovery, energy conservation and production, sustainability, treatment for non-traditional contaminants, and community engagement.

Nutrient Removal and Recovery – Nutrient removal to reduce nitrogen and phosphorous has been a reality in central Florida since the 1980s. In the future, nearly all treatment facilities will provide some nutrient reduction. Much of the near-term focus will be on meeting lower numeric limits; however, recovery and reuse of materials, initially phosphorus, will likely become mandatory at larger facilities over time. Taking a tiered approach to nutrient limits is likely the best long-term strategy, because the tiers allow flexibility to tailor effluent quality to a variety of reuse applications, thus providing the ability to maximize reuse while minimizing costs. One advantage to lower nutrient effluent limits is that treatment to meet lower effluent limits concentrates nutrients in the solids, where it may be more economical to recover and reuse.

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Table 1. Current Trends Identified as Significant to the Water Industry by Various Sources

Trend	Henderson[1]	WRF[2]	EC[3]	Kiwa[4]
Biotechnology				X
Climate change	X		X	X
Customer expectations		X	X	
Desalination	X			
Efficiency (demand destruction)	X		X	X
Emerging pollutants			X	
Emerging Technologies		X	X	
Energy		X	X	
Globalizing economy			X	
ICT and automation				X
Increasing risk (security)		X		
Industrial growth	X			
Infrastructure failure (or lack of)	X		X	
Infrastructure renewal	X			X
Membrane technology				X
Political environment		X		
Population/demographics	X	X		
Regulations/government		X		X
Sensors				X
Sustainable society				X
The information economy				X
Total water management		X		
Urbanization	X		X	
Wastewater to product	X			
Water reuse	X			
Workforce issues		X		

Notes:
(1) (Henderson, D., 2011)
(2) (Means, E.G. III et al., 2006)
(3) (Segrave, A. et al., 2007)
(4) (Zuleeg, S. et al., 2006)

Table 2. Common Tiers for Limitations on Nutrient Concentrations in Effluent

Tier	Numeric Limits (mg/L)	Required Technology
1	NH_3 = 1 to 4	Complete nitrification or split treatment with blended effluents.
2	TN = 10 to 12 TP = 0.5 to 2	Nitrification and denitrification to 7 – 9 mg/L as nitrate nitrogen. Biological or chemical phosphorus removal.
3	TN = 3 to 6 TP = 0.3 to 0.5	TN in this range is nearing the reliable limits of technology for BNR plants and tertiary denitrification processes. TP in this range generally requires effluent filtration for reliable removal.
4	TN < 3 TP < 0.3	Effluents in this range are close to current limits of technology and may require tertiary nutrient removal in addition to BNR. Achieving ultra low N and P limits may require additional barriers such as membranes or advanced oxidation.

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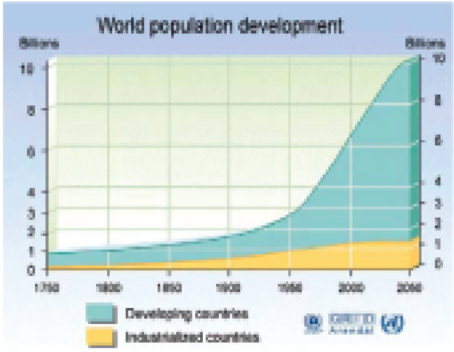
Energy Management – Rising energy costs paired with restrictions on greenhouse gases will provide the impetus to institute more effective energy management and alternative energy strategies. These trends are raising the bar for wastewater utilities toward being energy neutral or energy positive, whereby energy is not just managed, but instead recovered and reused. Current initiatives to increase biogas production, manage oxygen demand, and control equipment for efficient power use will move the industry in the right direction. A fundamental change in the use of aerobic biological treatment may be required to complete the transition from energy user to energy supplier.

Future treatment plants may incorporate additional anaerobic processes, or chemical and physical barriers, to remove pollutants without aerobic bacteria thus creating energy rather than using energy. However, there are limits to the ability to increase the energy efficiency of existing processes, and there are budgetary limits for implementing new processes and technologies that help achieve an energy neutral target. A prudent strategy dictates that utilities work to achieve the energy neutral goal incrementally. Toward that end, there are five key components that can frame energy optimization strategies including: 1) maximize efficiency; 2) provide more treatment for less power; 3) consider technologies to reduce or produce energy; 4) generate renewable power; and 5) evaluate the plant carbon footprint.

Sustainability – Better management of natural, human, social, manufactured, and intellectual capital to maintain a sustainable existence will become essential in the future. At wastewater treatment facilities, this will mean reduced consumption of resources and increased recycling and reuse of water, nutrients, and other materials contained in wastewater. In some areas, the need to increase reuse will require some decentralization with construction of satellite treatment plants. Caps on greenhouse gas emissions will affect the selection of treatment technologies and operating strategies particularly for sludge. Increased water conservation will alter both the flows and pollutant concentrations in raw wastewater, potentially leading to new challenges and opportunities.

Treatment for Non-Traditional Constituents – Public concerns over the presence of trace organic chemicals in water will accelerate the application of advanced treatment technologies to remove objectionable compounds from wastewater. Although there is reasonable certainty that removal of trace organic compounds will be needed, the timing, the specific compounds or classes of compounds that will require removal, and the technologies that will be needed, are unknown. Planning strategies might include leaving space on the plant site and in the hydraulic profile based on the technologies that we now know can remove some trace organics, including advanced oxidation processes and biological nutrient removal.



Population/Demographics
Source: GRID-Arendal

Urbanization/Living Standards

Climate Change

Scarcity of Resources

Global Patterns with Implications to the Water Industry

Community Engagement – The current trend for increased stakeholder involvement in utility decisions that affect neighbors of wastewater facilities or the cost of service should continue. Utilities can expect that their communities will demand to be part of the planning process for facility improvements, and that community enhancements be incorporated into utility projects.

Technical Innovations

The pace of innovation in the wastewater industry appears to be increasing, with every year bringing significant new concepts and technologies. Not all the technologies will succeed in the marketplace; however, some will. The following is a quick overview of a few promising wastewater treatment technologies that might be part of the treatment plant of the future.

Fine Sieves – Inert solids in sewage cause many problems after arriving at the wastewater treatment plant. Hair, fibers, and neutrally buoyant materials that escape capture by the influent screens tend to accumulate in aeration tanks where they braid themselves into ropes and amorphous masses capable of clogging most mechanical equipment and pipes.

Inert solids accumulate in the bioreactor in direct proportion to the solids retention time (SRT). Thus, the performance of long SRT processes, including nitrifying activated sludge and biological nutrient removal processes, will degrade to a greater extent than high-rate carbonaceous removal processes.

Experience with fine screens and sieves has expanded in recent years, mostly due to the growing use of membrane bioreactors. Fine screens (1.0-2.0 mm) may only increase the removal of biochemical oxygen demand (BOD_5) and total suspended solids (TSS) by 10 to 15 percent; however, full-scale treatment plants in Scandinavia with 350-micron openings report TSS removals of 50 to 80 percent.

Research in Europe estimates that cellulose fibers originating from toilet tissue comprise nearly 60 percent of the TSS in wastewater, which can nearly all be removed by 500 micron or smaller aperture fine sieves. This material can be washed and compacted up to 60 percent dry solids and burned as fuel, or recycled to make paper. Removal of cellu-

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lose fibers has the potential to reduce overall energy consumption by about 50 percent.

Anaerobic Treatment – Anaerobic treatment of municipal wastewater is an attractive option for secondary wastewater treatment. The high costs of aeration and sludge handling associated with aerobic sewage treatment are dramatically lower with an anaerobic process as no oxygen is required for removal of carbonaceous oxygen demand and sludge production is reduced dramatically. Historically, however, anaerobic processes have not been feasible for carbonaceous BOD5 removal in municipal wastewater because of relatively low concentrations, the slow growth rate of anaerobic microbes, poor settleability of anaerobic sludge, and the potential for odors.

The anaerobic membrane bioreactor (AnMBR) could have potential application in municipal wastewater treatment for several reasons: With an AnMBR configuration, the need for gravity settling is eliminated; the AnMBR process can provide for short hydraulic retention times (HRT) while maintaining high SRT because particulate matter is not expelled from the process, maintaining a small footprint; and, the AnMBR is a closed unit, thus greatly reducing the potential for odors.

Phosphorus Recovery - Projections for the exhaustion of the world's phosphorus reserves vary from less than 100 to over 300 years. More importantly; however, only eight countries contain over 90 percent of the known phosphate rock reserves, and just three (China, the United States, and Morocco/Western Sahara) have the bulk of the commercial reserves. Various predictions have the United States running out of phosphate rock within 25 to 30 years, although some of these predictions are at least that old. In some countries without phosphate rock reserves, the capture and recycling of phosphorus from wastewater has already become a major endeavor as a means to increase the security of their food supply.

Research into methods of recovering phosphorus from wastewater, originally initiated as a means for controlling magnesium ammonium phosphate (struvite), have accelerated over the last ten years. At present, the most feasible option is to precipitate struvite from side streams from dewatering anaerobically digested sludge. While side stream precipitation of struvite can recover about 40 percent of the influent phosphorus load, combining mainstream phosphorus removal with recovery from the sludge stream can capture up to 90 percent. Processes under development include additional precipitation methods, including one using a waste building material, and wet chemical and thermal methods for recovering phosphorus from sludge and incinerator ash. While phosphorus recovery and recycling may not be economical for some time, some are looking to the water industry to show the way, and to become an incubator for nutrient recovery technologies.

Nitrogen Cycle Revisited – Significant developments over the last 10 to 15 years have led to new processes for removing nitrogen from wastewater, particularly from warm, high-ammonia side streams from dewatering anaerobically digested sludge. Typical nitrogen removal at a wastewater treatment plant is a multi-step process in which a combination of autotrophic and heterotrophic bacteria sequentially converts ammonia to nitrogen gas. The classic nitrification-denitrification process can be managed so that the initial conversion of ammonia by ammonia oxidizing bacteria (AOBs) is stopped at nitrite (nitritation), and then the nitrite is converted to nitrogen gas (denitritation) by normal heterotrophic bacteria, thereby reducing the oxygen and carbon required for nitrogen removal. Coupling nitritation with denitritation provides a 25 percent savings in energy cost over conventional nitrification, and 40 percent savings in methanol cost over conventional denitrification.

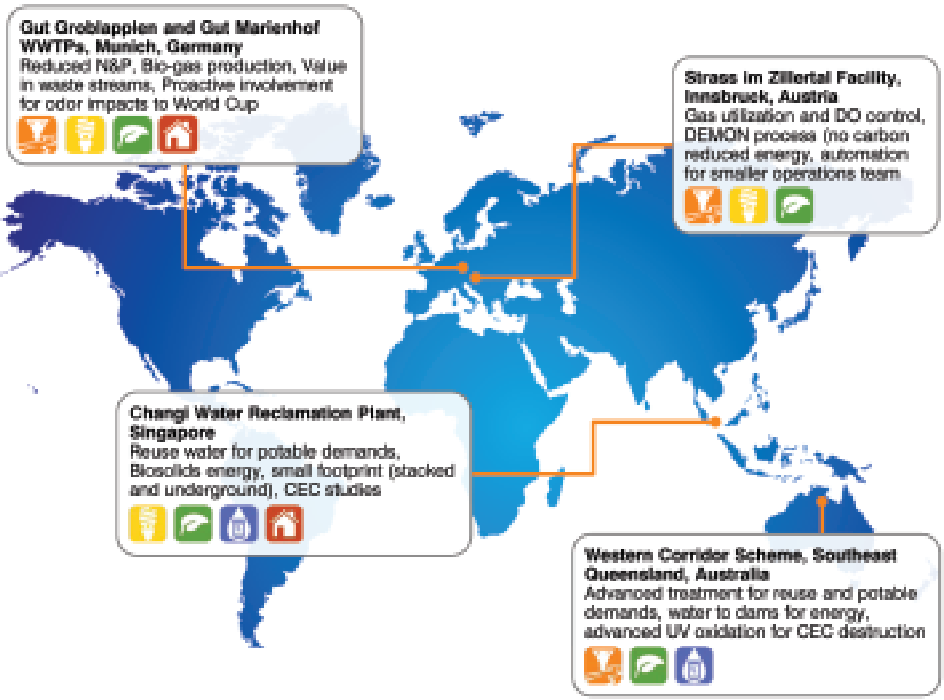
Advances in molecular methods, aided by serendipity, have led to the discovery of microorganisms in both natural ecosystems and in biological treatment processes that were unknown less than 20 years ago. We now recognize that many more microorganisms are involved and their interactions are more complex. For example, both archaea and planctomycetes are major players in the nitrogen cycle of the open oceans; both microorganisms were unknown 20 years ago.

In 1995, a researcher running a pilot denitrifying fluidized bed reactor discovered a microorganism capable of converting a mixture of ammonium and nitrite directly to nitrogen gas. Interestingly, the presence of this organism was actually predicted in 1977 based on the favorable thermodynamics of the reaction. These organisms, belonging to the phylum Planctomycetes, were given the name Anammox (anaerobic ammonium oxidation).

Since this organism is strictly autotrophic, nitrogen removal can be achieved without any carbon addition by coupling partial nitritation with Anammox. Because only about one-half the ammonium present in wastewater needs to be oxidized for this reaction to occur, and the ammonium oxidized only needs to be converted to nitrite instead of all the way to nitrate, oxygen requirements are reduced by about 60 percent. The theoretical maximum total nitrogen removal is 89 percent. Overall energy demands for nitrogen removal can be reduced by about half.

While knowledge of the nitrogen cycle is still not complete, further understanding will almost certainly increase significantly in the coming years; a number of new treatment approaches have been developed and more can be expected. For example, current research is exploring ways to retain and grow Anammox bacteria in mainstream nitrogen removal processes.

Pretreatment for Anaerobic Digestion and Feedstock Addition – A number of technologies



A Global Perspective

are being advanced to increase biogas production in anaerobic digesters by pretreating the digester feed or adding external wastes. One example is the Cambi process, which operates at high pressure (90 psi) and temperature (160-175 °C). Like other digester pretreatment processes, Cambi is typically used on waste activated sludge (WAS) to lyse cell walls, thereby releasing their cytoplasm, and leading to higher volatile solids destruction and biogas production. Some agencies are also using the high temperature to achieve Class A biosolids necessitating the pretreatment of all of the digester feed stocks. Addition of alternative feedstocks can also increase biogas production. Fats, oils, and grease (FOG) from grease traps, and food wastes from restaurants or food processing facilities are highly organic and readily degradable. Typically, these materials are ground into homogenous mixtures and fed at a constant rate to the digestion process. Aside from the increased energy potential from biogas, accepting these materials reduces plant loads, sewer system stoppages, disposal to landfills, and greenhouse gas emissions associated with hauling to landfills and decomposition. The increasing desire to be energy self sufficient along with the regulatory drive to reduce organics to landfills is also pushing separation of organics from municipal solid waste and feeding this material to POTW digesters.

Ozone with Granular Activated Carbon (GAC) and Biological Aerated Filter (BAF) – Conventional treatment does not provide effective removal for all trace organic contaminants (TOrCs), and advanced treatment may be required depending on the compound, concentration, and future regulations. While researchers have shown that ozonation provides excellent removal of numerous TOrCs, no single treatment process is capable of removing all TOrCs to below sensitive analytical detection limits (Benotti, M.J. et al., 2009; Snyder, S.A. et al., 2007). For example, fire retardants are one group of compounds that are not well removed by ozonation, but are well removed by GAC.

A plant of the future should include process flexibility to implement a multi-barrier approach for TOrC removal, where additional advanced treatment processes, such as GAC or BAF, would provide TOrC removal for compounds not well removed by ozonation alone.

Thermal Conversion – Recognizing the potential energy content of wastewater residuals, newer technologies are being developed to create energy independent systems. Gasification and pyrolysis are among the most promising of these technologies, which are being increasingly developed, both of which traditionally require sludge to be dried to 90 percent solids. Some new gasification developments appear to show promise at 50% solids or even 10% solids, thus eliminating the energy intensive drying stage. The gasification process heats solids to above 800 oC under oxygen-starved conditions to form syngas, which is mainly composed of hydrogen and carbon monoxide. The energy content of the syngas can be increased by adding steam to the process, a spin-off known as hydrogasification.

Pyrolysis creates syngas similar to gasification, but operates in the 700 oC range and in an oxygen-free environment. Both processes are designed as close-coupled systems, where the syngas is burned to heat flue gas, which is then used as the heat source for the drying process. In both cases, most of the recoverable energy is used to dry the solids, leaving little to produce power. As a result, many close-coupled systems are net-positive energy consumers.

The green energy and cleaner emission potential of gasification and pyrolysis are gaining momentum among alternative thermal treatment technologies. In a two-stage system, syngas can be conditioned for use in cogeneration systems to produce electricity. Newer systems are using the syngas to produce clean diesel or hydrogen. Alternative feedstocks, such as agriculture waste FOG, food waste, green waste, and wood waste, can increase the energy content of the syngas. Rather than using it to produce energy, syngas can be purified and injected into a natural gas grid or purified to create an alternative fuel commodity, essentially eliminating combustion and associated emissions.

Another emerging thermal technology of interest for treating sludge is the supercritical water oxidation (SCWO) process, also known as wet oxidation or wet combustion. The SCWO oxidizes organics under conditions of temperature and pressure above the critical point (705 °F, 3,200 psig). Under these conditions, sludge becomes homogeneous and solids are highly soluble.

The SCWO processes produce water, carbon dioxide, elemental nitrogen, and an inert material containing residual compounds. The volume of solids is significantly reduced as the organics are reduced to elemental chemicals by the process. Air emissions include carbon dioxide, oxygen, and nitrogen with no nitrogen oxide (NOx), sulfur oxides (SOx) or volatile organic contaminants (VOCs), and minimal odor. Oxidation reactions at supercritical conditions occur very quickly, typically 1 to 5 minutes, resulting in a small facility footprint. With an efficient heat exchange system to preheat the feed sludge, SCWO can be autothermal.

Benefits of SCWO are the small footprint, inert residuals, low air emissions, significantly reduced sludge volume, and the potential for recovery and recycling of heat and materials (including water, carbon dioxide, and phosphorus) from sludge.

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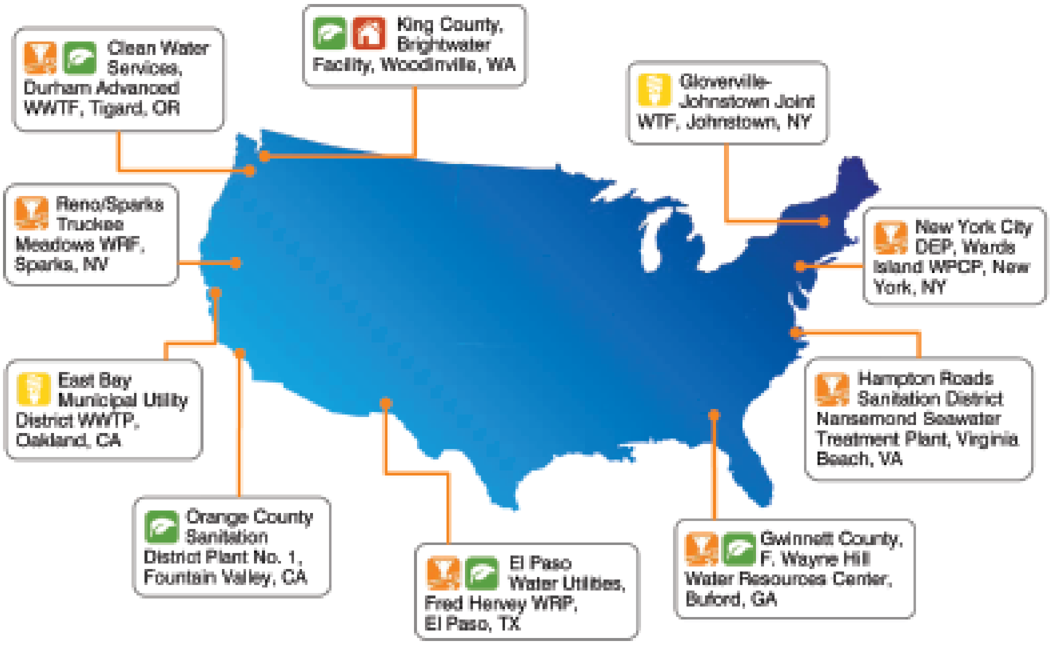

Innovation Closer to Home

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Summary

Many significant trends in wastewater treatment are now in play, and they will influence near- and long-term modifications at wastewater treatment facilities. To develop robust long-range plans that have the flexibility to respond to the challenges of an uncertain future, a utility must understand its existing facility operations, its underlying strengths and weaknesses, and the most pressing needs and opportunities for change. This knowledge of existing conditions, together with current trends and potential challenges and opportunities, can be combined with three simple tenants:

Address the Foreseeable Future – By definition, the future is uncertain. Yet there is sufficient existing knowledge of near-term external trends and institutional drivers, e.g., the need for optimum energy strategies, the reality of tighter regulations, and the expectation of sustainable operation, that near-term implementation strategies can be developed to stay current with industry practices.

Retain Conventional Wisdom – New is good, but not necessarily better. Prudent planning strategies for both the near- and long-term must be grounded in treatment approaches with a proven record of performance.

Anticipate the Unforeseeable Future – Long-range planning should define intended methods to implement change. Therefore, the implementation matrix must also define alternative methods to accommodate deviations from plans as necessary to meet the requirements of external driving factors that represent the unexpected, but possible, boundary conditions for planning.

Working within these tenants, a utility can define prudent planning strategies that balance expectation for change without undue risk or unmanageable consequences.

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