MARCH 2025

Water Innovations

UNLOCKING DESALINATION

A Pathway To Cost-Effectiveness

PLUS:

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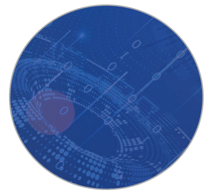

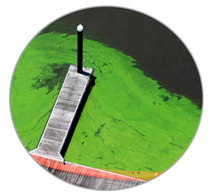

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FROM THE EDITOR

By Kevin Westerling
Chief Editor, editor@wateronline.com

Cybersecurity For The Win

Water and wastewater system operators are known to be a careful lot. Tightly regulated by the U.S. EPA and state agencies — and committed to public health — they cannot afford mistakes. This often results in "tried-and-true" methodologies winning out over innovative solutions, but the incredible upside offered by digital technologies has encouraged a wave of cyber adoption. Almost cruelly, it comes with cyber threats.

The benefits will outweigh any potential downside, however, so long as cybersecurity is in place. To better understand the scope of risk utilities face and the protection required, I spoke with Steven Taylor, Senior Global Product Manager of Cybersecurity Services at Rockwell Automation. Read on for insight to keep you confident in traversing the digital path to more efficient, sustainable, and effective water and wastewater management. Don't let bad actors impede our industry's progress!

How much at risk are water and wastewater systems to cybersecurity threats?

Water and wastewater treatment facilities are critical systems that are increasingly targeted by threat actors. In a recent IBM report, it was stated that attacks on vulnerable systems in industrial sectors had an 18% total cost increase compared to those costs in 2023. The impacts can be catastrophic if control systems at water treatment plants are targeted, potentially causing crippling disruptions, panic, widespread illness, and more. As a result, these systems are often considered highly vulnerable due to their traditionally outdated systems and legacy infrastructure. Some methods used often come in the form of ransomware attacks or insider threats.

What is the current regulatory landscape for cybersecurity protection of critical infrastructure?

Recent high-profile incidents in Pennsylvania and Kansas have highlighted the need for stronger cybersecurity frameworks, as many facilities still rely on outdated systems with limited security measures. Though many security professionals are pushing for stricter guidelines, implementation gaps remain a challenge. While formal regulations continue to be evaluated, cyber threats are evolving; therefore, a proactive and collaborative approach between government agencies and private sector operators is essential. In terms of best practices, current guidelines, provided by the Cybersecurity and Infrastructure Security Agency (CISA) and the EPA, are being leveraged by vendors to thoroughly serve as protection.

How does a utility ensure good "cybersecurity hygiene"?

Critical infrastructure operators should practice "good hygiene" by implementing a holistic, structured OT cybersecurity program rooted in industry frameworks. A good framework to follow is the National Institute of Standards and Technology (NIST) Cybersecurity Framework (CSF). The core functions of the latest framework are to identify, protect, detect, respond, recover, and govern. These functions of the CSF also act as steps for operators to take to help protect their systems before, during, and after a potential attack. Another tip to ensure good cybersecurity hygiene is to do an assessment of the current staff's awareness of tools and/or best practices. This could include involvement in proactive disaster recovery drills, general tabletop exercises, and penetration testing.

What are the challenges to meeting that standard, and how are they overcome?

While there are differences in the way that each individual water treatment facility is operated, they often face similar cybersecurity challenges. Water treatment infrastructure is often aging and outdated. It can also be difficult and expensive to upgrade security, especially when cybersecurity is underfunded or overlooked in critical infrastructure. However, operators must recognize that even newer facilities, with advanced technologies, are not immune to attacks. Operators must work to ensure that cybersecurity is integrated into both new and legacy systems to prevent service disruptions or more severe consequences.

What cybersecurity considerations must utilities make as digital technologies continue to proliferate?

The increasing reliance on automation and AI in critical infrastructure, including water and wastewater systems, will require significant and strategic shifts in cybersecurity protocols and investments. While modern technologies enhance efficiency and threat detection, they also introduce new vulnerabilities that adversaries can use to their advantage. Organizations must prioritize investments in AI-driven security measures, continuous monitoring, and adaptive risk management to stay ahead of evolving threats. Additionally, cybersecurity protocols will need to incorporate stronger safeguards against AI manipulation and system breaches. A balanced approach of leveraging automation while maintaining human oversight will be key to ensuring both operational efficiency and security resilience. ■

New Research Could Extend Membrane Life And Lower Desalination Costs

As water-scarce regions clamor for answers, developments in membrane anti-scaling bring desalination closer to viability.

By Christian Bonawandt

Membrane desalination is a critical technology in addressing global water scarcity and promoting a circular water economy. However, the high costs associated with desalination often hinder widespread adoption. In addition to the high energy demand associated with desalination, scaling and fouling of membranes can significantly increase costs and reduce process efficiency. However, researchers from Arizona State University and Colorado State University have made what is being called a breakthrough in the understanding and mitigation of scaling[1] caused by gypsum and silica. The findings, published in *Frontiers of Environmental Science & Engineering*, have the potential to notably improve the economics of desalination by enhancing operational efficiency and extending the lifespan of membranes.

Understanding Gypsum And Silica Scaling

Gypsum and silica scaling have distinct formation mechanisms, each influencing the thermodynamics, kinetics, and morphology of the scales. Gypsum scaling arises from a crystallization process involving the nucleation and growth of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) crystals. Earlier studies reveal that gypsum formation has multiple stages: the aggregation, rearrangement, and coalescence of nanocrystalline calcium sulfate clusters. This process can result in well-defined crystals with high aspect ratios, such as needles or rosettes, which adhere to membrane surfaces and impede water flux. Thankfully, gypsum scaling is relatively reversible and can often be addressed through physical cleaning.

In comparison, silica scaling stems from the polymerization of silicic acid, leading to the formation of amorphous silica deposits. Unlike gypsum, silica scales lack a crystalline structure, forming spherical particles that fuse into a gel-like layer on membrane surfaces. Silica scaling is notoriously difficult to reverse, with polymerized layers severely impairing membrane performance. As a result of these differences, desalination systems may require mitigation strategies tailored to each type of scaling.

Silica scaling is notoriously difficult to reverse, with polymerized layers severely impairing membrane performance.

Breakthroughs In Mitigation Strategies

The research indicates several innovative approaches can be used to mitigate both gypsum and silica scaling. For gypsum scaling, the new study proves the effectiveness of scaling-resistant membranes. In addition, hydrophilic polymer brushes, such as poly(methacrylic acid) and poly(acrylamide), reduce gypsum scaling by minimizing the attachment of gypsum nuclei. Similarly, zwitterionic polymers like poly(sulfobetaine methacrylate) (PSBMA) decrease gypsum adhesion, enhancing membrane performance. Superhydrophobic membranes with micro-pillar arrays can also be used in desalination to further mitigate scaling by reducing nucleation sites and promoting the detachment of gypsum crystals.

Additionally, researchers found antiscalants such as sodium hexametaphosphate (SHMP) and poly(acrylic acid) (PAA) inhibit gypsum nucleation and growth by interacting with calcium ions on the surface of nuclei. This increases the induction time for gypsum formation and prevents crystal growth. Pretreatment methods like nanofiltration (NF) also play a significant role by selectively separating ions, minimizing scaling during both pretreatment and subsequent reverse osmosis (RO) processes.

For silica scaling, researchers found scaling-resistant membranes with negatively charged surfaces are effective in repelling silica species, reducing local concentrations, and slowing polymerization. Antiscalants like poly(amidoamine) (PAMAM) and poly(ethylenimine) (PEI) hinder the polymerization of silicic acid, resulting in larger, slower-forming silica particles. Neutral polymers such as poly(ethylene glycol) (PEG) delay the formation of impermeable gel layers, enhancing resistance to silica scaling. Pretreatment approaches, including the use of nanomaterials like aluminum hydroxide and iron hydroxide, were also shown to efficiently adsorb silicic acid, while magnetic nanomaterials such as $Al(OH)_3@Fe_3O_4$ offer the added advantage of easy recovery and reuse through magnetic separation.

Dual-Scale Mitigation Strategies

While each of the above-mentioned solutions can address either gypsum or silica scaling, the study uncovered some that address both. Among them is electrocoagulation, an electrochemical process that simultaneously removes dissolved silica and hardness. Lime-soda softening is another effective strategy, wherein lime (calcium hydroxide) and soda ash (sodium carbonate) are added to precipitate calcium, magnesium, and silica, reducing scaling potential. Ion exchange softening, a commonly used prefiltration technology, uses cation exchange resins to remove calcium and magnesium, while anion exchange resins eliminate reactive silica, thereby mitigating scaling from both sources.

Implications For Desalination Economics

The adoption of these advanced mitigation strategies can significantly improve the economics of membrane desalination in three key ways:

- **Improved operational efficiency.** Scaling-resistant membranes and targeted pretreatment methods maintain higher water flux, reducing the frequency of cleaning cycles and minimizing downtime.
- **Reduced energy consumption.** Scaling increases hydraulic resistance, leading to higher energy demands. Effective mitigation reduces this resistance, lowering energy costs.
- **Increased longevity of membranes.** By preventing irreversible damage, such as that caused by silica scaling, these strategies extend the usable life of membranes, reducing replacement costs.

Scaling-resistant membranes and targeted pretreatment methods maintain higher water flux, reducing the frequency of cleaning cycles and minimizing downtime.

Moreover, novel approaches like the use of magnetic nanomaterials and electrocoagulation offer sustainable and cost-effective alternatives to traditional methods. The ability to recover and reuse materials further reduces operational costs and environmental impact.

While the study's results are promising, the researchers identified several areas that need further investigation. These include a deeper understanding of molecular interactions of scale precursors, an examination of the effect of temperature on scaling and scale prevention, and details on metal silicates, which have lower solubility than pure silica.

Researchers also noted that more studies are needed in real-world applications, particularly to analyze scale types formed from feedwaters with complex water chemistry. This includes feedwaters collected from various sources, such as industrial wastewater and natural waterbodies. Analyzing scale types on membrane surfaces in real desalination applications is important to ensure that mitigation strategies are effective in practical settings and thus further enhance the role of desalination in mitigating water scarcity. ■

References:

1. https://journal.hep.com.cn/fese/EN/10.1007/s11783-025-1923-9

About The Author

Christian Bonawandt is an industrial content writer for *Water Online*. He has been writing about B2B technology and industrial processes for 24 years.

How Water Reuse Projects Are Addressing Water Scarcity In The West — And Beyond

By Tama Snow and Ryan Murdock

As water scarcity becomes a stark reality around the globe, more municipalities, water utilities, and industrial enterprises are exploring water reuse projects and adopting regulations to support them. Fundamentally, water reuse can help drought-proof regions and diversify water supply portfolios with recycled water.

While water reuse is particularly prevalent in California, interest in direct and indirect potable reuse projects is growing throughout the Western U.S. and beyond. Although this work is heavily present in the West, there are a growing number of reuse projects in states experiencing rapid growth and climate change. In other regions, states such as Texas and Florida are implementing water reuse, and states in the Midwest are considering it.

As a sustainable design and engineering firm, Stantec is at the forefront of some of these notable projects for both municipal and industrial clients.

Water Reuse In Action

There are multiple water reuse efforts underway to address the issue of water scarcity. These efforts make use of existing local water resources to continue to provide access to safe, sustainable, affordable drinking water for everyone.

For example, Pure Water San Diego is a large-scale, direct potable reuse program that our team is working on in support of the city of San Diego. The program treats recycled water to potable reuse standards, stores that water in a reservoir, blends it with other water sources, and treats it further to meet drinking water quality standards.

Today, there is broader public acceptance of recycled water than there was in the last few decades.

In Palmdale, CA, Stantec designed an advanced water treatment demonstration facility for the Pure Water Antelope Valley project. This facility will be used to collect data to further inform design of a full-scale facility and obtain regulatory approval for this groundwater replenishment project.

In rapidly growing and arid southern Utah, the Washington County Regional Reuse Purification System is also underway. Stantec is serving as the Owner's Advisor to help implement a regional water reuse program that consists of more than 30 projects to improve the efficacy of local water supplies.

Today, there is broader public acceptance of recycled water than there was in the last few decades. Residents are realizing the realities of water scarcity and the benefits of environmental sustainability, and they have seen firsthand that treatment technology has been proven to produce water that exceeds drinking water quality requirements.

The Role Of Climate Change In Driving Water Reuse

Climate change amplifies the variability that has long defined water supply in the Western U.S. We're experiencing long-term climate variability (including increased temperatures) and droughts of longer duration, increased frequency, and/or higher intensity than reflected in historical water supply conditions.

Pure Water Antelope Valley groundbreaking

These will further stress water supplies already under strain from population growth, increasing demands, and industrial development. Hotter and drier climate conditions are also driving higher water needs for municipal outdoor irrigation and irrigated agriculture.

These water scarcity drivers are leading many water managers to seek solutions to balance water supply and demand through water supply portfolio diversification. Many water suppliers are looking beyond traditional surface and groundwater supplies to strategies such as reuse and treatment of impaired water sources (including desalination), water banking and acquisitions, and enhanced water conservation.

The rapid pace of change in demand and water availability can exceed the pace of adaptation. Over the past few decades, decision-making and permitting for water supply projects have become more complex in recognition of human, environmental, social, and economic implications and the heightened role of the public in water allocation decisions. When a state-level policy and regulatory framework has advanced sufficiently to allow clear project permitting and implementation guidelines, water reuse projects can often be implemented more efficiently and effectively than many other traditional water supply solutions.

Furthermore, water reuse projects can help buffer the impacts of climate extremes by providing a highly reliable local water supply that can be used to offset the loss of other water supplies and replenish groundwater basins and storage reservoirs during wet years for use during dry years.

With climate change, who knows what's next? We're seeing wild, unpredictable weather patterns that communities aren't prepared for. Utilities, industries, and municipalities need to plan for the unknown and consider a range of potential future scenarios and challenges. That is why it's imperative to make efficient use of available local resources. Having these local resources available is generally more cost-effective than importing water, and this local control also helps cities and towns prepare for worst-case scenarios.

Keeping The Public Informed

It's easy to take water for granted. If it runs from the tap when people turn it on, many water users don't think much about the availability of their water. But when rates go up or water becomes rationed, the public takes note.

Public outreach and education around water reuse and water supply are increasingly important, and many municipalities and industries are doing a great job of this. As a result, people are becoming much more open to the idea of recycled water as a drinking water supply. Regulations are also evolving in many states to better enable water reuse while simultaneously protecting human and ecosystem health. State and federal funding also plays a role in the implementation of water reuse projects.

With this positive momentum, there's reason for optimism about the future of our water supply — but there is a lot of work to do in the meantime. Public support combined with proactive planning, advancing policy and regulatory frameworks, proven technologies, and innovation from companies, utilities, and municipalities indicates that we can continue to take steps toward a sustainable water supply future. ■

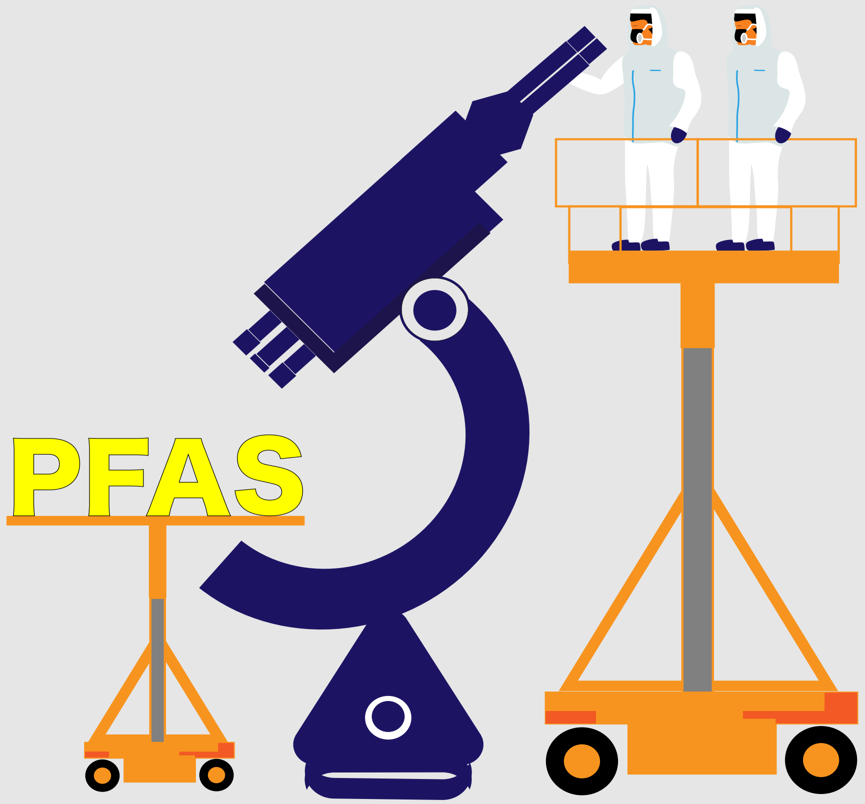
About The Authors

Tama Snow is VP and regional business leader of water (U.S. Pacific) for Stantec, responsible for building the Water, Wastewater, and Recycled Water Resources practice groups. A significant component of her work is mentoring staff and creating a diverse, inclusive, and inviting work environment for all.

Ryan Murdock is a vice president and water resources practice leader at Stantec. He has over 20 years of experience in comprehensive planning for strategic, large-scale water resources programs throughout the western U.S. from Texas to California.

PFAS TESTING BOOM:

U.S. Analytical Instrumentation Market Set For Rapid Expansion



By Shilpa Tiku

The U.S. per- and polyfluoroalkyl substances (PFAS) analytical instrumentation market is poised for strong expansion, with a projected CAGR exceeding 20% over the next seven years, according to a new report by Verify Markets.[1] Valued at approximately $190 million in 2024, the market is expected to surpass $800 million by 2031. Key drivers in the market include rising concerns over increasing risks associated with PFAS exposure, the U.S. EPA's federal rule on drinking water, and investments to boost testing and treating PFAS in water.

Commercial testing laboratories dominated the end-user market in 2024 and accounted for an estimated 52% of the market by revenue. Wastewater treatment facilities represented the second-largest segment and held an estimated 17% of market share by revenue. Most utilities rely on commercial labs for PFAS testing due to high instrumentation costs. With new EPA regulations, utilities are likely to become a key end-user market for PFAS analytical instruments. Demand from academic R&D laboratories is expected to stabilize within the next five to six years, while industrial facilities will likely expand testing, emphasizing pretreatment and stricter process controls to curb PFAS discharge.

Over the next five to seven years, drinking water and wastewater testing will see significant growth, while reliance on commercial labs will decline. Currently, commercial labs dominate because early adopters lack in-house capabilities and must outsource testing.

Cost competitiveness – In the PFAS analytical instrumentation market, price sensitivity is high, so companies must be cost-competitive to remain relevant and gain market share. To this end, companies should concentrate on back-end operations and cost control. In addition, it is equally important to maintain flexibility through balancing in-house manufacturing with outsourcing. Optimizing supply chains to remove inefficiencies and establishing solid partnerships with suppliers will likely assist in obtaining better pricing and guarantee product availability.

> **Currently, commercial labs dominate because early adopters lack in-house capabilities and must outsource testing.**

Consumables supply assurance – Reliable PFAS testing depends on the availability of consumables in a timely manner. During the forecast period (2024-2031), companies will likely leverage AI-driven demand forecasting and robust inventory management in order to prevent shortages and overstocking. Strengthening supply chain resilience and contingency planning will likely ensure operational continuity, reinforcing clients' trust and market leadership.

Distribution trends – Direct sales remain the primary go-to-market strategy, a trend unlikely to shift in the near future. While distribution may expand over the next five years, current PFAS-related equipment remains too complex for distributors to manage effectively. Manufacturers favor direct engagement,

mitigating risks associated with miscommunication. PFAS analysis represents an emerging and highly complex testing domain, demanding significant education and technical support. Limited availability of expert resources intensifies the challenge. Given the need for continuous training, risk management, and dependable after-sales service, end users prioritize direct sales over distributor channels. Manufacturers align with this preference, with direct sales accounting for over 50% of the market share by revenue, by channel, as they enable tighter control over equipment setup and operation. The specialized nature of PFAS-specific instruments, such as liquid chromatography-tandem mass spectrometry (LC-MS/MS) requires extensive hands-on guidance during installation and use, further limiting the role of distributors in the market.

> **The PFAS analytical instrumentation market is on the brink of significant expansion, with analytical instrument manufacturers heavily investing in next-generation solutions.**

Consolidated market – The overall PFAS analytical instrumentation market is highly consolidated with the top two or three companies holding over 90% of the market share by revenue.

Competitive factors – The key competitive factors within this market include price, after-sales services, and skill development training.

Market share by technology – LC-MS/MS is the predominant technology and is estimated to be over 70% of the market share by revenue in 2024.

The PFAS analytical instrumentation market is on the brink of significant expansion, with analytical instrument manufacturers heavily investing in next-generation solutions. With limited existing techniques and rising demand, companies recognize this as a major growth opportunity and are allocating substantial resources to advance PFAS instrumentation.

Automation is the future of PFAS testing, with major manufacturers prioritizing solutions that streamline the labor-intensive sample preparation process. As the industry shifts from manual to automated workflows, demand for these advanced instruments is set to rise, driving significant market growth. ■

References:

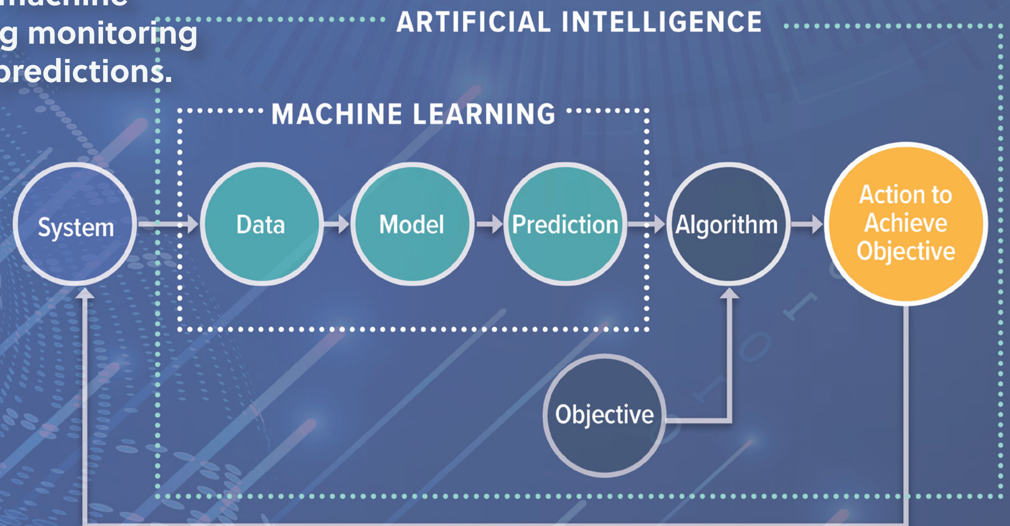
1. https://www.verifymarkets.com/blogs/news-and-interviews/pfas-federal-regulations-result-in-double-digit-growth-for-the-u-s-pfas-analytical-instrumentation-market

About The Author

Shilpa Tiku is the chief research officer and partner at Verify Markets (verifymarkets.com). Tiku has more than 20 years of experience in research and consulting. She focuses on monitoring and analyzing emerging trends, technologies, and market dynamics in several global markets. To reach her for comments, interviews, or market consulting, call 210.595.9687 or email her at shilpa.tiku@verifymarkets.com.

MACHINE LEARNING AND THE FUTURE OF WATER QUALITY MONITORING

Aided by "soft sensors," machine learning is revolutionizing monitoring and powering real-time predictions.



By Andrew Salveson, PE, Kate Newhart, PhD, and Kyle Thompson, PhD, PE

Machine learning (ML), a branch of artificial intelligence, is transforming how we monitor and manage water quality. At the forefront of this innovation are soft sensors — not physical devices, but intelligent algorithms that predict slow or expensive-to-measure water quality variables using readily-available data. This breakthrough is reducing monitoring costs and enabling more adaptive treatment processes.

Carollo is pioneering the application of these technologies in water treatment facilities across North America. In this article, we explore two case studies that showcase how ML is reshaping water quality monitoring in potable water reuse systems.

Predicting Total Organic Carbon In Virginia

Imagine being able to predict water quality faster than traditional methods allow. That's exactly what the Hampton Roads Sanitation District (HRSD) has achieved at the SWIFT Research Center in Virginia.

Total organic carbon (TOC) is a critical parameter for controlling ozone dosing in carbon-based reuse systems. Typically, TOC is measured less frequently than ozone levels, which could lead to less responsive control. Our solution? An ML-powered soft sensor for TOC.

Using three months of historical data from HRSD's SWIFT Research Center, a 1-MGD carbon-based reuse demonstration facility, Carollo developed a model that predicts TOC levels with remarkable accuracy. A boosted trees (bstTree) model outperformed the last-known value — a linear model with a root mean square error (RMSE) of 0.709 mg/L — by achieving an RMSE of 0.349 mg/L.

The model's success was based on a comprehensive data set that included measurements at five-minute intervals for 37 water quality and operational variables. Our team extracted 749 TOC measurements and paired them with predictive features such as UV transmittance, pH, and ammonia.

This translates to more precise and responsive ozone dosing, which could lead to significant energy savings and more effective water treatment.

Tackling NDMA In California

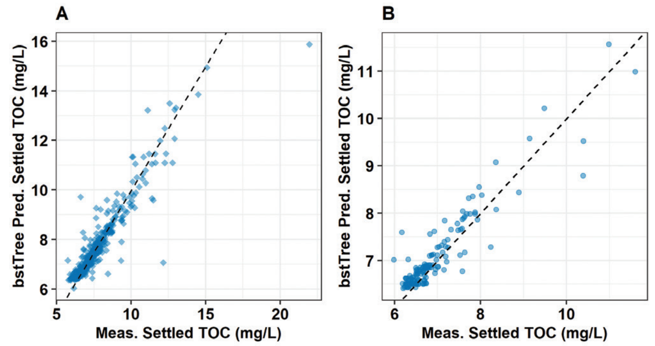
Our second case study highlights Las Virgenes Municipal Water District's (LVMWD's) Pure Water Demonstration Facility in California, where Carollo faced a different challenge: monitoring N-nitrosodimethylamine (NDMA), a critical disinfection byproduct in potable reuse systems.

NDMA levels can drive UV dosage requirements in advanced oxidation processes downstream of reverse osmosis (RO). Without real-time NDMA sensors, UV doses are typically set conservatively, based on maximum historical concentrations. This leads to unnecessarily high energy use; therefore, Carollo developed an ML-based soft sensor for NDMA.

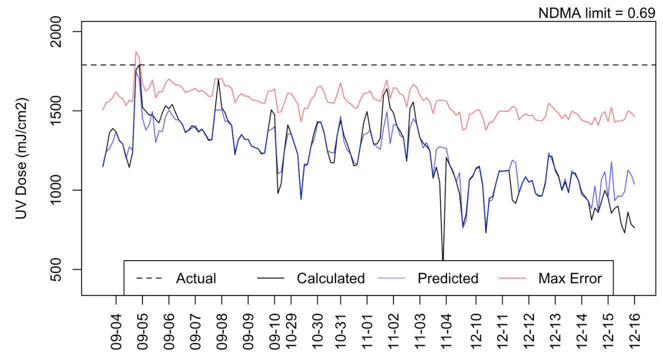
Using a dataset of 162 NDMA measurements from Orange County Water District's (OCWD) Groundwater Replenishment System, Dr. Kate Newhart of Oregon State University created a random forest model that predicts NDMA concentrations with an RMSE of 3 nanograms (ng)/L using measurements recorded every three hours over three weeks. Predictive features included ammonia, pH, turbidity, total chlorine, and pressure. As with HRSD, our team developed the ML models using open-source R programming, a powerful tool for statistical computing and data visualization.

Implementing UV dosage adjustments based on the predicted NDMA concentrations at OCWD would have resulted in less than 10% energy savings. The average NDMA post-RO was already low compared to the target for groundwater augmentation potable reuse. However, the water district would be held to a lower NDMA target for surface water augmentation potable reuse. Assuming the same model accuracy and starting NDMA concentrations, we estimated the reduced UV energy consumption at LVMWD could be 26%. Incorporating safety factors based on model uncertainty could still achieve 13% energy savings.

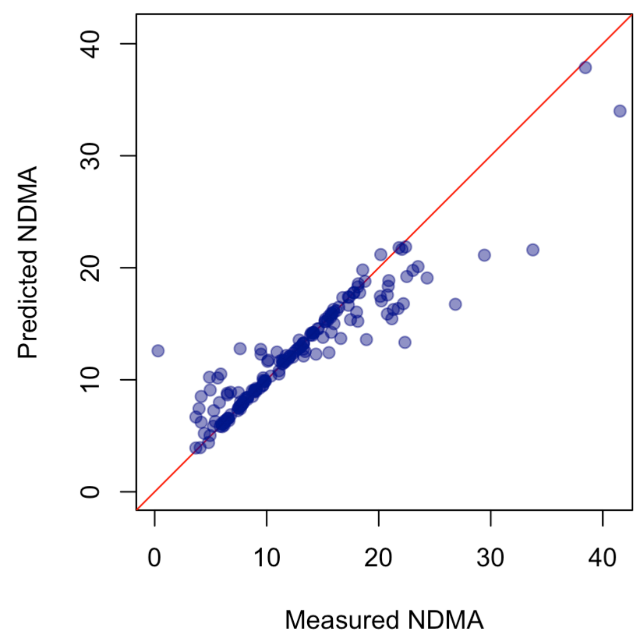
Therefore, Carollo is transferring this model to LVMWD's demonstration facility and collecting extensive new data to enhance the model's efficacy. This includes a comprehensive data collection effort spanning April 2024 to February 2025, and using approximately 200 NDMA samples from RO permeate, with daily sampling at random times to capture daily and seasonal variations. This data set will further refine and validate the NDMA ML model, which could lead to even greater energy savings and treatment efficiency.



Predicted versus measured values of settled TOC for HRSD's SWIFT Research Center bstTree ML model, showing the accuracy for the (A) training set and (B) testing set.



A comparison of predicted UV dose requirements for NDMA treatment for the Las Virgenes-Triunfo Pure Water Facility showcases the potential for energy savings with safety factors for the max error observed.



Predicted versus measured values of NDMA before UV/AOP at OCWD's Groundwater Replenishment System.

Looking Ahead

These advancements highlight the transformative potential of machine learning and real-time sensor technology in optimizing water treatment processes. By harnessing the power of AI, we're creating smarter, more efficient, and more sustainable water systems for the communities we serve.

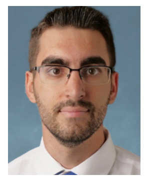
Acknowledgements

The Water Research Foundation funded the TOC soft sensor study as part of Project 5129, "Demonstration of Innovation to Improve Pathogen Removal and/or Monitoring in Carbon-Based Advanced Treatment for Potable Reuse." The National Alliance for Water Innovation funded the NDMA study under DE FOA 0001905 as part of Project 5.17, "Data-Driven Fault Detection and Process Control for Potable Reuse with Reverse Osmosis." ■

About The Authors

Andrew Salveson, PE, is Carollo's water reuse chief technologist and has received innovation awards from the International Water Association, the California Water Environment Association, and the WateReuse Association, the latter of which pertained to implementation of machine learning for purified recycled water treatment systems.

Dr. Kate Newhart is an assistant professor of Environmental Engineering at Oregon State University. Her research focuses on the development of statistical and machine learning models for full-scale water and wastewater treatment, water reuse, and resource recovery facilities.



Kyle Thompson, PhD, PE, is a senior technologist in Carollo's water reuse technical practice group and the firm's national PFAS lead. He has performed numerous research projects, including developing machine learning-based alert systems for drinking water and reuse, and screening chemicals as performance-based indicators or pass-through hazards in reuse.

NEW ARSENAL FOR ALGAE OUTBREAKS

How communities are protecting drinking water reservoirs without relying on chemicals.

By Dave Shackleton

The U.S. has over 84,000 reservoirs, ranging from large-scale ones like Lake Mead to small municipal reservoirs. Their combined storage capacity exceeds 600 million acre-feet of water. These reservoirs serve various purposes, including drinking water supply, recreation, irrigation, flood control, and hydropower. Some are exclusively for drinking water, some are recreational, and many are multiuse.

As public utilities, reservoirs are subject to more stringent management standards and must meet requirements for a range of water quality parameters that are not typically a concern for recreational waterbodies. Those responsible include federal agencies (e.g., U.S. Army Corps of Engineers, Bureau of Reclamation), state governments, municipal water districts, and private organizations. Drinking water reservoirs often fall under the jurisdiction of local water utilities and health departments.

For these agencies, maintaining consistent water quality is essential for the effective operation of water treatment plants. Seasonal changes such as stratification of the water column can result in reductions in dissolved oxygen levels and increases in pH; levels of dissolved metals such as iron and manganese; taste-and-odor problems due to geosmins; total organic content; algae levels; and, in extreme cases, toxic cyanobacteria bloom events.

Algae outbreaks can release toxins such as microcystins, which contaminate drinking water supplies. This contamination can cause water treatment disruptions, increased costs, and health risks including liver damage or gastrointestinal illness. Notable incidents include Toledo, Ohio's 2014 crisis, where residents were unable to use their tap water for days.

With greater volatility in weather and climate, seasonal changes in water quality are becoming more frequent and pronounced. This leaves many treatment plant operators battling to respond and cope. Many are now actively seeking solutions that can minimize fluctuations in water quality consistency to reduce chemical costs, eliminate plant downtime for backwashing, and assist in meeting compliance standards for potable water.

Algae Outbreaks

Algae outbreaks are more common in areas with high nutrient runoff, such as agricultural regions in the Midwest and Southeast. Outbreaks have been reported annually in states like Florida, Ohio, Oregon, and California, with increasing frequency due to rising temperatures and nutrient pollution.

High levels of algae in the upper water column and deoxygenated water in the lower column can create numerous problems. In the upper column, excessive aquatic plants and algae can clog plant intakes and filtration equipment. In the lower column, geosmins, high levels of dissolved metals, high organic content, and hydrogen sulfide can lead to taste-and-odor problems that result in customer complaints. The problem can become so severe that water drawn from deeper gates can become untreatable despite purification treatment.

Changes in raw water quality can result in elevated algae levels that block treatment plant filters, requiring frequent backwashing that disrupts production and increases chemical treatment and costs. Increased chlorination produces disinfection byproducts (DBPs), which can negatively impact compliance.

Algal blooms also contribute to the buildup of sediment, as well as fish kills that impact local wildlife in the food chain and can affect recreational activities such as fishing.

The Search For Effective Solutions

Despite significant financial investments over many years, there has been little improvement in the condition of U.S. lakes. In fact, according to a GAO report on water quality published in June of 2022,[1] the health of our lakes has deteriorated consistently over the past two decades.

Conventional approaches to addressing inconsistent water quality often involve the use of treatment chemicals and auxiliary treatment processes, which can increase plant operation costs and, in the case of chemical usage, may generate potentially harmful byproducts.

Chemicals can also lead to a detrimental cycle that accelerates the deterioration of the reservoir's ecosystem. The elimination of algae results in the release of toxins, leading to the destruction of more beneficial organisms and favoring the proliferation and dominance of harmful organisms in the lake. Over time, continued application of algaecides causes lake algal blooms to worsen. In other words, the symptoms are treated temporarily, but the patient never gets better.

Fortunately, there are more effective natural, chemical-free processes that can be implemented to address the root causes of water quality degradation, not just the symptoms.

The focus should be on maintaining the reservoir's balance of nutrients, organic matter, and dissolved oxygen, and promoting desirable aquatic organisms that help maintain a natural balance in the reservoir's ecosystem that ensures nutrient clearance.

To ensure a reservoir is suitable for public water supply, its quality must be consistent throughout the water column, and throughout the year, with a proper balance of nutrients and dissolved oxygen distributed evenly.

Sediment accumulation must also be addressed, which can become part of the permanent morphology of the lake. Simply physically removing and dumping sediment elsewhere through dredging techniques doesn't allow the nutrients to be recycled within the lake ecosystem. Bioaugmentation, which involves the use of enzymes to break down organic muck, like a compost pile, is a better solution.

Critical micronutrients can also be introduced to stimulate the growth of organisms that form the foundation of a productive food web.

The good news is that consistent use of these products over time reduces nutrient availability and helps maintain clean, healthy water.

In applications in the U.S. and in other countries, documented improvements in pH levels, increases in dissolved oxygen and reduced levels of manganese, iron, algae, turbidity, total organic carbon, dissolved organic carbon, nitrates, nitrites, hydrogen sulfide, and geosmins can occur within even a few months.

The result is more consistent reservoir water quality, reduced chemical usage, and lower operating costs of treatment plants.

CASE STUDY:

Bowling Green, OH, Drinking Water Reservoir

The city of Bowling Green, Ohio, draws water from the Maumee River into its reservoir prior to treatment to supply safe potable water to its citizens. In summer, the Maumee River is typically overwhelmed by toxic cyanobacteria for several months. Because the reservoir only holds about a 30-day supply, the city is forced to draw this cyanobacteria-ladened water into the reservoir.

For several years, this became a problem as cyanobacteria began to dominate the phycological profile of the reservoir to the same degree as it does in the river.

To resolve the issue, in the late 2000s a bottom-based aeration system was installed in the reservoir, but this did not control the cyanobacteria, and by 2016, it proved necessary to add the use of a peroxide-based algaecide to the reservoir.

These two interventions were unable to control the situation. In late 2016, the proportional dominance of cyanobacteria in the river and in the reservoir was still about the same at approximately 68%. The absolute numbers in terms of cell count were slightly reduced in the reservoir due to the application of algaecide, but this did nothing to constrain the dominance of cyanobacteria.

In April 2017, the city of Bowling Green decided to install rapid-acting dissolved oxygen restoration (RADOR) technology. Numerous studies have demonstrated that high, stable oxygen levels reduce nutrients and minerals in the water column and can keep phosphorus locked into the organic sediments.

By increasing dissolved oxygen levels throughout the water column, the RADOR system initiates a sequence of events that bio-dredge mucky sediment, control aquatic weeds, improve water quality, and reduce organic muck, nutrients, odor, harmful gases, and coliform bacteria. This helps to restore the nutrient clearing capacity of the food web by improving fish growth and health.

RADOR systems can be designed using compressors of various sizes based on the lake and application, along with self-sinking air lines and diffusers that maintain full oxygenation from the bottom to the surface of the water.

Data collected a year later showed that the total phycological cell count was reduced by around 75% and cyanobacteria were all but eliminated completely. By 2018, despite having to draw water from the river at a time when cyanobacteria levels were extremely high, total cell count and cyanobacteria levels were well controlled in the reservoir.

"The implementation of the … RADOR system enhanced water quality and it is an important tool for its reservoir management," said Daryl Stockburger, assistant director of utilities, city of Bowling Green.

CASE STUDY:

Toa Vaca, Puerto Rico, Drinking Water Reservoir

Toa Vaca reservoir in Puerto Rico, built in 1972, covers 836 acres and is over 51 meters deep when full. By 1985, the reservoir showed serious symptoms of water quality deterioration due to eutrophication.

The intake tower consists of six gates, numbered 1 to 6 from bottom to top. As early as 2009, due to eutrophication, only the upper two abstraction points (gates 5 and 6) could be used to draw water for purification treatment.

Water from deeper gates was untreatable due to high levels of manganese and contaminants causing foul tastes and odors, such as geosmins and hydrogen sulfide. However, drawing water from the upper levels also presented problems, as high algae levels clogged filters and required the use of high levels of flocculants and chlorine in the purification process, generating excessive levels of trihalomethanes (TTHMs), a carcinogenic byproduct of chlorination.

By 2012, high levels of manganese, hydrogen sulfide, and toxic cyanobacteria in the upper water column made it increasingly difficult to produce potable water that met regulated standards. The future prognosis for the reservoir was poor, with fish kills becoming so common that recreational fishermen and birds of prey had abandoned the reservoir.

Recognizing that conventional aeration would not achieve the necessary improvements due to the reservoir's size, depth, and chemical and biological problems, including severe manganese and cyanobacteria issues, the utility sought experienced engineering and specialized technology.

"In seeking a solution for the problems at Toa Vaca, we knew that conventional aeration would not achieve the necessary improvements. The problems were both chemical and biological with the severe algae and cyanobacteria problems. We needed experienced engineering and specialized technology," said Carlos Gonzalez, GIT Puerto Rico.

Initial bathymetric analysis revealed that the reservoir is up to 51 meters deep, but drought can cause the water level to drop by over 20 meters. Ensuring full oxygenation across the scale and scope of these variations required RADOR oxygenation technology.

Several key parameters were closely monitored during the first three months and significant improvements were observed almost immediately in the quality of potable water produced by the two purification plants drawing water from the reservoir.

Specifically, the goal to increase dissolved oxygen (DO) levels to at least 4 mg/L at the surface was achieved within approximately a month and maintained thereafter. The target was also achieved and maintained at 70 feet (21 meters) deep within the first three months of operation.

Establishing adequate dissolved oxygen levels is a critical prerequisite to being able to address the other problems being encountered, such as high levels of dissolved nutrients and manganese and taste-and-odor issues. The ability to rapidly de-stratify and oxygenate the water column of a large, deep body of water such as this is what distinguishes RADOR technology from conventional aeration and oxygenation.

A 75% reduction in total phosphorus levels to no more than 0.02 mg/L at the surface was achieved within the first two weeks, and the target limit was achieved after three months. The target was also achieved and maintained at 70 feet deep within the first three months of operation.

Excessive levels of metals such as iron and manganese are a common problem in reservoirs where dissolved oxygen levels are depleted. At Toa Vaca the problem was high manganese concentrations, and a target level of no more than 0.05 mg/L was achieved and maintained after approximately two months of operation. Initial manganese levels were higher at depth due to the deoxygenation of the water column, but the target was also achieved and maintained at 70 feet within the first three months.

Within the first year of implementing the RADOR solution, cyanobacteria and algal blooms were reduced to such an extent that chemical treatment costs at the water purification plant were halved, as were the levels of TTHMs.

The deterioration of water quality in Toa Vaca reservoir not only affected the water supply but had resulted in frequent fish kills and a significant reduction in the fish life in the dam. This resulted in a dramatic reduction in birds of prey; there was just a single pair of fish eagles and only five pelicans remaining. Fishermen had abandoned Toa Vaca as a site for recreational fishing. Two years after implementing the RADOR system, there were five pairs of fish eagles and 28 pelicans at Toa Vaca, and the fishermen had returned too.

Addressing the complex challenges facing drinking water reservoirs requires a shift toward sustainable, chemical-free solutions that tackle the root causes of water quality degradation. Algal blooms and nutrient imbalances pose significant risks not only to public health but also to the long-term viability of these vital water sources. By implementing natural processes that restore the ecosystem's balance, water management agencies can improve reservoir water quality and reduce the reliance on costly chemical treatments.

With such results in improving reservoir health, these approaches offer a path forward to safeguard clean, potable water for communities while fostering healthier ecosystems. It's time for water management agencies to prioritize these innovative and nature-based solutions to secure our nation's future water supply. ■

References:

1. https://www.gao.gov/products/gao-22-104449

About The Author

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Water-As-A-Fuel Market For The Future Of Clean Energy

By Bhushan Dhumal

The idea of utilizing water as a fuel source has been speculated by scientists, innovators, and researchers from all over the globe, envisioning a world where renewable, green energy can power the planet. However, as the world is evolving from the traditional fossil fuels and looking for cleaner energy sources, water can be a key contributor to ever-increasing energy demands while helping countries achieve climate goals.

Drivers, Barriers, Technological Progress, And Possibilities

Water-to-fuel conversion is truly a revolutionary process that focuses on the decomposition of water molecules in an energy-efficient manner. In layman's terms, water fuel refers to the means of using water as a source of energy, more particularly employing its hydrogen compounds as fuel. Electrolysis is a method used to decompose water into hydrogen and oxygen.

Water is a hydrogen source that contains energy. When burned or introduced into a fuel cell, hydrogen vapor emits water while burning. With the attributes mentioned above, hydrogen is a suitable replacement for fossil fuels. But, hydrogen fuel itself does not come from water. Instead, water is a medium that is used to extract hydrogen in order for hydrogen to be classified as an eco-friendly fuel.

Important Uses Of Water As A Fuel

The potential uses of water-derived hydrogen fuel span across various industries, making it an incredibly versatile energy source.

- **Transportation:** Hydrogen-powered fuel-cell electric vehicles (EVs) are catching on as a clean option to replace gasoline- and diesel-powered vehicles. Fuel-cell EVs, or FCEVs, can go further than battery-electric vehicles (BEVs) and fill up in just a few minutes. This makes them a good fit for long-distance travel and large transporters like trucks, buses, and ships.

- **Energy storage:** Hydrogen can be stored and used to generate electricity through fuel cells, offering a solution to one of the most significant challenges of renewable energy — intermittency. Excess renewable energy generated during periods of low demand can be used to produce hydrogen, which can then be stored and converted back into electricity when needed, providing a stable and reliable energy supply.

- **Industrial use:** Industries that require high-temperature processes, such as steel manufacturing, chemical production, and oil refining, are some of the most challenging to decarbonize. Hydrogen can serve as a clean alternative to natural gas and coal in these industries, reducing their carbon footprint.

- **Power generation:** Hydrogen can be blended with natural gas to reduce emissions from existing power plants. In the future, entire power plants could run solely on hydrogen, generating electricity without any carbon emissions.

- **Residential and commercial heating:** Hydrogen can be used in fuel cells to provide heating and electricity for homes and businesses. In areas with cold climates, hydrogen could replace natural gas as a clean alternative for heating systems, reducing greenhouse gas emissions.

Challenges Facing The Water-As-A-Fuel Market

While the potential for water as a fuel is promising, several challenges must be addressed for the market to reach its full potential:

- **Cost of production:** One of the primary challenges is the cost of producing hydrogen through electrolysis. Currently, producing hydrogen using renewable energy sources is more expensive than fossil-fuel-based hydrogen production. However, as renewable energy costs continue to decrease and electrolyzer technology advances, these costs are expected to come down.

- **Infrastructure development:** Hydrogen infrastructure, including production facilities, storage, and transportation systems, is still in its early stages. Significant investment is needed to develop a comprehensive hydrogen supply chain, from production to end-use applications.

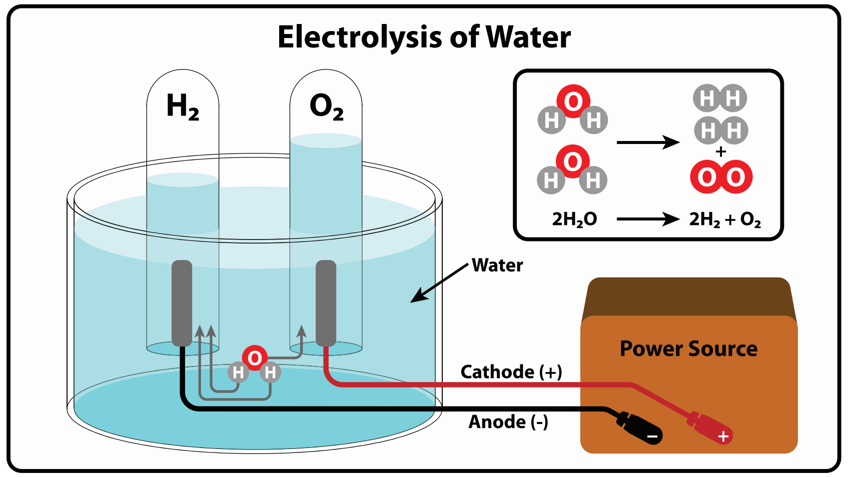
- **Water resource management:** Large-scale hydrogen production requires substantial amounts of water, raising concerns about water resource management in areas where water scarcity is a problem. It will be essential to develop water-efficient electrolysis technologies and ensure that hydrogen production does not strain local water supplies.

- **Energy productivity:** The process of producing hydrogen from water is energy-intensive. A significant amount of energy is lost during electrolysis, transportation, and conversion back into electricity or heat. Improving the overall efficiency of the hydrogen supply chain is crucial for its long-term viability as a clean energy solution.

The Future Of Water As A Fuel

These factors aside, the future of the water-as-a-fuel market is developing.[1] Additional investments, technological breakthroughs, and government subsidies ensure that hydrogen will be one of the backbone fuels during the world's energy transition.

Over the next 10 years, great strides shall be made in electrolyzer tech, the price of renewable energy will fall, and the appropriate bolstering of hydrogen infrastructure will take off. With all these pieces in place, hydrogen will further break out into the wider energy market, forming the base of energy's future. It will aid in the world's efforts for decarbonization and support the fight against climate change.



In conclusion, water as a fuel represents an exciting and potentially game-changing development in the energy landscape. By harnessing the power of hydrogen, derived from one of the planet's most abundant resources, we can unlock a future of clean, renewable, and sustainable energy for generations to come. The water-as-a-fuel market is not just a trend — it's a vital component of the global shift toward a low-carbon economy. ■

References:

1. https://www.transparencymarketresearch.com/water-as-a-fuel-market.html

About The Author

Bhushan Dhumal is a market research professional and industry analyst specializing in emerging technologies, renewable energy, and sustainability trends. With a strong background in market forecasting and strategic analysis, he has contributed to various publications and reports, providing insights into evolving industries.