Current, Emerging, and Potential Technologies in the Clean Water Space. . . Opportunities for the 21st Century Utility

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Executive Summary

Clean water utilities face significant challenges, including rising costs for energy and consumables, increasing regulatory pressure, and aging infrastructure. Many of these challenges are tightly interconnected, leaving opportunities for technological solutions to make a positive impact by helping to solve several challenges simultaneously. Promising technologies, in various stages of development, are available for deployment, yet barriers often prevent their large-scale or timely adoption.

This white paper will explore industry challenges best poised to be addressed with technology. It spotlights current and emerging technology areas where, with more resources, clean water utility goals could more efficiently and effectively be met. Barriers to technology adoption in each challenge area are identified, with mitigation strategies and considerations highlighted.

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Table 1. Summary of Technology Areas Poised to Support Clean Water Utility Challenges

Many clean water utilities are **adopting current, emerging, and potential solutions at scale**, technologies that have achieved various Technology Readiness Levels. However, technology adoption is not rapid enough, causing promising technologies to leave the market before gaining traction, often to pursue other sectors. Risk aversion, long procurement cycles, lack of resources to pilot at-scale and lack of staff training are common barriers to adoption at-scale. All technology areas have the potential to positively impact the communities they serve, and it could be argued that capital intensive equipment, equipment that can make step-change strides in energy and chemical reduction, could make the largest impact towards regulatory compliance and sustainability goals with appropriate levels of incentive and investment.

As the challenge areas described above are tightly interconnected, targeting one challenge area inevitably bleeds into another, cascading positive change across several areas. **Investment in research, pilot at-scale demonstrations, test beds, and capital costs would support de-risking adoption of innovative technologies, particularly those considered potential or emerging.** Consistent policy frameworks, guidelines, and incentives provide the justification and impetus for accelerating technology adoption particularly when it comes to resource recovery, energy reduction, or climate related areas.

Background

The challenges facing clean water utilities are compounding, broad in scope, and touch each aspect of the utility's business - from managing the aging infrastructure to preparing for a retiring workforce, from hardening assets against climate change while tightening the network against cyber threats, all while rising energy, chemical, workforce, and commodity costs put pressure on tight budgets and regulatory frameworks are becoming more complex and stringent. Many of these challenges are interconnected - with creativity and innovation, multiple challenges can be addressed simultaneously.

The technology pipeline in the clean water sector is robust, with a strong lineup of current, emerging, and potential solutions deployed, tested, or in development. Many utilities, including those serving small and rural communities, are actively and successfully pursuing innovation and technology to make a positive impact on their communities while meeting these challenges. Yet, several barriers exist for both the clean water utilities and the technology developers that deter widespread adoption of promising technologies meeting immediate and long term needs. This paper will describe technology areas best poised to support innovation and positively benefit communities facing the aforementioned challenges.

21st Century Clean Water Utilities Challenges

Due to the **Rising Cost of Goods**, utilities are faced with difficult decisions about prioritizing capital projects, as the actual cost of projects more frequently exceeds budgeted amounts. Increasing chemical and consumables costs drive utilities to harden their **System & Operational Resilience**, increasing efficiencies, improving emergency response, and preparing for the effects of climate change. Similarly, the **Rising Cost of Energy** challenges utilities to seek ways to lower their carbon footprint, exploit operational efficiencies, and deploy energy efficient technologies. **New and Tightening Regulatory Requirements** are making permit compliance more complex and often uncertain, leading utilities to invest resources in process control as well as new treatment equipment. **Population Variations** can put strain on undersized systems in rapidly growing areas and make oversized systems difficult to operate, especially with growing affordability challenges. Aging pipelines, plants, and processes as well as filling legacy data gaps make **Infrastructure Asset Management** challenging**.** Meanwhile, the increased digital connectedness makes **Customer Connection, Public Expectation & Perception** a keen area of focus through increased transparency and enhanced level-of-service among other internal optimization advantages digitization provides. While geographic and community size may influence the weight of these challenges within an organization, the challenges are largely inclusive and tightly interconnected across the industry.

The challenge areas most in need of investment are detailed in this white paper:

- Rising Cost of Energy
- Infrastructure Asset Management
- New & Tightening Regulatory Requirements
- System & Operational Resilience
- Population Variation

The interconnections among these challenge areas can be exploited through the adoption of innovative technology to efficiently and creatively address multiple challenges simultaneously and at-scale.

Technology Areas

Clean water utilities have shown a desire for new technology, in many cases developing solutions in-house when the market did not provide them. The private sector has accelerated technology and innovation development over the last decade, making a positive impact in communities served by all sizes of utilities. Partnerships between utilities, universities, test beds, engineers, and innovators demonstrate the collective will to move the needle. Technology areas can be broad and cross functional, and several technology areas could make a larger difference if more resources were available to advance their implementation. Investment in emerging and potential solutions will ensure continued innovation to meet the challenges of today and in the future.

For example, **sensors & data analysis platforms** can be quickly deployed, assist with real-time operational and regulatory decision making, and support reductions in chemical and energy use. Sensors and solutions explicitly targeting **energy efficiency and optimization**, such as energy management platforms and asset monitoring devices, allow utilities to understand and manage energy use. These tools, along with **condition assessment and monitoring tools**, **asset locators, and predictive failure platforms,** allow for more efficient infrastructure asset management and stewardship of capital dollars. To address regulatory and population challenges, **treatment intensification technologies** provide innovation in chemical or biological treatment, allowing utilities to achieve higher treatment in less space and **nutrient management & removal solutions** provide means to reach the very lowest permit limits. To garner public trust and transparency with regulators, **emerging contaminant monitoring and treatment tools** are staying ahead of the curve as these contaminants become increasingly ubiquitous in our environment.

Technology Readiness Levels

Developed by NASA in the 1970s, the Technology Readiness Levels (TRL) are a means to consistently describe the maturity of technologies regardless of the sector in which they are deployed. The 1 to 9 scale rates a 9 as the most mature. This paper will focus on **potential technologies** in the TRL 4-6 range, meaning the technology has a component that has been validated in a laboratory environment up to a prototype demonstration in a relevant environment; **emerging technologies** in the TRL 7-8 range, meaning the technology has a prototype demonstration in an operational environment or the actual technology is completed and qualified through test and demonstration; and **current technologies** in the TRL 9 range, meaning the technology has been proven through successful operations and is commercially available. In other words, emerging and potential technologies will emphasize developing research and innovation areas while current technologies will emphasize opportunities for advancement today at-scale.

Barriers to Technology Adoption

Despite the abundance of innovative technologies available and emerging in the water sector, **technology adoption continues to be at a slower pace than that of other industries**. As stewards of public and environmental health, water utilities tend to be **risk averse** as to not compromise their level of service or lose the public's trust. **Procurement cycles tend to be long**, particularly with capital projects, with most utilities utilizing multiyear planning outlooks, making them less adaptable to pivots and/or course corrections as new technologies become available. **Resources are tight and tightening** - both in capital funds as well as human capital. Many utilities are funded and staffed to "keep the lights on" with little left in the lean budget for R&D, pilots, or larger up front capital expenditures that would save in operating costs in the longer term. Barriers of technology adoption at-scale can vary by challenge area and depend on the technology area/application or the technology's maturity.

CHALLENGE AREA: RISING ENERGY COSTS

Utilities depend on electricity, gasoline, and diesel fuel to power process equipment and fleet vehicles. As these operational costs continue to rise, utilities must either cut other areas of the budget, i.e., delay maintenance or equipment upgrades, or raise rates. These difficult choices can have long term implications on the state of the utilities' infrastructure and relationship with the community. Rising energy costs are a driver to improve energy efficiency, which also allow utilities to meet targets set in climate and strategic action plans. Prior to and on the heels of the 2021 United Nations Climate Change Conference of the Parties, there is a growing trend in municipalities, from very small to very large, to establish Climate Action Plans that mandate efforts in energy reduction.

Technology areas that can support addressing this challenge today include energy management platforms, process optimization platforms, pump & rotating equipment monitoring, and step-change energy efficient equipment. There is a growing lineup of technologies that can provide on-site backup energy generation to ensure reliability, resiliency, and continuity and can be integrated onsite regardless of utility size, process, or location. These technologies include floating solar panels, microgrids, batteries and fuel cells, as well as innovative hydroelectric solutions and are illustrative of emerging areas of technology deployment for clean water utilities. Energy efficient equipment can include innovative pumps and blowers, and equipment to improve the production and subsequent use of biogas.

Use case spotlight of successful adoption:

Clean Water Agency: Gwinnett County Department of Water Resources, large (~56 MGD) utility in Georgia.

Drivers for implementation: Reduce electrical and maintenance costs of large (700 - 3000 HP) pumps.

Notable aspects of the operation that align with this technology area: The utility deployed asset monitors on three potable water pumping systems and a large regional wastewater pumping system; operations, maintenance, and engineering staff receive a text message when pumps run outside the preferred operating range that includes advice for operational changes; the utility achieved 15% energy reduction, saving $92,000+ annually, achieving an eight month payback period.

Current Technologies (TRL 9)

Energy efficiency can be approached from several angles, from the micro level of monitoring assets to ensure optimal operation, to the macro plant level of analyzing system energy trends and exploiting efficiency opportunities. Utilities have evaluated holistic approaches including efforts to work with customers to lower water demand, thereby lowering treatment demand and associated energy footprint. When most efficiencies have been exploited or the return on investment just may not justify an expenditure, utilities have also turned to renewables to offset unavoidable energy demands and rising costs, in turn increasing system resiliency.

Asset monitors, such as pump performance monitors, compare a pump's operation to its design curve to align with peak efficiency. These monitors have averaged up to 13% in energy savings with a payback interval of less than a year and also facilitated targeted capital expenditures on poor performing assets. Some monitors automatically change pump operation in response to pump efficiency readings, saving operator time and improving efficiencies, and others offer wireless versions to expand use cases. These monitors not only promote energy efficiency but can also signal early warnings before a failure causes upsets or service disruptions in the collection or treatment system.

Energy management and process optimization platforms utilize plant models, existing operational, geographic information system (GIS), and billing data, and can improve plant-wide energy efficiency by 15-40% through fine-tuning operation. These platforms can build from asset monitors, such as pump performance monitors, though do not require them. Energy management platforms take into account consumption and cost data, in addition to other service history and equipment data, to develop a framework built on ISO 50001 principles. Process optimization platforms input data from supervisory control and data acquisition (SCADA), laboratory information management systems (LIMS) and other field data, claiming 3-15% operational savings (including chemical and energy), 20% reduction in equipment downtime, and up to 15% increases in equipment life.

Energy efficiency is a normalized and well established technology area, though clean water utilities have a long way to go to demonstrate these technologies at-scale and at their full potential. Barriers may include organizational culture and workforce readiness, where process optimization platforms can be seen as threatening, rather than supporting, an operator’s job. Additionally, despite interest and need, utility strategic plans and urgent needs may supersede and overtake related projects which may be seen as additional investment or nice-to-have. Consistent policy coupled with targeted investment can accelerate the adoption at-scale of well-established technology solutions that have minimal risk of failure and proven operational benefits beyond energy efficiency.

Emerging (TRL 7-8) & Potential (TRL 4-6) Technologies

The social, economic, and political urgency has spurred support for innovative energy management and broad creativity and ingenuity. Emerging and potential areas include energy sensors, process equipment, and renewable energy generation. Investment can impact research and demonstration by focusing on innovative sensing equipment that expands use cases, equipment targeting energy intensive processes, and expanding options for renewable energy generation. Biogas generation and use is a strong example of emerging technologies addressing energy.

Developments in asset sensors are increasing their use cases. For example, sensors that incorporate vibration-energy harvesting to create self-powered sensors support energy reduction. Without wiring, sensors can be deployed by existing field maintenance teams on large assets in both accessible and remote stations. Monitors deployed in remote areas can prevent asset failure, saving resources in replacement equipment and emergency response.

Energy efficient processes and equipment challenge traditional approaches in energy intensive processes, such as aeration, fats, oils, and grease (FOG) treatment, and anaerobic digestion. Airlift pumps are entering the market at 10-50% cost savings than centrifugal pumps and provide a return on investment (ROI) of 1-2 years due to energy savings. As grease blockages cause equipment failures and SSOs, utilities are increasingly interested in source treatment of FOG, and technologies are emerging that produce high quality feedstocks from FOG in an energy-positive process. The sale of byproducts, along with hauler tipping fees, provide an ROI of 2-10 years. Anaerobic digestion is typically a highly energy intensive process, though pretreatment of sludge prior to digestion using thermal or chemical hydrolysis can increase biogas production by 50-60%. Technologies using supercritical conditions reduce sludge volumes by 99% while saving 75% of treatment costs versus anaerobic digestion.

Advances are also being made in renewable energy generation, with an increasing number of utilities deploying solar panels, rethinking the possibilities of biogas, or tapping into waste heat or thermal energy. Vendors claim that a utility can offset up to 50% of its energy demand by covering treatment tanks with solar covers, with a payback within 15 years dependent on local energy prices and subsidy regimes. Biogas will likely play a large role in energy reduction, as plug and play digester units entering the market make digestion more accessible. Biogas and solar energy can be stored in fuel cells and batteries, smoothing out inherent supply and demand mismatches with renewable energy generation. Converting to blowers that can run on biogas or natural gas can save up to 80% in operational costs. Similarly, the waste heat from flared biogas can be captured in a heat engine to generate an additional 15% electricity from a previously wasted resource.

Robust policy incentives would encourage clean water utilities to more aggressively adopt emerging and potential technologies that align with their energy and climate mitigation goals. As multiple stakeholders may be involved, and incentive programs may vary by state or locality, cohesive federal policies supporting this transition would smooth uncertainty. Investment in pilot at-scale demonstrations or full-scale deployment of more capital intensive technologies would accelerate adoption of technologies that support clean water utilities' energy goals. Also, providing a platform to celebrate successful energy reductions would build confidence in the strategies for other utilities to mimic.

Conclusion

- Energy efficiency process equipment and optimization tools are well established with a demonstrated ROI.
- Investment in research, pilot at-scale, and full scale development of step-change energy efficient process equipment will accelerate adoption of technology and support utilities in meeting climate action plan goals to improve their communities.
- Barriers to implementation may include organizational culture and uncertainty around incentives from federal, state, and local governments which could impact the return on investment.
- Consistent policy and incentives to accelerate the advancement of market-ready solutions, coupled with investment in research and pilot at-scale demonstrations of renewable energy generation and storage technologies will be critical for widespread adoption of these technologies.

Challenge Area: Infrastructure Asset Management

Receiving a D+ grade in the 2021 ASCE Report Card, the nation's wastewater infrastructure is in need of maintenance, rehabilitation, and replacement, and the clean water industry is far behind the recommended replacement schedule. The majority of the infrastructure was installed in the first half of the 20th century, with substantial assets past or reaching the end of their useful life. The aging and aged infrastructure is ubiquitous regardless of geographic region, treatment process complexity, or utility size. Many utilities are developing Asset Management Plans to support short and long term asset health, though many struggle with large data gaps, are unsure where the underground assets are located, and lack sufficient information to make data-driven decisions for long term planning.

Robust condition assessment and rich asset data sets are important to improve utility resiliency, harden against the effects of climate change, and reduce the environmental effects of pipe breaks and SSOs/CSOs caused by infiltration and inflow. Understanding network assets will ensure proactive maintenance regimes and stewardship of utility resources for data-driven network rehabilitation and replacement.

Technology areas positioned to support this challenge include solutions that can identify and locate underground assets, improve on conducting or tracking preventive maintenance, and enable predictive maintenance. For data driven planning, several solutions exist and are under development for the rehabilitation and replacement of both vertical and horizontal assets, including solutions that can analyze asset information to calculate likelihood and consequence of failure to support utilities in prioritizing capital projects.

Use case spotlight of successful adoption:

Clean Water Agency: San Antonio Water System, large (~225 MGD) utility in Texas.

Drivers for implementation: Difficulty choosing which assets need to be replaced in any given year; desire to utilize Likelihood of Failure (LOF) and Consequence of Failure (COF) approach to properly allocate capital funding.

Notable aspects of the operation that align with this technology area: Deployed a comprehensive cloud-based SaaS solution that ranked pipes by their LOF from ten previous years and compared results to actual pipe breaks. If the top 1% of pipes ranked by the platform had been replaced, 24% of the breaks would have been avoided.

Current Technologies (TRL 9)

Condition assessment of both force mains and gravity lines is critical to plan long term rehabilitation and replacement activities. Data gathered from condition assessments, such as pipe thickness, material, and locations of infiltration or potential blockages, inform operational or capital decisions. Software platforms can leverage this field data, in addition to also importing pipe break history and other geospatial and environmental variables to provide predictive and prescriptive maintenance. Several technologies are available for assessing gravity mains, using techniques such as deployable floating spheres equipped with miniaturized wastewater quality sensors, acoustic measurements, and satellite imagery. Acoustic tools are used to assist field crews in narrowing inspections to the areas most likely to be problematic, saving 80-90% of operating costs over closed circuit television (CCTV) inspection or traditional cleaning. For utilities that utilize CCTV inspections, several tools that use artificial intelligence and machine learning are available to automate the analysis of CCTV footage, reducing the time for damage classification by 75 - 95%, with a 30% reduction in operational costs. Locating and addressing problematic pipes hardens against infiltration, reducing the risk for SSOs / CSOs and lowering the flow to treatment plants.

Force mains are more difficult to assess, as access points are limited, and pipeline shutdowns are often impossible or impractical. However, force main breaks can be catastrophic to utility operations and the communities affected by them and carry significant response and repair costs. As such, force main condition assessment tools are an area of opportunity for further investment. When field data is difficult to obtain, software solutions can still provide support for utilities focused on force main rehabilitation and replacement, achieving 20% reductions in infiltration and inflow, 7% reduction in treatment and pumping costs, and less than one year return on investment due to catching pipe failures before the failure occurred.

Clean water utilities may have the perception that field assessment tools that leverage digital functionality may not be an option for them, due to the absence of critical data. However, investment in use cases and field deployment bolsters the data bank available for artificial intelligence, strengthening the algorithms using complete data sets, which can then be deployed in scenarios with incomplete data and at-scale. There may be a hesitancy to adopt a software platform, particularly if it requires an annual subscription, as utilities can suffer from software platform fatigue with too many digital tools and not enough staff to adequately exploit them.

Emerging (TRL 7-8) & Potential (TRL 4-6) Technologies

Filling asset data gaps around infrastructure asset management is a common need for clean water utilities, particularly if they rely on internal data only to achieve holistic analysis. Data gaps may include asset location, material, and condition. Several asset location tools are emerging in the market, tools that are smaller, more adaptable to field conditions, trenchless/non-invasive, and increasingly user-friendly. By minimizing the need for exploratory or pilot excavations, these tools have decreased the time required for underground asset marking and dig damage abatement by 85%. These tools link to digital asset management systems and geographic information systems, allowing field crews to easily update asset information. The asset data capture is fundamental to data analysis and visualization, and to prioritize infrastructure rehabilitation and replacement.

An area of opportunity is the development of tools that promote underground asset identification, specifically tools that have the ability to determine not only pipe location and depth, but material, thickness, and diameter, as well. Trenchless condition assessment tools need attention and continued investment to reduce labor and excavation costs, improve safety conditions, and minimize disruption to communities.

Pressure transients are short lived pressure waves that occur within pressurized pipes, waves caused by pipe design, installation, or pump operation, that can cause pipe deterioration or breakage over time. Monitoring of pressure transients is common in water networks, and there is an emerging interest in pressure transient monitoring in collection system force main networks as well, particularly to prolong asset life and avoid unpermitted discharges due to pipe breaks. The nature of force mains and their installation may make deployment of pressure transient monitors more complex, as hydrants are not available as insertion points for sensors. Innovation in deployment, power, and communication logistics are needed to increase usability of this technology in clean water networks.

Trends indicate that utility staff are more comfortable with and accepting of technological field devices, and continued investment in training and education would support this trend. Similarly, investment in research and technologies that are easily deployed by field staff without significant specialized training, as well as reaching a price point consistent with the risks of field work, would accelerate the adoption of asset locators, pressure sensors, and similar field equipment.

Conclusion

- Investment in research and pilot at-scale demonstration of condition assessment tools is needed to support utilities in prioritizing linear asset rehabilitation and replacement to improve today’s dismal infrastructure outlook.
- Investment in research and tools assisting utilities in filling data gaps and collecting data for predictive maintenance will support utilities in targeting resources to areas most in need.
- Incentives and policy to exploit use of available technology today, particularly software and artificial intelligence based tools, will accelerate their adoption at-scale.
- Barriers to implementation may be data gaps, addressed through development of field tools, and lack of training & education.

Challenge Area: New & Tightening Regulatory Limitations

Regulations nationwide continue to tighten, where limits are lowering for existing parameters and new contaminants are added to National Pollutant Discharge Elimination System (NPDES) permits. Nutrient treatment is a key area of need for utilities, driven by regulation in environmentally sensitive watersheds. In some cases, particularly with emerging contaminants or parameters with very low limits, laboratory methods do not yet exist to detect constituents at the regulatory level. The uncertainty leaves utilities in a difficult position to reach compliance, conducting nationwide searches for laboratories that can meet their niche needs. With "zero tolerance" regulatory atmospheres for unpermitted discharges in many communities, combined sanitary overflows (CSOs) and sanitary sewer overflows (SSOs) draw regulatory and public ire, putting further scrutiny on NPDES permits.

Several technology areas can support utilities in meeting this challenge, as innovation in process control, treatment technology, and ancillary equipment all promote efficiencies. For example, sensors and systems to monitor process control, effluent quality, and receiving waters can identify process concerns and promote data-driven solutions. Sensors that can be field deployed with minimal maintenance, detect low levels of contaminants, and reliably measure emerging contaminants expand the use cases for sensor deployment and process digitization. Advances in process and ancillary equipment, such as nutrient polishing and filtration media, allow plants to react to process trends and meet compliance with greater flexibility. Regulatory compliance and permitting management software can tie network, treatment, and ambient monitoring under one platform. Innovations in treatment options for CSO and SSO discharges require particular footprint and retention time considerations. Tightening regulatory limits can create opportunities for utilities to consider resource recovery or clean water reuse, particularly with nutrient removal and recovery options.

Use case spotlight of successful adoption:

Clean Water Utility: Las Virgenes WRF, small utility (~10 MGD) in California.

Drivers for implementation: Facing continuous CSOs and looking for ways to better leverage data to prevent spills.

Notable aspects of the operation that align with this technology area: The utility has 3000 miles of collection system pipe, in hard to reach/rural access areas. With one field staff member dedicated to the collection system, keeping up with maintenance was an impossible task. Deployed sensors ensured 24/7 monitoring of the collection system, saving the utility resources by avoiding dedication of additional full time staff while better managing the risk of spills.

Current Technologies (TRL 9)

Nutrient management is a key technology area where investment in current technology can significantly support clean water utilities, particularly where clean water utilities are faced with responsibility despite the cause of environmental events being triggered by varying and unregulated non-point sources. Several regions nationwide are tightening regulations on nutrient discharges, namely the watersheds of the Puget Sound, San Francisco Bay, the Great Lakes, among other sensitive regions, at an unprecedented speed often requiring unfunded/ unplanned projects. Excessive nutrient discharges can cause algae blooms in receiving waters, which can cause cascading environmental disruption throughout the habitat. Treatment plants required to meet tighter nitrogen and phosphorous limits vary in their current capabilities for nutrient removal. Some plants do not remove nutrients, and a shift to nutrient removal will require significant capital investment and operator training, whereas other plants who are removing nutrients must tighten process control or install polishing equipment to reach lower levels. Treatment plants may focus on side streams of the treatment process, where nutrient concentrations are highest.

There is a wide suite of established technologies that can help utilities meet current and anticipated permit requirements. Phosphorus is a critical ingredient in agricultural fertilizers, and its global supply is dwindling. Targeting the liquid effluent (i.e., centrate or filtrate) from biosolids treatment processes, through a sidestream struvite recovery process, such as Ostara or STRUVIA, can not only remove phosphorus to reach permit compliance, but can also provide a marketable product and revenue stream for the utility. The City of Atlanta, Gwinnett County of Georgia, and Hampton Roads Sanitation District are among several utilities that have deployed sidestream phosphorous treatment technologies. These technologies can capture up to 95% of the phosphorus in process sidestreams, allowing the utility to reach ultra low nutrient limits. Other algae based treatment processes provide nutrient polishing, while also producing an algae biomass that can be land applied as a fertilizer or soil augmentation.

SSOs and CSOs can be a source of nutrient pollution in receiving waters. As storms become more frequent and intense, utilities are charged with optimizing hydraulic capacity, and responding in real-time to the effects of infiltration and inflow. Several platforms are available to support utilities in monitoring flows, high levels, and spill locations, reducing pollution events by up to 60%. These systems can be scalable and applicable to any size utility. Network hydraulic management platforms that allow utilities to optimize storage capacity have saved 60-90% in stormwater related costs and reduced CSOs by up to 70%.

Despite a strong array of technologies to support nutrient removal and prevention of pollution events, barriers to implementation remain. Treatment plants may struggle to find adequate land area to install new tankage or large capital equipment, making new technology that can repurpose or retrofit existing equipment appealing. Long lead times to budget, design, and build new capital equipment can be painful for innovators. As regulatory compliance hinges on the success of an adopted technology, funding to support the pilot at-scale and capital investment needed for clean water utilities to procure nutrient management solutions and train staff to operate the equipment is critical. Additionally, demonstrations at-scale of resource recovery technologies that have the potential to provide a marketable end product are needed to illustrate the commercial value and drive new market opportunities and investment from the private sector that can in turn augment high capital or operating costs for clean water utilities.

Emerging (TRL 7-8) & Potential (TRL 4-6) Technologies

Emerging contaminant monitoring and treatment are becoming increasingly necessary and are focus areas for technologies that need investment in research and development. Constituents of concern may include PFAS, microplastics, pharmaceuticals, personal care or household cleaning products, pesticides, herbicides, or fertilizers. More jurisdictions are moving towards a one water model with indirect and direct potable reuse, increasing the importance of advanced monitoring and treatment of wastewater. Although it is understood that biosolids, though beneficial as fertilizer and soil amendment, can carry or concentrate contaminants, the potential for contamination is site specific. Stricter state regulations on land application are imposed as a precaution when there is a lack of site specific studies, as well as monitoring and treatment options, for biosolids. As drinking water utilities employ desalination technologies with higher water recovery, emerging contaminants may be further concentrated in the brine prior to being discharged to a clean water utility.

Before clean water utilities can make decisions on capital equipment for treatment, they need data to understand the type and concentration of contaminants. Many existing sensor technologies are expanding their capabilities to measure emerging contaminants, while a handful have available solutions. The family of emerging contaminants is vast, which is a challenge when innovators are deciding which parameters to target when developing a sensor or sensor suite. Some technologies are beginning to utilize artificial intelligence to correlate indicator parameters to the presence of emerging contaminants, which may make these types of sensors more widely relevant to a larger application. A similar approach detects deviations from baseline water microparticle “fingerprints” that alert to potential contamination, rather than monitoring for individual contaminants.

Areas of notable innovation in the treatment landscape for emerging contaminants include filter media and membrane advancements, with many media exploring sustainably sourced raw materials such as corn husks or crustacean shell waste. These media can be designed to remove specific contaminants, such as PFAS, to be coupled with more traditional media for more basic treatment. There is increased need from end-users in regenerative media, which could make operations more sustainable as well as cut down on media disposal costs. Disposal and destruction methods for contaminated media is an area for needed innovation. Membrane systems can remove a wide range of contaminants in one system, unlocking additional capital and footprint savings, particularly for smaller utilities, while also providing higher water recovery by up to 20%.

Barriers to the development and adoption of sensor technology for constituents of emerging concern may be challenges with the EPA certification process, particularly when the sensors utilize non-traditional methods such as proxy indicators or artificial intelligence. Without the certification, it may be difficult for utilities to adopt the technology, and thus disincentivizes the private sector to invest in new solutions. Similarly, when introducing new filtration media to the market, that media often requires NSF or other certifications before utilities can implement it, which can be a challenge for innovators to navigate, particularly if looking to reclaim or reuse wastewater. This further emphasizes the need for investment in research and demonstration of emerging solutions that can make an impact in this very critical area for the clean water sector.

Conclusion

- Investment in nutrient removal technologies, with an emphasis on resource recovery technologies, can support clean water agencies in meeting tightening nutrient regulations nationwide.
- Investment in research and pilot at-scale demonstrations of emerging contaminant monitoring will support utility compliance with emerging contaminant limits, the safe movement of utilities to indirect and direct potable reuse, as well as support vendors navigating industrial and regulatory certification processes, including regeneration and disposal management beyond current limitations.
- Barriers to implementation may be rigidity in the regulatory approval process, for vendors developing products as well as for utilities wanting to pilot them. There is little incentive to innovate if the risk is too high. Capital costs are a notable barrier nationwide.

Challenge Area: System & Operational Resilience

Resilience is the ability to recover quickly from setbacks or difficulties - for clean water utilities, resilience means maintaining service despite threats by climate change, cyber security vulnerabilities, supply chain issues, and a workforce approaching retirement. Though these threats can feel outside the utilities' control, the utility can control its preparedness, redundancy, and adaptability through the deployment of technologies that ensure continuous and reliable level-of-service to the communities they serve. System and operational resilience refers to the ability of treatment processes, conveyance networks, and the workforce to adapt to and bounce back from threats and emergencies.

There are several approaches a utility can take when considering technology areas to increase system and operational resiliency. Fundamentally reducing the dependency on chemicals, driving efficiencies across the treatment footprint, streamlining emergency response, and improving the use of data and monitoring for real-time decision support are examples that utilities of every size and region have used to meet the service needs of their community. On the horizon are several technologies looking to address supply chain challenges. Examples include production of process chemicals on-site to reduce reliance on bulk deliveries, smart chemical delivery systems that fine tune dosing based on operational parameters to save costs, and chemical-free technologies that remove the reliance on consumables altogether- a true indicator of what is possible in the future.

Use case spotlight of successful adoption:

Clean Water Utility: San Francisco Public Utilities Commission, large (>300 MGD) utility in California.

Drivers for implementation: Monitoring influent wastewater; characterizing wastewater entering extended aeration basins; obtain real-time data on wastewater quality and biomass activity; automate oxygen feed rate to aeration basins.

Notable aspects of the operation that align with this technology area: Deployed microbial sensor; utility noted the significant impact of rainfall events on microbial activity; used data generated to optimize aeration processes and controls.

Current Technologies (TRL 9)

Utilities are commonly described as data-rich and analysis-poor, with loads of data and few tools to translate that data to action. With real-time monitoring, visualization, and response tools, the sector can improve response times, discover and exploit process efficiencies, train staff, and make data more readily available to larger audiences within the organization, improving process and workforce resilience. Sensors are becoming more affordable, can detect more parameters, and can be deployed in more diverse applications, while more sophisticated platforms can aggregate and analyze the data produced, creating reports, predicting operational outcomes, or automatically taking operational action.

Applications for real-time monitoring can span all aspects of clean water management, including collection, treatment, and distribution of reuse water. Use cases may include deploying pressure sensors in the collection system to detect pressure transients, also known as water hammers, and avoid pipe breaks, deploying water quality sensors in the treatment processes to monitor and optimize chemical use, or using flow meters and hydraulic modeling to manage infiltration and inflow in the collection system. Small to large utilities can benefit from real-time monitoring and increased system awareness, as sensors and platforms are easily scaled. Technologies that support maximizing sensor placement to ensure a budget friendly and data productive deployment typically have a short return on investment.

Software platforms that pull data from real-time monitoring sensors focus on validating, calculating, merging, and storing data to provide operational analysis, data reporting, and, for some technologies, automatic response to system alarms. These platforms vary in integration and output capabilities, though provide a wide variety of options to utilities who are looking to digitize one business unit or expand that digitization across the organization. Platforms can sync multiple operational databases, providing reports, insights, scenario planning, training, and other analytics.

Adoption barriers to real-time monitoring include the lack of trained staff/workforce readiness, as integration and databasing can require specific expertise not typically housed in utilities, particularly in smaller organizations. However, workforce trends show a new openness to technology that analyzes, predicts, and acts on data, assisting the operator in day-to-day decisions. A barrier for utilities eager to deploy dashboarding/visualization tools may simply be poor or incomplete data, that would be supported by record keeping and a well-sensored network or the ability to integrate existing data sets. The commercial model of Software-as-a-Service or Data-as-a-Service are not always an attractive option for utilities when the benefits of streamlined data and reporting are often intangible or underutilized. Capital investment is a barrier, as it is difficult to change course once committed to a platform, and adopting a new software can be risky – especially if the company discontinues the platform or if the company or platform is purchased by another company. The utility can, as such, be left invested in unsupported software. With cyber security threats top of mind for utilities, connecting data or SCADA systems to the cloud can make them hesitant to pursue digitization.

Emerging (TRL 7-8) & Potential (TRL 4-6) Technologies

Supply chain concerns have always plagued chemical dependent utilities, and the exacerbated supply chain conditions of recent times have deepened concerns around resilient operations. Options for on-site chemical generation, which had historically been expensive, required complex operations, and was limited to disinfection, are expanding to process chemicals, such as flocculants/coagulants, odor control, and polymer tuning. Opportunities could be further expanded into chlorine quenchers for surface water discharge of chlorinated effluent and electron donors for denitrification. On-site generation is scalable, though likely more applicable for small to medium sized utilities.

Equipment is in development to produce a ferrous/ferric reagent using a sidestream, electrochemical process. The reagent can be used in any coagulation or flocculation treatment process where ferric products are used, such as odor control, phosphorus removal, or lowering hydrogen sulfide. The system has been demonstrated at bench scale to deliver the necessary concentration of ferrous reagent to match the performance of bulk ferric chloride and is in the early stages of pilot demonstration. If commercially available at-scale, this solution could eliminate or reduce reliance on the supply chain and global market, building resilience around treatment operations.

If converting from bulk chemical use is not an option, adoption of technology that tightens chemical dosing supports reducing and/or optimizing the overall demand of chemicals needed. Particularly for larger utilities, a small chemical reduction can translate to a large operational economy, not to mention, extending the use of product for a longer period. For example, monitoring and dosing solutions optimizing the sludge dewatering process, have saved 5-15% in total operational expenses, mainly due to lower sludge disposal costs, and decreasing dewatering polymer usage by 50%. Technology is in development to create polymers that can be tuned on demand to adapt to variations in seasonal sludge quality. Early market research with end-users demonstrated interest in this concept. These are notable areas of development that can result in less chemical usage and increased independence and resiliency in treatment operations.

Electrocoagulation is emerging in the municipal space, an approach that eliminates the need for chemicals. With developments in energy efficient design coupled with renewable energy generation, electrocoagulation may be attractive when compared to conventional treatment, particularly for smaller and/or rural communities. For example, when coupled with biological treatment, electrocoagulation can lower capital and operational costs by 40% and 25%, respectively. Some vendors offer turnkey or packaged systems, with full maintenance packages. Developing successful on-site chemical generating technology (or regional facilities that serve several clean water utilities) requires significant R&D and investment, leading to a long product development cycle for innovators and can be an area of attention for increased funding and support.

Utilities, used to traditional bulk delivery, may be uncomfortable with the perceived lack of redundancy in an on-site generator, making regional collaboration between peers a potentially attractive solution. Furthermore, innovators would likely have to demonstrate the system in several field deployments to raise the confidence of more potential end-users. Finding these early adopters can be a challenge, though investment in subsidizing pilots and capital costs may accelerate field testing and adoption for full conversion or a hybrid approach. Bulk chemical purchases typically originate in a utility's operating budget, and the installation of an on-site generator would need to be programmed into a long-term capital plan, leading to a long procurement cycle for innovators.

Conclusion

- Investment in digitization can help clean water agencies of all sizes and geographies to manage operations, respond in real time, and be resilient during unplanned events.
- Investment in research, pilot at-scale demonstrations, and capital costs for clean water utilities to generate onsite/regional chemicals will build resilience to supply chain woes and rising costs of chemicals to meet treatment and operational requirements.
- Barriers to implementation of data platforms may include cybersecurity risks, and barriers to implementation of on-site chemical generation may be lack of resources to pilot adequately for the comfort and confidence of the utility and the regulator.

Challenge Area: Population Variation

Population shifts are a major challenge in many areas of the country, defined by rapid increases and decreases in customer base. Areas with rapid growth struggle to keep up with treatment demand, expanding both potable water supply as well as wastewater treatment capacity. Other areas, either projected to grow but never did or experiencing a rapid net loss of population, struggle with oversized assets. Growing communities often need to increase treatment capacity in existing or minimal footprint or treat wastewater effluent to higher standards than before. The shrinking communities have some flexibility to be creative in how to best utilize excess capacity.

Technology areas best positioned to meet these challenges may include treatment intensification processes, advanced or sidestream treatment processes, network hydraulic modeling or optimization platforms, and sensor and monitoring equipment. Intensification processes support growing communities to achieve more treatment in the same footprint, and optimization platforms identify and exploit efficiencies. Shrinking communities can use hydraulic models to capitalize on storage capacity in the network, take advantage of excess capacity by receiving septage, FOG, or landfill leachate, or employ optimization platforms to best utilize existing capacity.

Use case spotlight of successful adoption:

Clean Water Agency: Town of Sturbridge, small (1.6 MGD) utility in Massachusetts.

Drivers for implementation: increasing operational costs, difficulty complying with new regulations, periodic filamentous bacterial blooms.

Notable aspects of the operation that align with this technology area: doubled plant capacity within existing space at lower cost than an MBR, integrated tertiary treatment to meet tighter limits, and met regulatory compliance.

Current Technologies (TRL 9)

Intensification is a broad term for technologies and processes that allow facilities to achieve better treatment performance in a smaller footprint or increase treatment capacity without increasing treatment footprint. Intensification provides system flexibility so that cities can adapt to population shifts while sustaining a healthy thriving community and economy while meeting public and environmental health compliance targets. Intensification technologies can be deployed from primary treatment through effluent polishing to solids handling, serving system flexibility throughout the treatment train.

Many process improvement and intensification concepts have been born out of university studies, where innovators have adapted the theory to practice, and others have been discovered and commercialized by engineering firms. Technology areas in biological treatment include membrane bioreactors, BioMag, integrated fixed film activated sludge, moving bed biofilm reactors, and aerobic granular sludge. The latter process, for example, requires less mechanical equipment, eliminates clarifiers and return activated sludge pumping stations, and uses far smaller tanks than conventional activated sludge, translating to significant capital expenditure reductions and 30-50% less energy consumption. Similar advancements that intensify primary filtration achieve up to 30% savings in downstream secondary treatment in a smaller footprint. These systems can also be deployed for primary treatment of CSOs.

Biosolids handling can be a complicated and expensive undertaking, for both rapidly growing areas as well as peri-urban and rural areas. Pretreatment options to enhance sludge dewatering and thickening deliver a net project payback of less than five years due to reductions in sludge volume and polymer consumption, as well as improvements in plant performance. Pretreatment options for anaerobic digestion, such as thermal hydrolysis or chemical hydrolysis, reduces the volume of solids entering the digester as well as shortens the digestion time, therefore increasing the capacity of existing digesters. These pretreatment options also boost biogas production, leading to more opportunity for renewable energy generation.

Historic barriers to implementing intensification technologies were common because of the risk averse nature of many utilities. However, with increasing population pressures, the driver for adoption is stronger, with conventional treatment just not an option for many communities due to footprint limitations or capital expenditures for large tankage. Investment in research to explain the mechanisms of intensification to promote system modeling would provide a level of comfort and assurance, along with pilots at-scale, for increased technological adoption. Technologies that can be retrofitted within existing tankage and technologies that provide increased system flexibility are areas of focus. Last, investment in operator training and education is critical for organizational acceptance and operational success of these technologies.

Emerging (TRL 7-8) & Potential (TRL 4-6) Technologies

In rapidly growing areas, as well as those geographies where communities historically served by septic systems are connected to sewer service, hybrid centralized / decentralized treatment options may provide increased resilience to growing communities or those located in environmentally sensitive areas. Other communities, with seasonal population changes or seasonal permit requirements, may consider plug and play solutions that can create flexibility within the treatment process to accommodate flow or loading fluctuations.

Some decentralized systems are well established in industrial or commercial settings and are now looking to adapt to the municipal market. Technology in development aims to convey just the liquid portion of a resident's underground tank, creating a network of shallow, small-diameter collection lines. The underground tanks, primarily collecting solids, are required to be pumped at a much lower frequency than a septic tank accepting both liquid and solid waste, and significant construction savings is achieved in the smaller diameter, shallow conveyance lines. The design also reduces the loading on the receiving treatment plant. The development of more innovative decentralized systems may allow utilities to be more creative in accommodating new growth, provide sewer access to more residents, and achieve environmental protection in sensitive areas without the burden of significant investment of new infrastructure where long term demand and financing are uncertain.

Decentralized biosolids handling is an area of innovation for emerging and potential technologies as well. Decentralized package treatment systems utilizing supercritical conditions that negate the need for anaerobic digestion can save up to 75% in treatment costs while producing reuse water and mitigating carbon dioxide emissions. This approach can also target emerging and non-biodegradable contaminants and be deployed off-grid in regional or remote locations. These systems could support regionalization of biosolids treatment in areas where individual utility scale would not be economically feasible.

Decentralized systems are not widely deployed though technologies emerging in this space are filling a need expressed by utilities facing rapid and sprawling development, seasonal population fluctuations, or as a path to make the infrastructure more flexible and resilient at the lowest capital costs. Investment to pilot at-scale, in order to demonstrate capital and operating savings, will be important to accelerate deployment. The benefits in cost savings, as well as the environmental benefit of removing failing septic systems in environmentally sensitive areas, are a strong business case, though structured policy frameworks and guidelines are needed to support alignment of stakeholders and achieve community buy-in.

Conclusion

- With urbanization driving rapid population growth for many utilities, investment in research and pilot at-scale intensification processes will expand flexible, low chemical and energy treatment options, particularly where footprint is constrained.
- Decentralized treatment systems are an emerging area that would benefit from policy advocacy, deployment frameworks and guidelines, as well as pilot at-scale demonstrations to increase utility acceptance.
- Barriers to implementation of intensification systems historically had been a lack of driver in many areas, though this is waning as populations grow and utilities don't have the land area available to expand.
- Barriers to implementation of decentralized systems may be coordination among utilities, communities, and developers.

Conclusion

Clean water utilities are facing several challenges, with the areas of **System & Operational Resilience, New & Tightening Regulatory Requirements, Rising Cost of Energy, Population Variations, Infrastructure Asset Management** best poised to leverage innovative technologies at scale to promote positive outcomes in communities of all sizes. Many clean water utilities are **adopting current, emerging, and potential solutions at scale**, technologies that have achieved various Technology Readiness Levels. However, technology adoption is not rapid enough, causing promising technologies to leave the market before gaining traction, often to pursue other sectors.

By the nature of the technology application, level of risk involved, complexity of the equipment, and available resources, some technology areas are more easily or quickly adopted than others, such as sensors, software platforms, or other ancillary equipment. Other technology areas, particularly treatment, resource recovery, or other capital intensive equipment, are typically much more difficult to deploy. All technology areas have the potential to positively impact the communities they serve, and it could be argued that capital intensive equipment, equipment that can make step-change strides in energy and chemical reduction, could make the largest impact towards regulatory compliance and sustainability goals with appropriate levels of incentive and investment.

As the challenge areas described above are tightly interconnected, targeting one challenge area inevitably bleeds into another, cascading positive change across several areas. **Investment in research, pilot at-scale demonstrations, test beds, and capital costs would support de-risking adoption of innovative technologies, particularly those considered potential or emerging.** Regulatory certainty and streamlined paths to product certification or validation would be supportive of end-user adoption as market ready products could be marketed more effectively. Last, consistent policy frameworks, guidelines, and incentives provide the justification and impetus for accelerating technology adoption particularly when it comes to resource recovery, energy reduction, or climate related areas.