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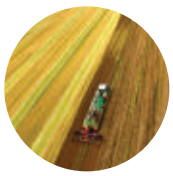
FEATURES

ON THE COVER
Biosolids treatment processes and products offer several opportunities to recover such resources as energy, nutrients, and carbon from wastewater. For example, biosolids products such as the ones shown on the cover not only provide an economical way to reuse these materials but also deliver nutrients and sequestered carbon back to nature. Paul Cockrell



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The Water Environment Federation (WEF) is a not-for-profit technical and educational organization of more than 30,000 individual members and 75 affiliated Member Associations representing water quality professionals around the world. Since 1928, WEF and its members have protected public health and the environment.

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Connect water professionals: WEF develops an engaged membership that is representative of the multiple practice areas of the water environment industry.

Enrich the expertise of water professionals: WEF provides a broad range of professional content and programming that is relevant and widely valued by the water sector worldwide.

Increase the awareness of the impact and value of water: WEF generates an increased public awareness of the value of water leading to increased funding to protect water quality through appropriate levels of infrastructure, management approaches, and services.

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FROM THE EDITORS

Big Biosolids Issue

The big biosolids issue is here! This *WE&T* is packed with in-depth reading about this important practice area.

Flip to "Proving Phosphate Claims on Biosolids-Based Products" (p. 18) to see the latest in phosphate testing. Called *water extractable phosphorous*, this new measurement will enable producers of carbon-based biosolids fertilizers to indicate their products' distinction from chemical fertilizers.

The authors of "Pyrolysis & Gasification" (p. 34) present an overview of thermal processing. They also have compiled product and feature information from several manufacturers — including projects those manufacturers have completed.

You can get more technical information about biosolids land application from Operator Essentials (p. 54).

p. 18

p. 34

In addition to biosolids, you can explore Philadelphia's decades-long effort to get to the heart of an odor problem in "Nuisance Odors: No Longer Such a Mystery" (p. 44). And follow up on "Passing the Sniff Test" (p. 50) to get the second part of the story on common odor myths.

And we have something new for you on the last page. *WE&T* is excited to introduce a new section. Maintenance Essentials is designed to highlight preventive and predictive maintenance one piece of equipment at a time. Tell us what you think and send in your suggestions on which pieces of equipment to feature next. Email us at magazine@wef.org.

— The Editors

WATER ENVIRONMENT & TECHNOLOGY
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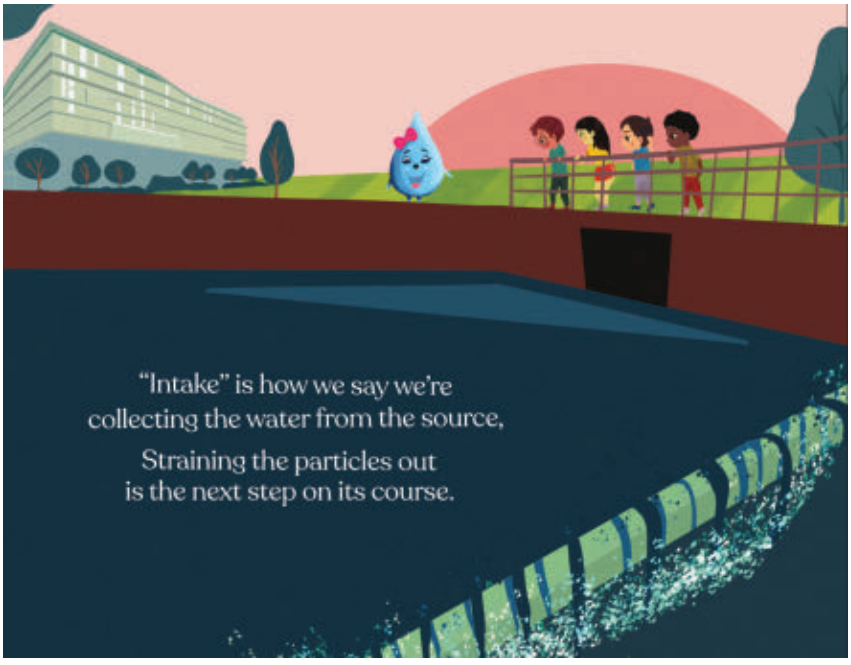


Fluoride Fallout

The sector can get stuck between public perception and policy

By Will Fowler

Concerns over the public health danger of water fluoridation have been broadly discredited for decades, but fluoride conspiracy theories persist. The fallout can leave water treatment professionals stuck in the middle.

From a mayor in Alaska to minor British political parties, conspiracy theories about water fluoridation have been commonplace in fringe circles for decades. They first emerged in the 1950s, shortly after public water fluoridation began in the U.S. to fight tooth decay.

Back then, far-right organizations, such as the John Birch Society, claimed fluoridation was a Soviet plot designed to poison the American public, a view so absurd that it was satirized in the 1964 movie *Dr. Strangelove* as the motivation for the delusional character Gen. Jack D. Ripper to begin World War III. The character sought to stop the communists plot to "sap and impurify all of our precious bodily fluids."

Today, fluoridation conspiracy theories persist on the far right, but also have found a home on the left. The Green Party of England and Wales has routinely flirted with such theories and supported anti-fluoridation measures. One Green Party politician called fluoride "harmful to humans, animals, and the environment" and said water fluoridation "defies

"Fluoridation is something that we have done for millions of people for the better part of a century, and we would probably know by now if it caused serious health problems."

Alexander Morris
University of Birmingham (United Kingdom)

all common medical ethics."

The public health effect of water fluoridation is seen by most medical and dental organizations as beneficial. There is no strong evidence that water fluoridation causes any health problems.

Conspiracy theorists instead rely on scientific misinformation and misinterpretation, and when anti-fluoride officials are elected, their policies can force water treatment professionals into the spotlight.

'Can We Just Shut It Off?'

In October 2021, Anchorage, Alaska, suddenly stopped fluoridating its drinking water. The fluoridation halt was not decided by a change in water treatment policy or processes. It was never voted on by Anchorage residents or city council. In fact, it was never even announced. Instead, the city's water fluoridation stopped because the mayor requested it during a private tour of the treatment facilities.

Just 5 hours later, the fluoridation resumed by employees of the Anchorage Water and Wastewater Utility (AWWU). This, too, was the decision of Mayor Dave Bronson, who learned after his tour that water fluoridation is regulated by Anchorage municipal code. According to Alaska Public Media, that decision to restart fluoridation might have come when Bronson discovered he was potentially violating code and overstepping his authority.

Following the incident, differing accounts emerged about how and why the water fluoridation was paused. The mayor's office twice denied that it had happened at all. In a public statement days later, the office admitted fluoridation was halted during Mayor Bronson's tour. The statement claimed the pause was for AWWU employee safety. The mayor's office also claimed that the request came not from the mayor but from AWWU's Manager Mark Corsentino, who allegedly told Bronson that water fluoridation products were a "health hazard" that routinely "burned [workers'] eyes and throats."

However, both Corsentino and the union representing his staff have contested the mayor's claims. The union called the statement "shocking" and told Alaska Public Media they "have not had a single report" of fluoride-related injuries or health problems. Corsentino said neither he nor any other employees asked Mayor Bronson to stop fluoridation, and that they never discussed occupational risks of handling fluoridation products.

Corsentino said that Bronson brought water fluoridation up first, including the "growing" number of people against it, but he assumed the discussion was related to infrastructure management.

"We're getting ready to spend a million-plus dollars

on an upgrade to that fluoride system. If we do the upgrade and then it's turned off, that would be concerning to me," Corsentino told the Anchorage Assembly in a work session, according to *The Anchorage Daily News*. "He took everything he heard in context and said, 'Well, can we just shut it off?'"

Although he thought it was surprising, Corsentino said he thought Bronson had already gotten approval to stop or would do so right away.

Anchorage Assembly leadership have accused Mayor Bronson of halting fluoridation based on his personal beliefs. They have launched an official inquiry into the fluoridation incident.

Anti-Science Parallels

Bronson has never explicitly supported fluoridation conspiracy theories, but many have suggested that his changing, contradictory claims and belief in other theories might indicate that he believes in them.

A week after the fluoridation incident came to light, Bronson spoke at an anti-vaccination conference he helped organize.

"I am not certain of the facts," Anchorage Assembly Vice Chair Christopher Constant told *The New York Times*. "But if proven true, this fits squarely into the Venn diagram of anti-science arguments so common these days: COVID denial, anti-vaccine rhetoric, and anti-fluoride politics."

According to Alexander Morris, Senior Dental Public Health Lecturer at the University of Birmingham (United Kingdom), actively prompting such beliefs typically "do not stop with just one subject."

Fluoridation was halted in Anchorage, Alaska, for 5 hours after the mayor toured the water facility. The state's General Assembly has been investigating the situation.

"It's quite rare that you see someone who's saying fluoridation is a sinister plot, but who otherwise has no unusual beliefs."

Morris, who also works as a consultant expert on combating anti-fluoride beliefs for the British Dental Association, continued, "In public health, you see anti-vaccination beliefs occurring alongside the belief that water fluoridation is far more dangerous than we've been told."

Full Understanding

Morris said it is important that professionals in public service, whether in water treatment, healthcare, or government, understand the science behind the fringe theories they may need to address. For instance, there is general scientific consensus that in high doses fluoride can cause severe health problems.

"Fluoridation conspiracy theorists stretch legitimate findings on the dangers of fluoride to say that water fluoridation is bigger factor than it is," he said. "Primarily, they misuse these studies by not communicating the dose that actually causes these health outcomes."

Many studies that show heavily fluoridated water can cause dental fluorosis, a condition that stains the teeth. Although it is usually only a cosmetic concern, in extreme cases it can cause major dental problems.

"In some areas with very high naturally occurring fluoride levels, you see mild fluorosis," said Brittany Seymour, spokesperson for the American Dental Association. "But natural water fluoride levels are not controlled. Whereas in community water fluoridation, it is carefully controlled. You can't draw the comparison between natural levels and water fluoridation."

There is less evidence, however, to support claims of severe fluoridation-related health problems.

"Causation is not something we have been able to decipher yet," Seymour said. "If you look at a body of literature for any given topic, you can find studies that contradict each other, but you have to compare the quality of the studies."

Seymour recommends that public officials concerned about the topic review studies that analyze many other studies, rather than rely on any single piece of research. Review studies seek to control for research quality, sample size, and other variables.

"Cherry-picking is a problem in that it can affect community consideration of water fluoridation," she said. "Science involves evaluating all the studies, not making all the decisions around one cherry-picked study."

Surviving the Fallout

Public officials dealing with a conspiratorial backlash to health measures may think they are faced with a unique problem. But according to Seymour, these backlashes are nothing new.

"Conspiracy theories always surround the current social context," she said. "Right after World War II, people associated Hitler with water fluoridation and even tobacco regulations. Then during the Red Scare, you had people associating fluoridation with communism. Now, we see fluoridation conspiracy theories around Big Pharma. Conspiracy theories grab onto the fears

of authority we have in our culture and time."

Handling public health backlashes can be especially difficult when opponents ask officials to prove a negative. And proving a measure is 100% safe can be nearly impossible, according to Morris.

The scientific method does not prove that a substance is *safe*; instead, it repeatedly finds that the substance does not create harm. Scientists will say, "You can't prove anything is safe."

"As scientists, we tend to say that out loud without explaining how the scientific process works," Morris said. "And those are easy sound bites for conspiracy theorists to spread."

Morris said that although social media has made it easier for misinformation to spread, it also has made it easier to disseminate accurate information.

"It is a good idea to share evidence, but first briefly explain how we determine whether things are true," Morris said. "If you can communicate that in a way people understand, without infantilizing them, that helps improve the public understanding of science and helps the audience understand the evidence."

He continued, "And then you can say at the end, 'like anything else, we can't prove it's safe, but we have all sorts of evidence that the concerns don't amount to much of anything.'"

The Best Approach

Opposition to water fluoridation likely will persist for some time. In Anchorage, the future of the city's water and Mayor Bronson's administration remains uncertain. As investigations and debate sparked by Bronson's actions continue, AWWU staff probably will remain entangled with the issue.

However, Corsentino has earned praise for clear messaging and his desire to make a deliberative, legal, and evidence-based decision about fluoridation in the community. According to Morris, that is the best approach.

"We have a broad consensus on this," Morris said. "If we can communicate that properly, then the people that can listen will listen. Fluoridation is something that we have done for millions of people for the better part of a century, and we would probably know by now if it caused serious health problems."

"I joke that since I moved to a water fluoridated area at 19, I've gotten grey hair, wrinkles, weight gain, mild memory loss, and other symptoms." Morris said. "I'm 59 now. Humor goes a long way."

***Will Fowler** is* WE&T *Associate Editor. He can be reached at wfowler@wef.org.*

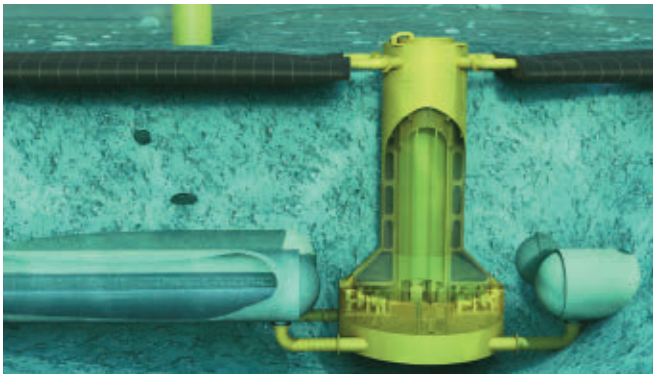
‘Ocean Battery’ Could Help Offshore Wind Farms

One of the biggest challenges with wind energy is energy storage. Wind turbines often produce more energy than necessary on windy days but fail to meet demand when winds do not blow. But the startup Ocean Grazer (Groningen, Netherlands) has a solution: an “ocean battery” that bridges the gap between over- and under-production.

The ocean battery is “charged” when wind turbines produce excess energy, filling gargantuan bladders on the seafloor with water. When the wind dies down, the pressure of the ocean forces water back out of the turbine system, generating consistent electricity without relying on unpredictable weather patterns. Each reservoir bladder can hold up to 20 million liters of water, producing enough electricity to support power consumption without failure, according to Ocean Grazer CEO Frits Bliek.

“Minimal discharging time is 30 minutes, sufficient for the highest demands in the utility sector,” said Bliek. The ocean battery can also be integrated with floating solar arrays and other renewable energy sources.

“As we can adapt the charging capacity independently from the discharging capacity, we can tune the [ocean battery operation] to rapidly absorb the solar peak around noon and discharge the accumulated power of the rest of the day. In this way, we can optimally tune into the business case of a floating array.”



An underwater bladder could be the answer to storing wind energy while gusts are high and then releasing the storage on calm-wind days. Ocean Grazer

The ocean battery was made to optimize electrical infrastructure, and the battery was designed with ecological and economic benefits in mind. The device has won the Consumer Electronics Show 2022 Best of Innovation Award.

Although full implementation is years away, Bliek said one ocean battery pilot system will be functional onshore in the Netherlands by 2023.

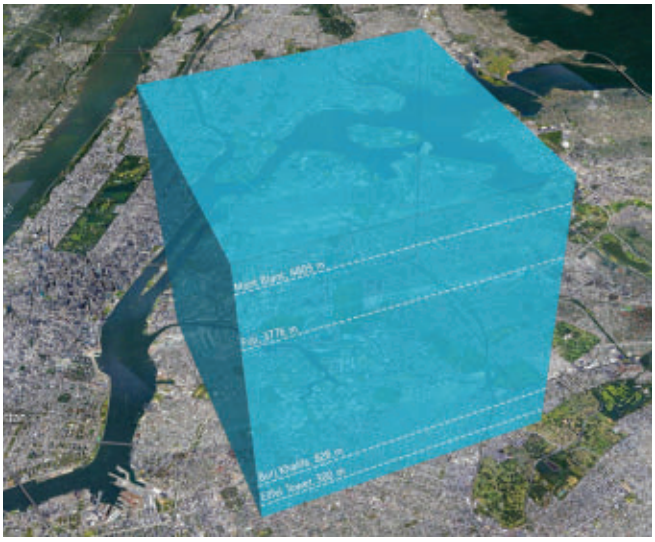
Iceberg Releases 152 Tons of Fresh Water

A chunk of a massive iceberg that split from the Antarctic ice shelf in 2017 continues to melt as it drifts gradually nearer to the South Georgia and Sandwich Islands. The melting iceberg chunk, known as A-68A, has so far released 152 tons of fresh water that threaten the tropical ecology of the region, according to a study that recently appeared in the journal *Remote Sensing of Environment*.

For the first 2 years after A-68A broke off from its source — an iceberg that the European Space Agency (ESA) estimates had nearly double the surface area of Luxembourg — it remained in the icy Weddell Sea and melting was not a concern. Now, it is in warmer waters near South Georgia Island, where it is melting rapidly and being monitored by satellite.

"Our ability to study every move of the iceberg in such detail is thanks to advances in satellite techniques and the use of a variety of measurements," said Tommaso Parrinello, ESA's CryoSat Mission Manager, in a release. "Imaging satellites record the shape of the iceberg and data from altimetry missions like CryoSat add another important dimension as they measure the height of surfaces — which is essential for calculating changes in volume."

Icebergs release cold, fresh water and nutrients as they melt. The process changes the ocean circulation near the iceberg and creates a localized ecosystem around it. Anne Braakmann-Folgmann, lead author of the new study, credits the satellite data for detailed information about the iceberg's journey.



The iceberg has released enough water to form a cube higher than Mount Fuji and wider than Manhattan. European Space Agency

"Because A-68A took a common route across the Drake Passage, we hope to learn more about icebergs taking a similar trajectory, and how they influence the polar oceans," she said in a release. "This is a huge amount of meltwater, and the next thing we want to learn is whether it had a positive or negative impact on the ecosystem around South Georgia."

PROVING PHOSPHATE CLAIMS ON BIOSOLIDS-BASED PRODUCTS

State Plant Food Control officials recognize slowly available phosphate claims in biosolids, compost, and other recycled organics products

Ron Alexander

A new testing method and labeling guidelines have been approved to enable producers of biosolids-based products to measure and advertise the amount of phosphate in a carbon-based fertilizer that is readily water soluble (and slowly releasing). This measure is referred to as water extractable phosphorous (WEP).

Biosolids manufacturers can use these new tools to express to customers what differentiates their products from chemical fertilizers. Biosolids- and other carbon-based products typically have less WEP; therefore, the phosphate from these products is more likely to stay put where applied, rather than run off into nearby waters.

Over-Application

The biosolids management sector, as well as farmers and turf managers who use its products, understand concerns regarding over application of phosphorus. Over-application not only has been caused by poor fertilization and waste management practices, but also by the fact that phosphorus is bound by the soil. This means much of what is applied is not absorbed by plants in a timely manner, and because most plants can tolerate the over-application of phosphorus (called "luxury" application), it does not harm their growth.

However, over-application of phosphorus, whether by biosolids, chemical fertilizer, manure, etc., is a major concern because the nutrient can migrate to various water resources. Addressing this issue protects drinking water, reduces surface water contamination (eutrophication), and keeps an important nutrient required for plant growth and food production in the soil where it belongs.

While phosphorus is bound tightly to finer textured soils, long-term over-application can lead to its leaching through the soil profile — that is, over-manuring — while soil erosion (as phosphorus is attached to soil particles) can lead to the migration of phosphorus into surface waters. The leaching of phosphorous through coarse- or sandy-textured soils is much more likely to occur during normal fertilization practices, than it is in finer or silt or clay-textured soils.

Regulations

Concerns and actual damage caused to water resources has led to tighter state regulation over the use of phosphate-based fertilizers in many agricultural settings. This includes products containing phosphorus, such as biosolids and manure. Over the past decade, these regulations have expanded to encompass the use of phosphate fertilizers on turf and other "ornamental" applications.

Unfortunately, many states have been overzealous in their regulation. Some have gone so far that they almost eliminate even maintenance applications of phosphate fertilization on turf. Others have failed to deal with more significant causes of nutrient contamination, such as over-fertilization or over-manuring on agricultural land and lax enforcement of National Pollutant Discharge Elimination System (NPDES) Phase II regulations to control sediment during construction.

Sadly, most regulation has ignored certain aspects of relevant science. Instead, these rules treat all phosphate sources the same; they ignore the phosphate's actual mobility.

In most states, Class A biosolids products are affected by these regulations, if the products are registered as fertilizers, which means the products make legal nutrient claims and sometimes even when they do not.

In response to this trend, the American Association of Plant Food Control Officials (AAPFCO) developed recommended language regarding "Fertilizer Restrictions for Urban Landscapes," as well as other related Statements of Uniform Interpretation and Policy to assist states in developing science-based regulation. AAPFCO is an organization of officials from state departments of agriculture. Its voting members are the control officials who register and regulate the distribution of fertilizer, soil amendments, and liming agents. in each of the U.S. states, territories, and Canada. (They sometimes oversee pesticides and animal feed, too.) The organization creates model laws and regulations to assist interstate commerce of these agricultural and horticultural staples. Its primary goals pertain to consumer protection, by requiring

DEFINITIONS

- Phosphorus — A chemical element (symbol P) with an atomic number of 15, that exists in several allotropic forms.
- Phosphate — Any salt or ester of phosphoric acid.
  Available phosphate (P_2O_5) — The sum of the water-soluble and the citrate-soluble phosphate, according to AAPFCO since 1993 (P_2O_5 is the form in which phosphate is expressed on fertilizer labels).
- Water Extractable Phosphate — The amount of phosphate in a carbon-based fertilizer that is readily soluble, as determined by the Southern Extension & Research Activity-17 (SERA-17) test method, according to AAPFCO tentatively in 2020.

truth in labeling, and uniform regulation among states and territories.

AAPFCO also promotes the four Rs of fertilizer management:

- right source (type and form of the fertilizer or nutrient),
- right rate (suitable application rate),
- right timing (related to the growth pattern of the crop), and
- right placement (as close to the root zone as possible).

While it is understood that the proper usage of nitrogen and phosphate fertilizers must be regulated to appropriately protect the environment, it is equally important to understand that these nutrients must be utilized in agricultural settings to grow food and in ornamental applications to grow healthy plants and reduce soil erosion.

Further, as it relates to biosolids, compost, and other organic recycled products, there is a great need to apply carbon to the soil (even if it innately contains some slowly available nutrition) as a mean to ameliorate the effects of climate change and improve soil quality. Therefore, a more science-based (and maybe practical) approach to regulating phosphate application is required, and unfortunately, this may lead to more complicated best management practices related to their usage.

The U.S. Composting Council (USCC; Raleigh, North Carolina) having an Industry Liaison to AAPFCO, decided to try to address the phosphate issue as it relates to carbon-based products. It also rallied several biosolids organizations to the cause, including the Water Environment Federation, California Association of Sanitation Agencies, Mid-Atlantic Biosolids Association, Northeast Biosolids & Residuals Association, and Northwest Biosolids.

Defining & Measuring WEP

The group sought a way to illustrate the difference between phosphorus in biosolids and other carbon-based products and those found in many chemical fertilizers. Fortuitously, extensive university research data shows that the phosphorus in most biosolids and other carbon-based products is naturally less water-soluble or water extractable than the forms found in typical chemical fertilizer products.

WEP is less mobile, which also means that it is less readily available to plants. To claim that carbon-based products contain lower amounts of WEP, an acceptable analytical testing method had to be identified. These efforts led to the identification and evaluation of the Southern Extension & Research Activity-17 WEP test method, called SERA-17. This method originally was developed for manure and biosolids products.

Researchers have been testing biosolids-based products for WEP content for several years, as have some Class A biosolids products manufacturers, especially those who are using their products in environmentally sensitive applications or locations. (See the table below.) Working with Penn State University (University Park) and Colorado State University (Fort Collins), USCC proposed both SERA-17 and a definition for WEP.

The importance of this claim relates not only to the potential negative environmental effects of highly soluble phosphate sources, but it also helps biosolids, compost, and other carbon-based product customers better manage nutrient addition for proper plant growth.

At the July 2021 AAPFCO meeting, the SERA-17 test method for WEP was found to be acceptable. The group added that sampling methods need to be further "fleshed out." And at the February 2021 AAPFCO meeting, the group finalized the definition. The definition states "Water extractable phosphorous — the amount of phosphate in a carbon-based fertilizer that is readily water soluble, as determined by the SERA (Southern Extension & Research Activity)-17 test method."

Products and Water Extractable Phosphate (WEP)

Phosphorus Source	WEP Content (as % of Total P)
Heat dried biosolids	Less than 2%
Biological Phosphate Removal – type biosolids	5% to 25%
Poultry manure	20%
Dairy manure	50%
Triple Super Phosphate (0-44-0 synthetic)	85%

Data provided by Dr. George O'Connor, University of Florida

Labeling Changes

The final piece of this puzzle involves illustrating how testing for the WEP content could be used to make labeling claims on carbon-based products. State control officials were concerned that using the term *WEP* on the label would create confusion, because fertilizer phosphorus is expressed as "available phosphate." Therefore, WEP testing will instead be used to illustrate "slowly available phosphate" on a label, similar to the way slowly available nitrogen is claimed.

This strategy enables the new phosphate claims to align more closely with existing labeling regulations and formats. The figure on the right shows how to note the amount of phosphate that is not water extractable; this portion is claimed as slowly available phosphate.

The slowly available phosphate claim can be a tool for biosolids product manufacturers who market registered fertilizer products. Not only can it educate customers and regulators about the characteristics of phosphorus in biosolids-based products, but it also may lead to more well-informed nutrient management practices.

Since the July 2021 AAPFCO meeting, some states already have approved labels where "slowly available phosphate" was claimed, and some have questioned it. Now is the time for the biosolids industry (perhaps starting with Class A biosolids product producers), where appropriate and deemed beneficial, to modify their fertilizer labels and include a slowly available phosphate claim. This will assist in instituting the allowance of this claim on a long-term basis.

Using This Option

Now that testing for WEP is an acceptable method to make slowly available phosphate claims on biosolids and other carbon-based products, product manufacturers should consider how they will use this new option. Biosolids managers, who have been able to measure and claim that the lion's share of nitrogen in their product is in slowly available form, can now do the same with phosphorus. Perhaps more biosolids managers will register their products as fertilizers, enabling them to make legal fertilizer (nutrient) claims. Companies producing dried and granulated biosolids (or manure) products, which almost always register them as fertilizers, could easily make the slowly available phosphate claim once testing is completed. Similar considerations will also exist for compost, anaerobic digestate, and biochar products.

In the near-term, biosolids product manufacturers can use this option in several ways:

- If their biosolids product is registered as a fertilizer, they can test for WEP and make a new claim.
- If they are selling or distributing their product to farmers, turf managers, and other end users because of its nutrient content, this additional test data could assist them in better helping customers manage any additional nutrients that may need to be applied along with their the biosolids product.
- It could allow biosolids managers to better defend the application of their products where environmental concerns exist, related to nutrient addition.

With WEP test data in hand, it will be important for biosolids managers to discuss phosphate availability with customers in a slightly different way, but it may also allow them to make some related environmental claims. For instance, "The majority of nitrogen and phosphate nutrition in Super Fertilizer 6-4-0 is in 'bound' form and is slowly releasing. … These types of nutrients significantly reduce the likelihood of nutrient leaching."

These properties could help biosolids product manufacturers have more meaningful discussions with environmental regulators, as well as environmentally conscious customers. It may even lead to related conversations where the land application of dewatered Class B and A biosolids are applied.

The final question is this: Is it time for you to test your biosolids product for WEP content?

Example of New Labeling Language

6-4-0
GUARANTEED ANALYSIS

Total Nitrogen (N) ……..……...6.0%
5.5% Water Insoluble Nitrogen*
0.5% Water Soluble Nitrogen
Available Phosphate (P_2O_5)**…….4.0%
Iron (Fe) ……..…….4.0%

Derived from biosolids

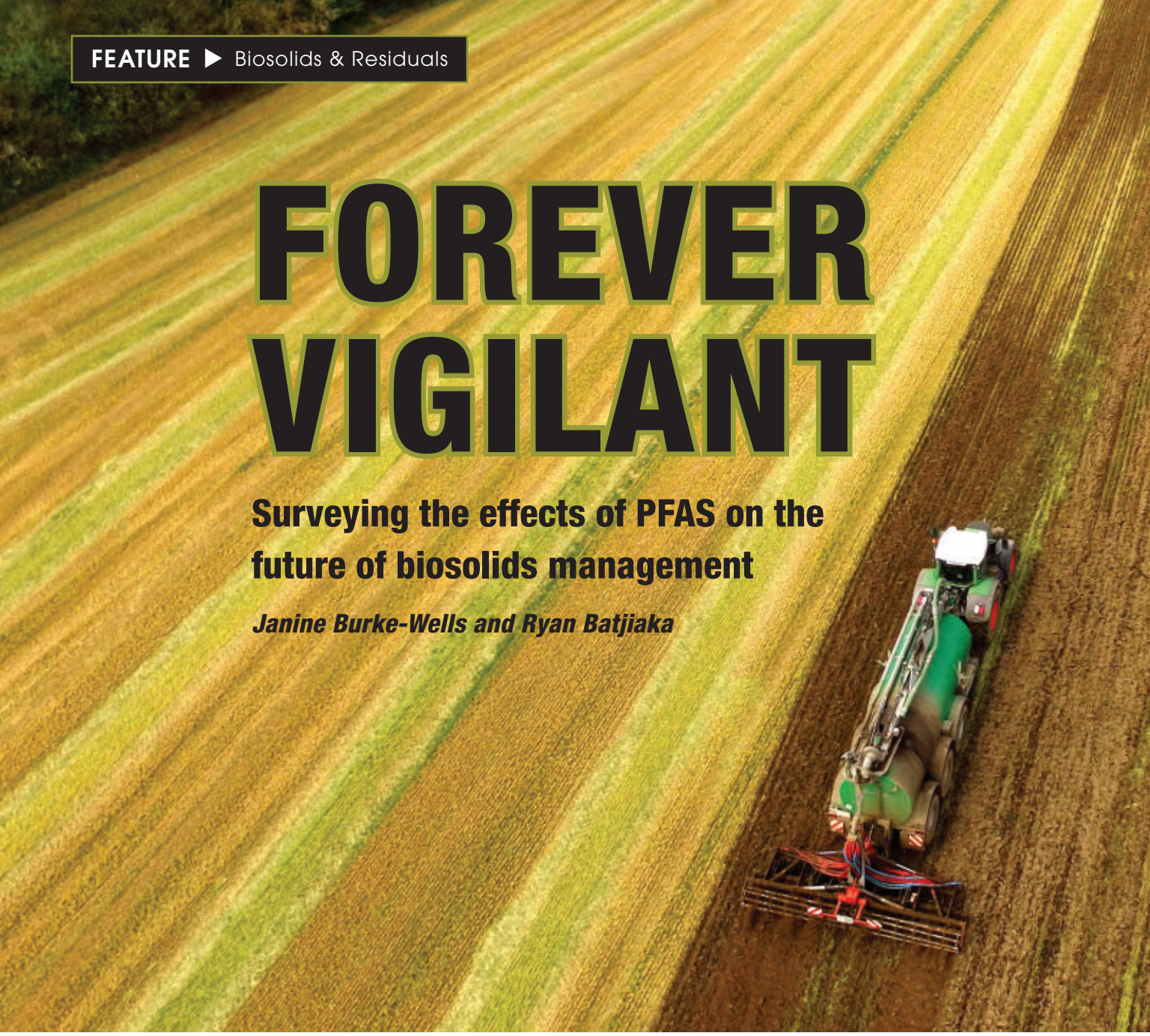
*5.5% Slowly available nitrogen from biosolids
**3.9% Slowly available phosphate from biosolids

Ron Alexander *is President of R. Alexander Associates Inc. (Apex, North Carolina) and author of* The Practical Guide to Compost Marketing and Sales. *He is a WEF member and an industry liaison to AAPFCO.*

FOREVER VIGILANT

Surveying the effects of PFAS on the future of biosolids management

Janine Burke-Wells and Ryan Batjiaka



With an increasing focus on creating a more circular economy and the dire need to address climate change, biosolids and residuals management can offer major opportunities to recycle carbon and nutrients, reduce climate effects of our operations, and even help sequester carbon. But hyperfocusing on the presence and concentration of per- and polyfluoroalkyl substances (PFAS) could disrupt realizing these benefits. In fact, the disconnect between science and policy surrounding this topic could threaten the sustainability of biosolids management altogether.

The biosolids management community must remain updated and active on what is happening with PFAS regulations, research, and technologies related to the future of biosolids management.

The Basics

Managing wastewater solids is the second or third largest operating expense for most water resource recovery facilities (WRRFs). And it is getting more expensive. In some cases, increasing costs are having a major effect on local utility budgets and decisions about managing their solids. Currently, three methods prop up managing biosolids and residuals — a three-legged stool, if you will. These are landfill disposal, incineration, and recycling into soil amendments.

Creating soil amendments is not always the easiest or cheapest option, but it is the most sustainable. Proven benefits include enhancing soil health, recycling nutrients, reducing chemical fertilizer/pesticide use, and strengthening farm economies. Biosolids also contain such micronutrients as zinc,

iron, manganese, and copper — all things that healthy soils need and that other soil amendment products often lack. Perhaps the biggest bonus to recycling biosolids into soil amendments is increasing soil carbon content and helping sequester carbon.

Concerns with recycling biosolids have been around forever and include odors, over-application of nutrients, and trace contaminants. We already have worked through some major concerns around these microconstituents in the past, including dioxins, polychlorinated biphenyls (PCBs), and others.

But there's something different about PFAS. We should be prepared for a long haul in dealing with this class of water contaminants that includes literally thousands of chemicals. Existing WRRFs are not designed to destroy PFAS and other emerging contaminants, so the compounds end up in the wastewater solids.

But science has many tools to offer. We already know the concentrations of PFAS in biosolids. Numerous studies worldwide have provided data and we can say average concentrations are currently in the tens of parts per billion (µg/kg). Figure 1 (p. 24) shows the concentrations from across many different products. We need to learn much more about the fate of PFAS in the environment and the risks from different routes of exposure.

East Coast Perspective

Without federal standards to lead the way, several states in the Northeast U.S. have taken their own action on PFAS due to several major contamination concerns. New Hampshire found PFAS contamination around Pease Air Force Base and a major manufacturing facility. Another manufacturing facility in Vermont was the cause of contamination. And in Maine, the state Department of Agriculture found very high levels of PFAS in cow's milk. The discovery shut down several farms and led to a moratorium on the land application of biosolids or biosolids composts in Maine in March 2019.

Maine subsequently applied soil screening standards to biosolids-based products — currently the only such standards in the nation. See "Maine Takes Hard Line on PFAS, Biosolids" on p. 26 for more on this. Likewise, the line on Figure 1 shows how this standard compares to many different products. Now, Maine's legislature is poised to pass a bill that would effectively ban the recycling of biosolids in the state. And Massachusetts is working on PFAS screening limits for land-applied residuals.

The challenge for states like Maine and Vermont that rely heavily on beneficial reuse is what to do with those solids. Maine and Vermont do not allow incineration, so the only other option is landfilling the materials, which is not a great long-term solution from a carbon emissions standpoint.

Other states have been watching and following the lead of the Northeast in some cases. Figure 2 (p. 25) shows the PFAS limits that states across the U.S. have placed on drinking water. In New Hampshire, the legislature enacted PFAS drinking water limits into law — an unprecedented action and an end run around the process of developing enforceable regulatory standards based on risk and taking costs into consideration.

With similarities to Oregon — at least in how solids are managed — wastewater operations in Maine will have a difficult and expensive venture figuring out what to do with the approximately 70% of solids currently recycled as various soil amendments.

West Coast Perspective

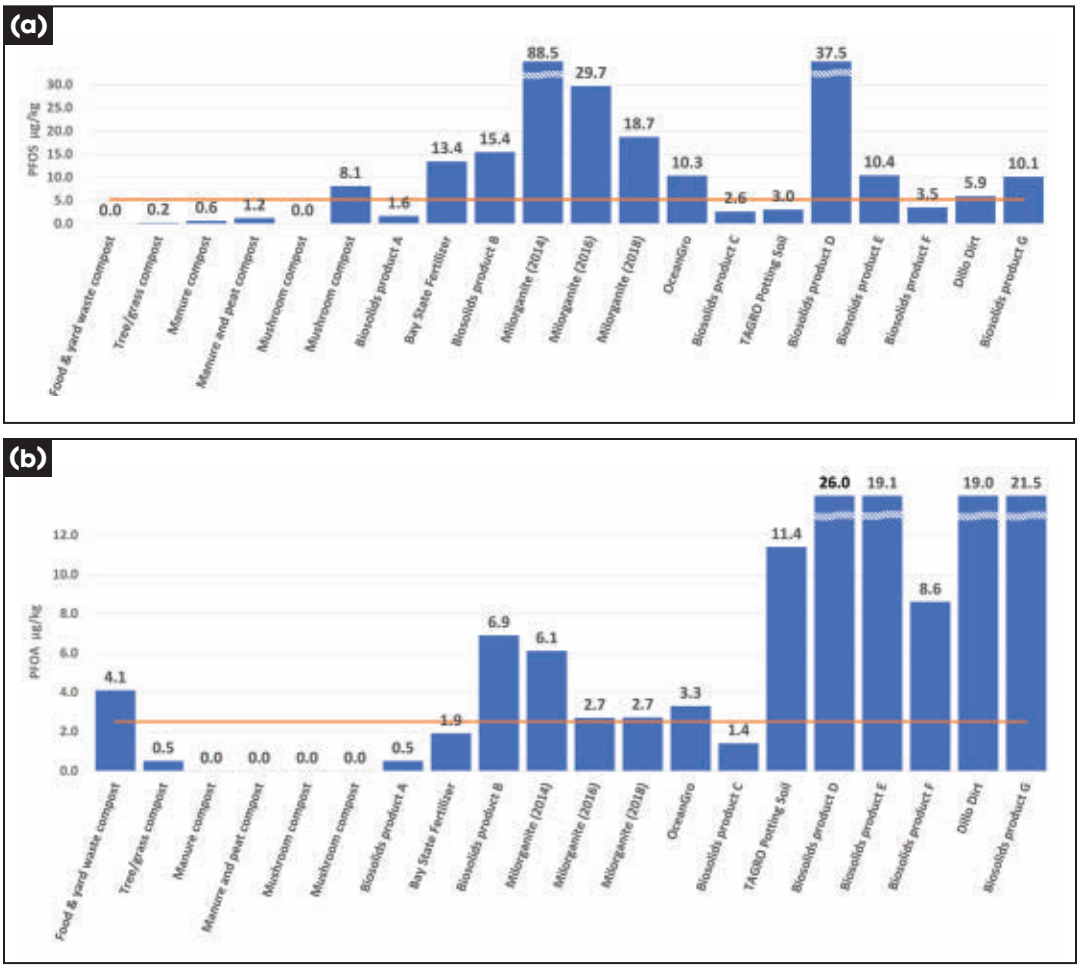
PFAS have been on the radar of West Coast regulatory bodies since the early 2010s, but the amount of energy and focus given to the issue has increased greatly in the past several years. As early as 2012, California was coordinating with the U.S. Environmental Protection Agency (EPA) to test for six PFAS compounds in 2,807 public water wells. Fast forward to today: The state is wrapping up a massive investigation that required PFAS testing at landfills, chrome-plating facilities, refineries, airports, water supply wells, and WRRFs. Groups are just beginning to sift through the massive data set, which includes results for biosolids as well as wastewater influent and effluent. One hope is that data analysis might reveal point sources for specific compounds as well as determine the baseline PFAS input from residential areas.

Californians are exposed to PFAS from several sources, particularly in their homes. While exposure to PFAS is not occurring from the use of biosolids to improve soil health, the wastewater community recognizes the need to address the issue. Stronger source control legislation is being sought in coordination with several, diverse nongovernmental organizations. Recent victories include a prohibition on the use of firefighting foam containing PFAS.

In California, the recent implementation of SB 1383 will make it difficult to send biosolids to a landfill. This law greatly restricts the amount of organic material that can be landfilled because of the methane emissions associated with the practice. Biosolids are encouraged to be used as a soil amendment instead. This legislation highlights how biosolids can either be a beneficial tool in the fight against climate change when they are used as a soil amendment, or they can be detrimental to the climate if they are wasted and disposed of in a landfill.

It is possible that through PFAS source control legislation, a focus on the larger climate change benefits of recycling biosolids, and a collaborative approach with regulatory bodies, California will manage to address the PFAS issue and continue to see the environmental upside of biosolids use. With the conclusion of the state's

Figure 1. PFOS (a) and PFOA (b) Concentrations in Various Commercial Soil Amendments



Source: Adapted from from Lazano et al., 2020

PFAS investigation and possible wastewater regulatory changes stemming from that, the next year will be critical for the wastewater sector to address the PFAS issue in California.

Further north, the state of Washington put forth a PFAS action plan in November 2021. This plan takes a pragmatic approach to ensure safe drinking water, clean up existing contamination, reduce PFAS sources, and evaluate PFAS in wastewater treatment and biosolids. The state indicated that changes to biosolids regulations were premature, but that it would be evaluating risk models and exposure pathways for biosolids, stressing that "realistic modeling parameters" and "science-based risk assessments" must be used for these investigations. The Washington legislature also has been taking meaningful action on source control. It implemented bans on PFAS in firefighting foam and certain kinds of food packaging and has upcoming legislation that would ban PFAS in cosmetics.

A Practical Approach in the Middle — Michigan

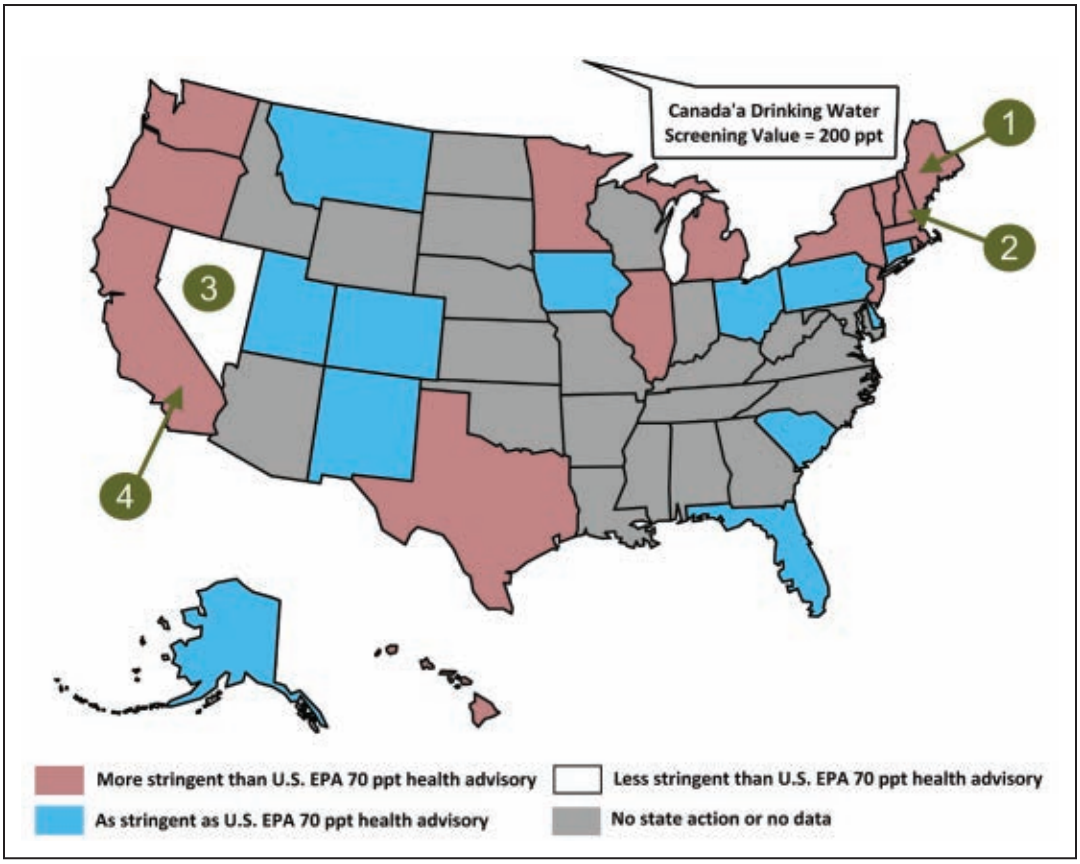
In March 2021, the Michigan Department of Environment, Great Lakes, and Energy (EGLE) published *Interim Strategy for Land Application of Biosolids Containing PFAS*, which formalizes its guidance for recycling biosolids in light of major PFAS concerns in the state. EGLE based its findings on a comprehensive study of PFAS in municipal wastewater and biosolids.

The study found industrially contaminated solids and worked with wastewater utilities to eliminate the sources. This source control decreased the PFAS levels in those biosolids dramatically.

Now, biosolids must be tested for PFAS prior to land application and EGLE established the following guidelines for perfluorooctanesulfonic acid (PFOS):

- Biosolids with concentrations of 150 µg/kg or above are considered industrially affected and cannot be land applied. WRRF biosolids managers must immediately notify EGLE of these

Figure 2. Drinking Water and/or Groundwater Standards for PFOA



1 **Maine has a total interim drinking water standard limit of 20 ppt that combines PFOA and five other PFAS chemicals.**

2 **New Hampshire has a maximum contaminant level drinking water limit of 12 ppt defined by law.**

3 **Nevada has a screening level of 667 ppt for drinking water.**

4 **California has a drinking water limit, called a response level, of 10 ppt.**

This map depicts formally adopted, interim, and proposed limits for state drinking water and/or groundwater standards for each state for PFOA. (In cases where ground water or drinking water standards within a state differ, the more stringent is represented.) Some have been set by law and others by regulatory actions. Drinking water and groundwater limits are important as they set expectations and drive subsequent regulatory limits for soils, biosolids, surface waters, and wastewater effluent. This map is derived from data in the Interstate Technology and Regulatory Council Water and Soil Tables of Regulations, Guidance and Advisories for PFAS (February 2022), visit pfas-1.itrcweb.org to access the most recent data. *Source: Cost Analysis of the Impacts on Municipal Utilities and Biosolids Management to Address PFAS Contamination*

test results and begin wastewater sampling and an investigation into potential sources of PFOS in their sewershed. The WRRF also must make other arrangements for treatment or disposal of the effected biosolids.

- For concentrations less than 150 ppb but greater than 50 ppb, the generators again must notify EGLE immediately and initiate wastewater testing and investigations into the sources of PFOS to develop a source reduction program. Materials in this concentration range can be land applied. But, to reduce the overall PFOS loading to a site, EGLE restricts application rates to 1.5 dry tons per acre.
- Biosolids with concentrations below 50 ppb, which was the case for the majority of WRRFs that EGLE studied, can continue to be land applied. When concentrations are above 20 ppb, EGLE recommends the WRRF consider investigating possible sources and conducting additional sampling.

EGLE is also conducting a statewide soil study to help provide context for the PFAS in soils issues in Michigan. The full strategy report can be accessed by visiting Michigan.gov and searching for *Land Application of Biosolids Containing PFAS Interim Strategy*.

Michigan and Maine are spending a ton of time and money dealing with these legacy pollution sites. Both need to be lauded for doing their best to deal with the major PFAS effects in their states. But it shifts the landscape for biosolids land application and will result in longer hauls and higher costs for managing the solids, not to mention a larger carbon footprint for these operations that could outweigh the benefits of putting the carbon back into the soil.

U.S. EPA Actions

In October 2021, EPA released its *PFAS Strategic Roadmap*. EPA's strategy is a multimedia, multipronged attack on PFAS in the environment with three major aims: research, restrict, and remediate. A drinking water standard for PFOS and PFOA seem imminent. That will translate into surface water standards and make its way into National Pollutant Discharge Elimination System (NPDES) permits.

The key takeaways from EPA's roadmap, related to biosolids, is that the risk assessment is not scheduled to be completed until the winter of 2024. This timeline is a disappointment to many biosolids managers as it continues the situation that already has created a patchwork of state regulations and continues uncertainty with respect to long-term capital planning.

EPA's proposed approach to the biosolids risk assessment includes

- a proposed method for prioritizing PFAS and other contaminants to be assessed;
- a deterministic, screening-level model; and
- a framework for probabilistic risk assessment.

This approach will undergo peer review, likely to begin this spring, by its Science Advisory Board. EPA plans to use the proposed probabilistic risk framework approach for PFOA and PFOS on all other PFAS chemicals in future biosolids risk assessments. If

Maine Takes Hard Line on PFAS, Biosolids

Maine is one of the very few U.S. states with guidance on PFAS related to biosolids recycling, and it is the only state to set formal screening levels for PFAS in biosolids and biosolids-based products. And these regulations, along with pending legislation, could end biosolids recycling in the state.

Setting the Limits

In 2018, the Maine Department of Environmental Protection (ME DEP) adopted screening concentrations for three PFAS compounds for the beneficial reuse of solid waste — not including biosolids (Chapter 418, Appendix A, July 8, 2018):

- PFBS — 1,900 ng/g (ppb)
- PFOA — 2.5 ng/g
- PFOS — 5.2 ng/g

These screening concentrations were derived from models and calculations consistent with ME DEP determinations of other Maine Remedial Action Guidelines for petroleum-contaminated sites. The methodology included use of the U.S. Environmental Protection Agency Regional Screening Levels calculator, followed by evaluation of leaching potential using SESOIL and AT123D models.

Measuring Biosolids

In 2019, ME DEP applied these screening levels to biosolids-based soil amendments. ME DEP's choice of model — versus, for example, the PRZM model for pesticide application — and variations in assumptions going into the model, may account for the wide discrepancies between Maine's screening concentrations and those developed elsewhere.

EPA determines that PFOA or PFOS in biosolids may adversely affect public health or the environment, EPA will consider options for numerical limitations and best management practices for these compounds.

Sampling will be required under NPDES permits. EPA plans to restrict PFAS discharges from industrial sources using the Effluent Limitations Guidelines program and establishing national technology-based regulatory limits for at least nine industrial categories.

Lastly, EPA plans to designate a couple of PFAS as hazardous substances under the Superfund law. This designation raises many concerns for residuals managers. EPA also is planning a national testing strategy, perhaps treating PFAS compounds as a class, and fast-tracking approved analytical methods.

Research Efforts

Research on PFAS chemicals and their fate and transport in the environment has accelerated considerably. In September 2021, EPA's Office of Research and Development awarded nearly $6 million USD in grants to four projects under its national priorities program to evaluate pollutants in biosolids. The research projects will study the effects of biosolids treatment processes on the environmental fate of contaminants of emerging concern, plant uptake, and mobility in the environment following land application of biosolids. Some researchers will contribute to the development of a framework for prioritizing risk assessment in biosolids. View details of these projects on EPA's website at bit.ly/EPA-PFAS-funding.

At the University of Arizona (Tucson), Ian Pepper, Regents Professor and Director of The WEST Center, is spearheading a collaborative national study on the fate and transport of PFAS following long-term land application of biosolids. The project scales up his local research on behalf of Pima County, Arizona, following a land application ban there in 2020. The national study will focus on numerous sites across the country with good records on land application of biosolids to evaluate whether land application of biosolids is a significant public health route of exposure to PFAS.

At the University of New Hampshire (Durham), Paula Mouser, Assistant Professor in the Civil & Environmental Engineering Department, and her team continue to publish research into the fate of long-chain and short-chain PFAS compounds through WRRFs. The research involves extensive sampling for PFAS at numerous WRRFs in New Hampshire's Great Bay watershed. In summary, the researchers found fractionation of PFAS through the wastewater treatment process — that is, PFAS separating into the water-loving compounds (mostly shorter chains that end up in the effluent) and water-repelling compounds (mostly longer-chain and precursor compounds that end up in the wastewater solids). They also found further fractionation depending upon the solids stabilization process.

Future of Biosolids Management

The Water Environment Federation (WEF; Alexandria, Virginia), in collaboration with the National Association of Clean Water Administrators (NACWA; Washington, D.C.) and the North East Biosolids & Residuals Association (NEBRA; Hope, Rhode Island) released a report titled, *Cost Analysis*

Biosolids managers in Maine were required to test the materials for these PFAS and all had detectable levels of PFAS. Only a few samples did not exceed the screening values for PFOA and/or PFOS. ME DEP also required testing of soils at long-term biosolids land application sites. This testing included sites that had received paper mill and/or other residuals. Any soils exceeding the PFAS screening levels can no longer receive biosolids.

Considerable Effects

Adhering to these rules had a considerable effect on the amount of biosolids sent to landfills. In 2018, about 35% of Maine's biosolids were landfilled. In 2020, that percentage had skyrocketed to 76%.

Class A products, such as compost, were able to be used as soil amendments if it was demonstrated, by calculations, that typical uses and application rates would not lead to soil levels of the three PFAS compounds exceeding the screening levels. Thus, compost and other Class A EQ sales and uses have continued, albeit at reduced quantities.

Stricter Legislation Pending

At press time, pending legislation in Maine would impose a complete ban on the sale, distribution, and use of "sludge and sludge-based composts." This bill has passed out of the joint committee on Environment and Natural Resources by a vote of 10 to 3 and next will be considered by the full legislature. An emergency clause had been added that would make the law effective immediately after being signed by the governor. If passed into law, Maine would be the first and only U.S. state to ban biosolids recycling. This bill could be further amended before seeing the full floor.

of the Impacts on Municipal Utilities and Biosolids Management to Address PFAS Contamination, in October 2020. The report, written by CDM Smith (Boston), found average costs for managing biosolids increased 37% in states with stringent PFAS regulations, mainly in the Northeast. The study found a major effect on beneficial use programs with little to no effect on programs relying on landfilling and incineration as primary management methods. The report — available at bit.ly/biosolids-pfas — contains nine case studies of WRRFs and businesses affected by PFAS. Figure 3 (below), excerpted from the report, shows cost increases by biosolids management method.

The future of biosolids management will be driven by these costs, which hopefully will lead to innovation and new solutions.

Promising Technologies

Pyrolysis/Gasification, a technology from the solid waste space, already is in commercial operation for biosolids treatment. One operating biosolids pyrolysis facility in California has obtained a California Air Resources Board permit for its operation in Redwood City. Linden, New Jersey, also has an operating biosolids gasification facility. At the same time, several WRRFs nationwide are conducting pilot studies.

Overall, we know how to get PFAS out of drinking water. We have several established technologies and numerous viable ones. Figure 4 (p. 29) shows the relative effectiveness of various technologies in removing PFAS from drinking water.

Emerging technologies for destroying PFAS in biosolids or wastewater include supercritical water oxidation, vitrification, plasma-assisted sludge oxidation, hydrothermal liquefaction, foam fractionation, coagulant/flocculant, electrochemical oxidation, and electrocoagulation.

EPA's PFAS Innovation and Treatment Team (PITT) has completed its investigations into emerging PFAS destruction technologies. PITT has prepared a series of research briefs on four technologies that hold promise for PFAS destruction including pyrolysis and gasification and supercritical water oxidation. For more information and to read the briefs, go to bit.ly/EPA-PITT. Additionally, the Water Research Foundation (Denver) has a project investigating the fate of PFAS through sewage sludge incinerators; and there is much more research forthcoming.

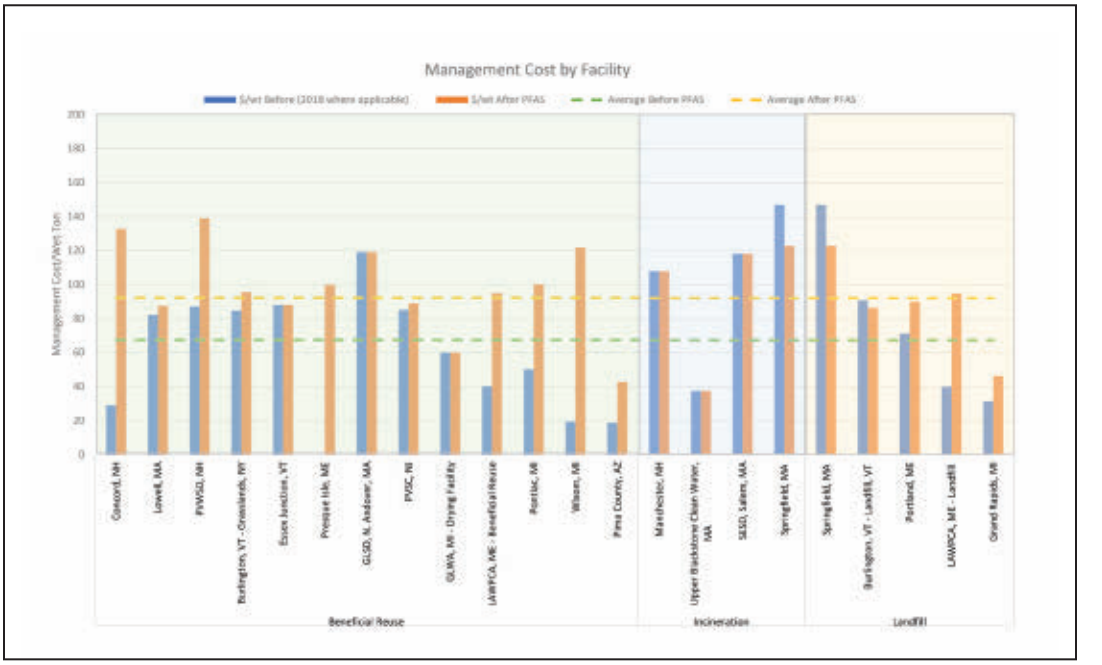
What Can WRRFs Do?

First, focus on source identification and reduction!

Since the ban on manufacturing PFOS and PFOA in the U.S., concentrations of these chemicals have dropped in biosolids; we know source reduction works. Even without local limits, utilities can use industrial pretreatment programs to identify and cooperatively eliminate PFAS sources into their collection system. For example, the New Hampshire Department of Environmental Services Residuals Management Section has created helpful guidance, titled *Interim Best Management Practices for Emerging Contaminants in Certified Biosolids*. You can find it at bit.ly/NH-BMP.

Second, reduce the amount of solids being handled! Drying systems make sense even though they do not remove PFAS; having a smaller amount of drier material will give you more options.

Figure 3. Management Cost Increases After PFAS



Third, innovate! Raise your hand to pilot emerging technologies that have potential to be sustainable and reduce climate effects. Or get involved with WEF as it develops a PFAS roadmap for utilities. The federation welcomes your suggestions and insights.

Fourth, talk about it! Discuss the effects on your operation with community leaders and elected officials. WRRFs are encouraged to use the estimate of 37% increase to calculate the effect on their budget and customers. Relay that information to your local, state, and federal elected officials. Talk to legislators and decision-makers about the unintended consequences of their well-intentioned policies and the long-term solutions needed. Focus on the benefits of beneficial reuse if possible.

Final Thoughts

The future of land application is in the hands of the regulators. Now is the time to get involved to ensure our important perspective as receivers of these chemicals is heard. We want to get PFAS out of our biosolids so we can maintain all our management options. If sustainability is the goal, that means putting that carbon and all those nutrients back into the soils locally, close to where they are produced.

This challenge is not going to fade away. It is time to talk to and educate your customers and legislators about PFAS. These chemicals are literally everywhere and affect everyone.

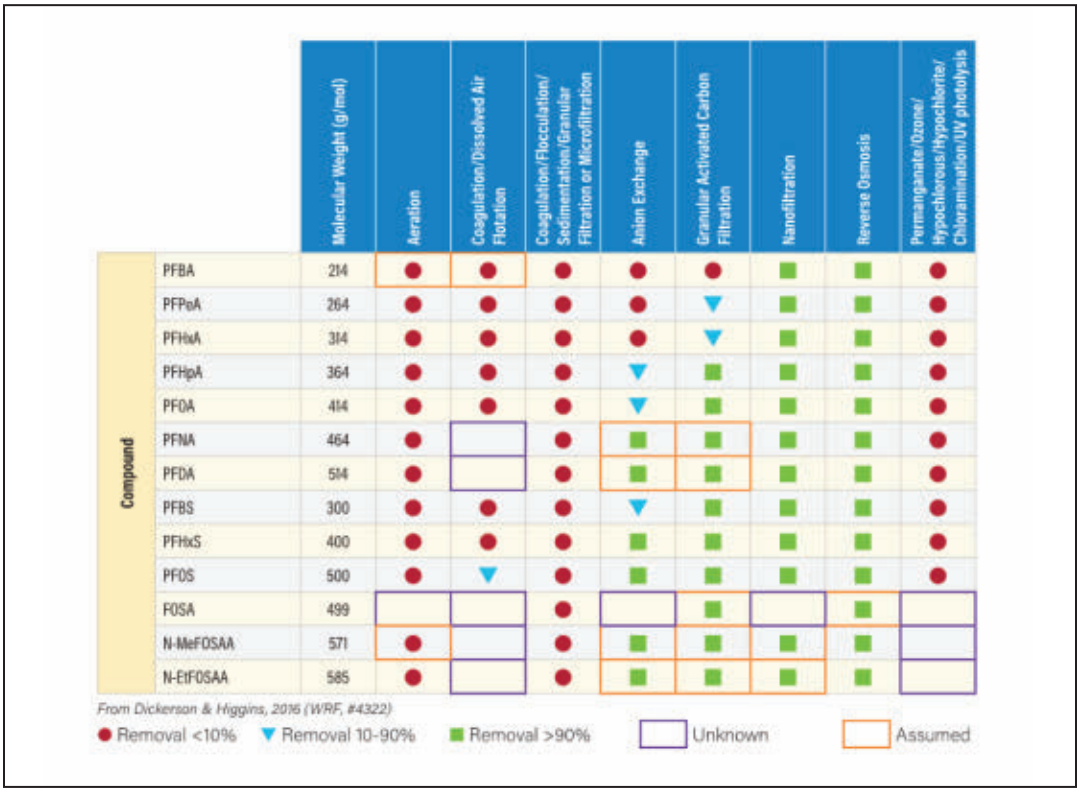
These leaders and ratepayers need to know that if we do not get rid of PFAS at the source, we will be forced to waste a lot of time, money, and effort to remove it from biosolids. The processes will create more carbon emissions and raise costs to maintain a baseline. Without careful consideration, it is going to get expensive to flush your toilets in the U.S.

Ultimately, the cost of these "externalities" should be borne by the chemical producers. But that likely means lawsuits to recover costs. Even that process requires more dollars and time spent with unsure outcomes.

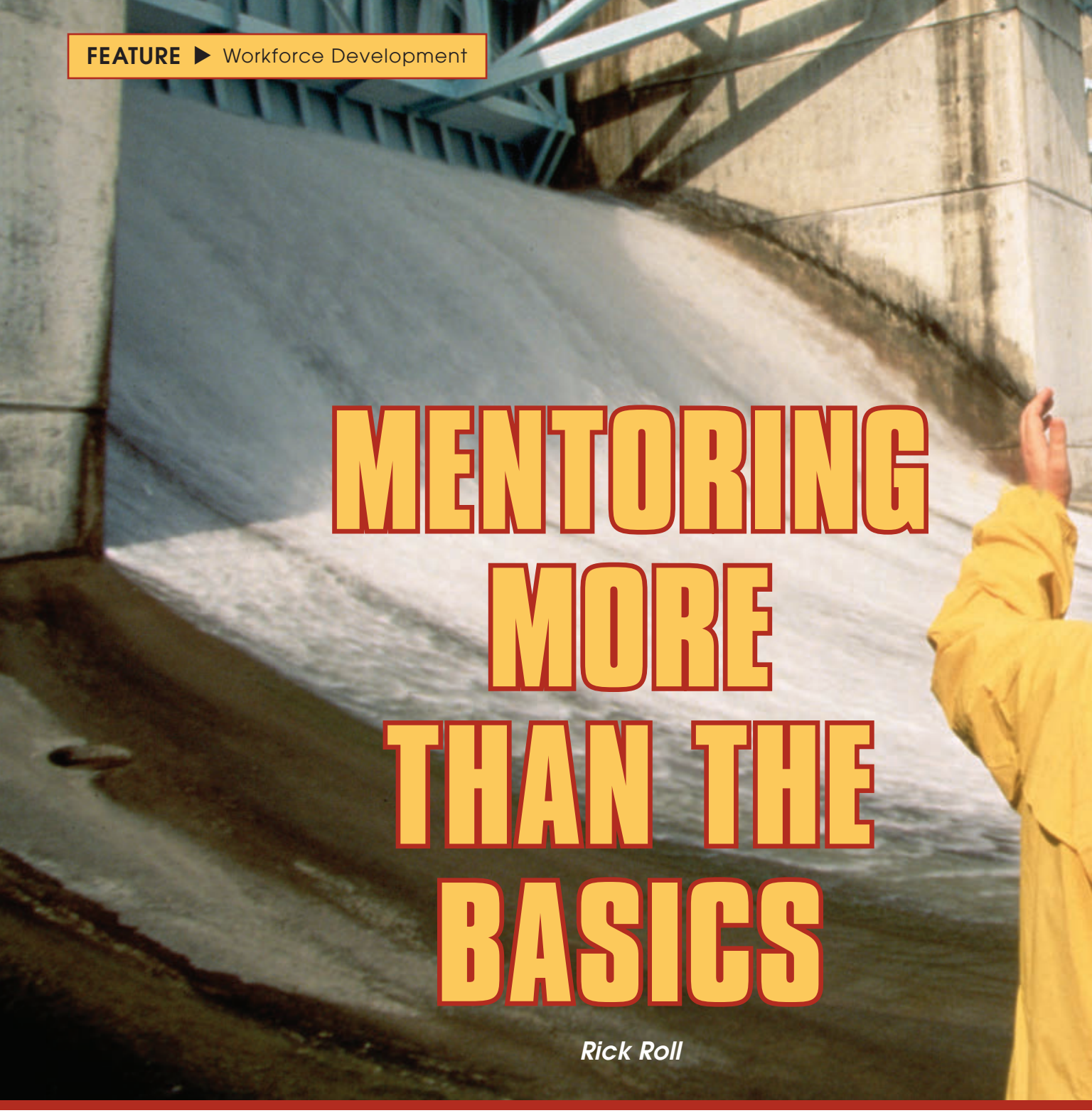
We need smart policies and regulations to maintain all currently available solids management methods and protect public health. We need research to fully understand the science and movement of these chemicals. And we need participation and investment to find additional technologies and process to make the future more sustainable.

Janine Burke-Wells *is Executive Director of the North East Biosolids & Residuals Association and represents the WEF Residuals and Biosolids Committee (RBC) on the WEF PFAS Task Force.* ***Ryan Batjiaka*** *is a Resource Recovery Specialist with the San Francisco Public Utilities Commission and Chair of the WEF RBC's ABBA Subcommittee (Association of Biosolids and Byproducts Associations).*

Figure 4. PFAS Removal Efficiency of Various Water Treatment Processes



Source: *Cost Analysis of the Impacts on Municipal Utilities and Biosolids Management to Address PFAS Contamination*



MENTORING MORE THAN THE BASICS

Rick Roll

For newcomers to the water sector, mastering a new job fully (or even a new skill) requires several levels of learning and input from different sources. A basic two-step approach relies on teachers or instructors to convey the core information and supervisors and shift leaders to ensure it is used properly. In both cases, asking questions is essential but can lead to frustration, especially when challenges arise.

One effective way to bridge this gulf is to facilitate new employee development with the occasional aid of a mentor, a senior employee removed from the chain-of-command, perhaps even outside of the work unit. Mentoring can help convey needed information to be productive in a particular work environment. It also can enable employees to develop higher level and longer lasting aspects of judgement, ethics, cooperation, and leadership.

"First, determine what the right thing to do is. Then, determine if there are any possible good reasons to do something other than the right thing. Chances are, you can't."

— Rick Roll

Formal and Informal Settings

Some employers have established formal, structured mentoring programs to develop a new employee's professional knowledge and skills in a comprehensive and time-efficient manner. This represents an investment in the employee, as most meetings and sessions occur on company time. Scheduling these meetings, with some expectations during the periods in-between, keeps progress on track and allows the meetings to sunset after a reasonable time, often 6 to 12 months.

These meetings represent give-and-take discussions, rather than specific direction that is the purview of supervisors. This can only occur in an atmosphere of trust, honesty, and confidentiality. With that established, the mentee can better express their problems and benefit from the mentor's experience and guidance.

Specific questions from the mentee will be an opening for the mentor to provide a big picture understanding of the technical, legal, and regulatory framework defining their

profession. Within the framework will come details governing day-to-day activities, including codes and standards, client/customer interaction and confidentiality, and standard operating procedures. A good understanding of these work aspects is invaluable for guided growth and career achievement and were usually not covered in depth back in the classroom.

More common are instances of less formal mentoring or coaching. Absent a structured program, mentors may be asked to check in with mentees regularly to provide an outlet for problems and a source of ideas and inspiration.

The informal relationship can thrive on opportunities for small interactions as they occur. These include hallway passing, breakrooms, elevator rides, and driving out to remote facilities or customer's sites. Something of a sensitive nature can be pursued in private at the first chance. These casual moments supplement, but do not replace, the private, one-on-one meetings.

The formal programs have a specific duration by which time its goals are met, and the participants move on with the benefits gleaned from the regular interaction. A side benefit is a diminished hesitancy for approaching other senior staff with issues that a little bit of advice may resolve. Informal mentoring usually doesn't have that breakpoint, with get-togethers gradually tapering off over time. Whether that is seen as better or worse, it reflects the flexibility of the arrangement, and flexibility is an ingredient for growth and improvement.

Many employers as well as professional societies encourage networking among their young professionals. Group events include facility tours, project presentations, community activities, game and amusement evenings, and even regular dinner meetings with rotating speakers that pass along mentor-like wisdom during dessert. These opportunities are great on their own but are more effective when coupled with a formal or informal mentoring program.

More Than Technical

We all use facts, references, and procedures for our jobs in the water sector, but it is the open-ended questions or unusual problems that force us to think things through. That exercise, and the associated thought process, sticks with us as we encounter the next problem, then the one after that.

The mentor is in a great position to exercise younger minds and start watching light bulbs go off. Thought exercises can range from design conflicts to process upsets. Approaching problems as puzzles instead of obstacles is an acquired skill for some but brings more satisfaction and even a dose of enjoyment.

Technical and analytical abilities combined with a solid work ethic count for a great deal, but other qualities are necessary for workplace and career success. A conscience and the sense of right and wrong that has been developed in the first couple decades of life are the rudders that steer our career ship, directing us along healthy journeys or onto the other kind of journey. We can all name personalities that have stood out in their field for their morbid absence of ethics, but they best serve the rest of us as bad examples to avoid.

Mentors have a couple of tools to reinforce and build upon the ethics their mentees already possess. Those open-ended questions also apply to ethical scenarios that a junior member has not encountered yet. Pushing a hypothetical situation to an uncomfortable extent (What if it's a small mistake? What if nobody knows? What if it doesn't matter much? What should you do about it then?) prepares them for when something similar occurs in the real world.

Responsibility for one's conduct and work is tied to ethics, of course. Even though you have a minor role in a larger effort, your responsibility is on display with the care you take and how you own up to your mistakes. As solid as our internal compasses are, mentors give us reminders by word and deed to continue doing what you already know you should always be doing. Think of the reminders as booster shots for an already active immune system.

There are examples everywhere of how simple civility has taken a hit due to our electronic connectivity. Showing thanks and appreciation now stands out and distinguishes those who recognize the need for it and express it. Some of that may get set aside when things are going sideways and stress rises; maintaining grace under pressure is a fine theory but is harder to practice. It only takes a couple of reminders from a mentor to reset one's mindset toward gratitude and appreciation for those with whom we interact, both internal and external customers.

Technical competency, ethics, responsibility, and teamwork form the foundation of leadership. Despite protracted debate as to whether a leader is born or made, the skills and qualities supporting leadership can be developed, enabling the trait to be applied and become self-sustaining through practice. A little encouragement will end up going a long way.

Fire Drills

The mentoring opportunities described above largely deal with planned meetings and controlled settings. Even informal programs will fall into a rhythm that works for the mentor and mentee. The comfort of routine helps reinforce the trust and openness needed for the relationship to function. What about stepping outside the comfort zone occasionally?

There's a great deal to learned by watching how one's mentor responds under unusual or urgent circumstances. Imagine the learning potential of these situations:

- Dealing with three simultaneous backups in your collection system when only two of your portable pumps will start.
- Trying to help a customer who is frustrated and angry, demanding something you cannot produce on the spot.
- Responding to a client who has a serious facility problem *now* and needs your assistance *now*, not tomorrow morning and certainly not Monday morning.
- Responding to an emergency, such as a facility flood in progress during record rainfall, for which you don't have an SOP on the shelf.
- Soliciting help from outside your working group for a project report whose deadline has just gone critical and crucial changes need to be worked through.

Getting the junior staff involved when these situations present themselves is not normally at the top of the to-do list. But these provide golden opportunities for learning that will be better remembered and appreciated than a story shared afterward in the break room.

The strongest memories and lessons come from experiences and usually have some sort of an associated emotion. Case studies — your team *is* capturing lessons learned within brief case studies, right? — describe the situations and help, but you are less likely to remember them from a seat at a desk.

Differences as a Strength

The mentoring process isn't just about coaching and sharing knowledge and experience to benefit those participating as well as benefitting the company/utility. It also builds connections between people that can last a career or longer. The more links and connections made between elements, the stronger and more resilient a structure becomes.

The principal difference between mentor and mentee is their body of experience, professional and otherwise. Of course, other differences exist because we are all different individuals with diverse backgrounds, talents, and personalities. Our differences collectively make us stronger by counteracting groupthink, confirmation bias, and the scenario fulfillment effect. If you have ever thought "I'm glad I don't think like they do" you might just as well have told yourself "It's a good thing everyone doesn't think like me."

Some aspects of diversity among us are obvious, such as gender, race, and language. Others are not so obvious, like neurodiversity.

Transitioning from the educational environment to the workplace environment is a big change. Some people handle it better than others. Those new employees who are on the near end of the autism spectrum can have a harder time than others managing all the associated changes. Disrupting established routines, perhaps moving to a new home in a new city, dealing with new personalities in new roles, understanding new expectations, recognizing and using new resources — all of it can start resonating to elevate stress and anxiety to an unhealthy and outwardly noticeable level.

It is a lot for anyone to deal with; it is harder yet with minor shades of autism in play.

We must remember that this does not constitute a disease requiring medication or isolation. These friends and colleagues of ours have a different pattern of thinking and their own set of comfort zones. Odds are good that you are unaware of regular encounters with several such individuals since these tendencies can be very subtle and on a spectrum — not on the other side of some arbitrary dividing line.

A good supervisor will observe these difficulties and help smooth the workplace acclimation to the extent that work rules can allow. Reasonable accommodation has been a standard for some time now. A mentor, however, is in a better position to help the employee recognize ways to make their transition easier. The private and confidential nature of their relationship presents a forum to defuse the stress and allay fears, many of which can be baseless.

Those of us living on the spectrum have much to offer an employer by making our own unique and meaningful contributions. Strengths that can include persistence and focus, procedure and pattern skills, and being detail-oriented are valuable commodities in any workplace. The intuitive mentor is particularly important for encouragement to build on these strengths and successfully integrate their mentee into the organization.

Every Day in Every Way …

We continually serve as an example for others, whether we are aware of it or not, and whether we have the title "Mentor" or not. Hopefully we are setting good examples, although the other kind can serve a purpose too. The messages we send — spoken and unspoken — will have a lasting effect on those who look to us for guidance, as well as fostering improvements in ourselves. We excel when we're aware of this as it is occurring.

Let's keep distilling the best of us and continue passing along our collective wisdom.

***Richard R. Roll**, P.E., DEE, recently retired after 38 years in the water and wastewater sector.*

Pyrolysis is the first stage of all biomass combustion. The charcoal-like product created from pyrolysis and shown here is called biochar. BioForceTech Corp.

Pyrolysis & Gasification

New approaches for treatment of biosolids that can address beneficial use, energy, disposal, and regulatory compliance

Stan Chilson, Charles Winslow, Jeremy Kraemer, Ian Piro, Joseph Regnery, Valentino Villa, Andrew Friedenthal, and Chris Holcomb

Editor's Note

Water Environment & Technology editorial guidelines discourage listing specific product and company names. In this case, however, we feel the reader gains more by seeing the specific capabilities of each of the technologies and their manufacturers.

Managing and disposing of residuals and biosolids from wastewater treatment is not an enviable job. It continues to become more difficult with each passing year. Availability of land application continues to be more restricted, and the availability of landfills continues to decrease or be banned altogether. These issues result in increased transportation distances, higher costs, and a need to diversify end products and markets to mitigate disposal risk. More contaminants continue to receive public scrutiny, such as microplastics and per- and polyfluoroalkyl substances (PFAS). Regulation of biosolids quality is important for public acceptance of beneficial reuse, which has over time led to higher levels of treatment, such as drying. However, higher levels of treatment can result in higher energy consumption, which may not align with utility or jurisdictional energy and/or greenhouse gas emission reduction targets.

Processing of biosolids by incineration has been utilized by large water resource recovery facilities (WRRFs) to provide a reliable disposal option for biosolids. It has been utilized for 90 years and remains a viable alternative. Pyrolysis and gasification are new approaches to thermal processing that can be applied at a broader range of WRRF sizes, and therefore, are garnering significant interest by biosolids managers looking to address risks in their existing program.

Being thermal treatment technologies, all three have several fundamental similarities. All employ high temperatures that support volatilization and conversion of nearly 100% of the volatile solids (VS), produce excess bioenergy as hot gas that can be recovered and utilized, produce a sterile residue (no biological or pathogen content), and can utilize either raw untreated sludge or digested biosolids. The three technologies differ in terms of carbon conversion, uses and applications for the residue (biochar or ash), amount of bioenergy recovery, type of pre-treatment needed, and air emissions.

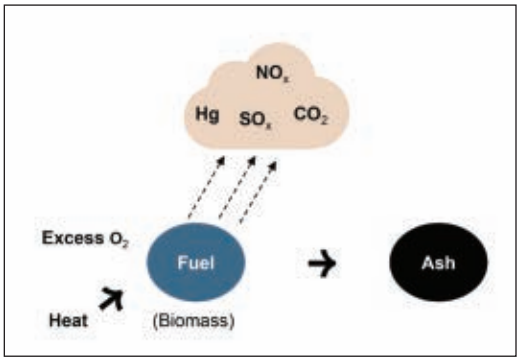
This article provides an overview of the similarities and differences between pyrolysis and gasification. Incineration also is discussed to provide context in how the two newer technologies compare to what is well-established. The article finishes with overviews of five pyrolysis and gasification technologies operating or being demonstrated in North America.

Thermal Processing 101

Incineration. Biosolids are dried and oxidized in a single reactor and nearly 100% of the fixed carbon is oxidized to carbon dioxide. Two types of systems are commonly used: fluidized bed and multiple hearth.

The multiple hearth system operates with negative pressure while the fluidized bed is positive pressure. The fluidized bed system has been shown to require less excess air than multiple hearth system, thus

Incineration



less fuel demand. An afterburner is required with a multiple hearth system to meet regulatory standards while the fluidized bed system does not. Multiple hearth systems produce bone-dry bottom ash while the ash is entrained in the fluidized bed system exhaust gas and removed in the wet scrubber liquid.

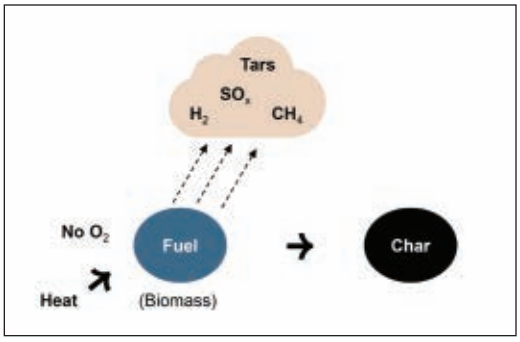
Pyrolysis. Pyrolysis is the first stage of all biomass combustion. It is the thermo-chemical decomposition of organic matter at high temperature in an inert atmosphere (no added air or oxygen). The conversion of wood to charcoal is an example of pyrolysis. In charcoal, the fixed carbon from the wood is concentrated, and that is the reason why charcoal burns longer than wood. The charcoal-like product of pyrolysis is called biochar.

During pyrolysis, heat causes solid molecules to vibrate so rapidly they "crack" into lighter volatile molecules that become synthesis gas ("syngas"). After these volatile gases contact oxygen, they ignite. The ignition temperature of biosolids syngas is about 540°C to 1,150°C (1,000°F to 2,100°F).

Biosolids pyrolysis reactors are fed dried biosolids and are "indirect heat" type, meaning the heating medium does not come into direct contact with the feedstock. There is no flame in an indirectly heated pyrolysis reactor.

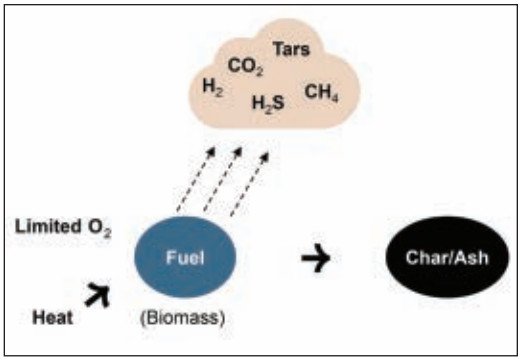
The syngas is oxidized in a separate chamber by simply adding oxygen (air) and a portion of the resulting heat is used to maintain the reactor temperature. After operational, pyrolysis is autothermal (no external fuel) and excess heat can be captured to offset the dryer heat demand. Depending on the VS content of the biosolids and system design, the pyrolysis reactor's heat demand varies from about 30% to 50% percent of the heat from syngas combustion. The other 50% to 70% of the heat is available for other uses, such as drying dewatered cake.

Pyrolysis



Gasification. Gasification is a two-step process, pyrolysis followed by gasification. In gasification systems, a controlled amount of air, oxygen, or steam is added to the reactor to make it an "oxygen-starved" reducing environment. Under the appropriate time and temperature conditions,

Gasification



a controllable amount of the fixed carbon in the biosolids can be thermochemically converted to increase the calorific value of the syngas. The syngas is then fully oxidized in a separate chamber with excess air for complete combustion.

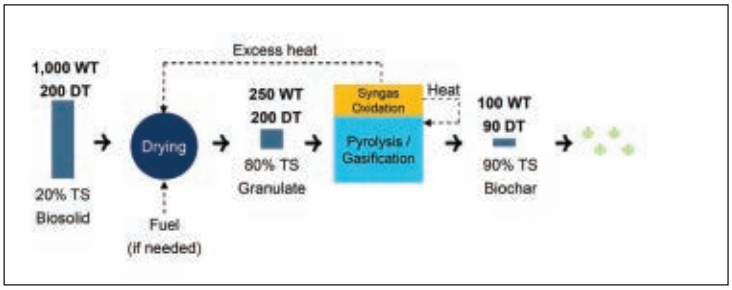
Compared to pyrolysis, gasifiers produce more syngas at a higher calorific value, increasing carbon dioxide emissions, and reducing biochar quality proportional to the increased calorific value of the syngas.

Typical process flow. One typical process flow and mass balance is illustrated in Figure 1 (p. 37). Biosolids are first dried to about 80% percent total solids (TS), using excess heat from the thermal reactor plus fuel to make up any heat deficit. The dried biosolids are heated in the pyrolysis or gasification reactor to produce syngas, which is used to generate heat to keep the reactor hot, and excess heat is sent to the dryer. Note the process scheme shown in Figure 1 is generalized; each manufacturer's implementation and operation will be different. The actual reduction in total solids is dependent on technology, configuration, and degree of carbon conversion.

How Do They Compare?

Pretreatment. Incineration achieves autogenous operation at about 28% TS and 75% to 80% VS. Pyrolysis and gasification require dewatering to a minimum 20% dry solids followed by drying to a minimum of 80% dry solids. Energy efficiency is improved in all cases by dewatering to as high a dry

Figure 1. Generalized Process Flow for Pyrolysis and Gasification



VS = volatile solids, TS = total (dry) solids, SSI = sewage sludge incinerator, PFAS = per- and polyfluoroalkyl substances.

solids content as can be economically achieved.

Operating temperature. Incineration operates at the highest temperature range, approximately 815°C to 900°C [1,500°F to 1,650°F]. Pyrolysis and gasification reactors operate at similar temperatures to each other: pyrolysis from 500°C to 850°C [930°F to 1,560°F] and gasification at 675°C to 815°C [1,250°F to 1,500°F].

Mass reduction. All three thermal processes convert near 100% of the VS in the biosolids. Digestion converts 40% to 65% of the VS depending on type of sludge and digestion process. Lignocellulose from wood-derived products do not readily degrade in a digester; however, they do convert in thermal systems. This enhanced VS conversion decreases end-product mass for off-site disposal relative to digestion only.

Total solids reduction is highest for incineration, lowest for pyrolysis, and in-between for gasification.

Product. Incineration produces a sterile inert ash. Heavy metals in the feedstock are concentrated in the ash, and this can sometimes restrict utilization or disposal options. Incinerator ash has little to no measurable carbon.

Pyrolysis does not oxidize carbon in the reactor. Rather, it concentrates carbon into the biochar. In pyrolysis, the dry mass of biochar is typically 20% to 30% more than incinerator ash. Heavy metals in the feedstock are concentrated in the biochar. The carbon content of pyrolysis biochar from biosolids

Table 1. Comparison of Biosolids Thermal Processing Technologies

	Pyrolysis	Gasification	Incineration
Pretreatment	Dewatering & drying	Dewatering & drying	Dewatering
Operating Temperature	500°C to 850°C [930°F to 1,560°F]	675°C to 815°C [1,250°F to 1,500°F]	815°C to 900°C [1,500°F to 1,650°F]
Mass Reduction	VS: near 100% TS: 30 to 55%	VS: near 100% TS: 55% to 65%	VS: 100% TS: 70% to 80%
Product	High-carbon biochar	Varies from high-carbon biochar to ash	Ash
Product Uses	Agriculture, Horticulture, Coal substitute, Manufacturing feedstock	Soil admixes, Cement or concrete additive, Landfill depending on carbon and metals content	Landfill disposal, Phosphorus recovery, Cement or concrete additive
Syngas Calorific Value	6 to 9 kJ/m^3 [150 to 250 BTU/ft^3]	9 to 13 kJ/m^3 250 to 350 BTU/ft^3	Not applicable
Air Emissions	To date, exempt from SSI Rule	To date, exempt from SSI Rule	Subject to SSI Rule
Bioenergy Recovery	Offset thermal dryer heat demand by 50 - 75%; offset BioDryer heat demand up to 100%	Offset thermal dryer heat demand up to 100%; potential excess heat recovered for other uses	Excess heat recovered for electricity generation, building heat, etc.
Carbon Sequestration	Yes in biochar	Yes in biochar (less than pyrolysis)	None in ash
PFAS	Initial research indicates no PFAS in biochar	Initial research indicates no PFAS in product	Initial research indicates no PFAS in ash
Opportunities	Synergy with solid waste management Disposal of dried solids as risk mitigation Beneficial uses of biochar	Synergy with solid waste management Disposal of dried solids as risk mitigation Beneficial uses of biochar/ash	Bioenergy recovery Beneficial uses of ash

Table 2. Syngas Characteristics

Syngas Constituent	Composition
Carbon Monoxide	10%-60%
Hydrogen	20%-30%
Methane	0%-30%
Carbon Dioxide	5%-15%
Water Vapor	2%-30%

Note: composition varies based on technology type and mode of operation.

is between 30% and 40%. By comparison, charcoal from wood is about 85% to 90% fixed carbon. The difference is wood ash is less than 3%, while biosolids ash is 20% to 30%.

The residual product quality from gasification depends greatly on the degree of carbon carbon conversion to syngas in the reactor. Gasification converts 30% to 90% of the fixed carbon to carbon monoxide and carbon dioxide. At the low end of the range, the product is like pyrolysis biochar, while at the high end the product is more like ash from incineration. The carbon content of gasifier ash or biochar is a function of carbon converted in the reactor. Heavy metals are concentrated in the ash/biochar.

Product uses. Ash from incineration is typically landfilled, although other beneficial uses are emerging, such as use in cement or concrete production and recovery of the phosphorus.

Biochar is the carbon-rich charcoal-like product of pyrolysis, which is a 2,000-year-old practice to convert agricultural waste into a soil enhancer. Biochar uses include

- soil amendment;
- local public use for horticulture and landscaping;
- coal substitute for power plants;
- filtration media (feedstock for producing activated carbon);
- industrial feedstock, such as colorant, additive or dye.

The U.S. biochar market was valued around $100 million USD in 2019 and predicted to grow by 18% per year through 2027.

Soil enhancement is the most common biochar application. Biochar is hygroscopic, meaning it holds water, so water and nutrients are retained improving crop yields and minimizing leaching of fertilizers into surface water and groundwater. It is also devoid of pathogenic contaminants. The International Biochar Initiative (IBI) (biochar-international.org) provides a platform for fostering stakeholder collaboration, good industry practices, and standards for biochar products. For example, to address concerns around the presence of toxicants in biochar, the IBI established standards that require testing for heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and dioxins/furans.

Given biochar is a new end product in the biosolids market, some equipment suppliers provide pyrolysis or gasification as a service, taking the biochar off-site and selling it through their own network of reuse outlets. This biochar management can be done potentially at zero cost or revenue sharing, as is already done with some biosolids fertilizer and struvite products.

For gasification, product use will generally be the same as either of the above, depending on the degree of carbon conversion.

Syngas quality. Syngas is formed during pyrolysis and gasification. It is considered a "weak" gas because its calorific value is lower than biogas or natural gas; syngas is typically 6 to 13 kJ/m^3 [150 to 350 BTU/ft^3] compared to 22 kJ/m^3 [600 BTU/ft^3] for biogas or 37 kJ/m^3 [1,000 BTU/ft^3] for natural gas. Natural gas and biogas consist primarily of methane, while syngas is comprised of hydrogen and carbon monoxide and other constituents as outlined in Table 2 (above). The syngas calorific value from pyrolysis is at the lower end of the range and gasification at the higher end of the range.

Air emissions. At the time of writing this article, the U.S. Environmental Protection Agency (EPA) was seeking comments and data to consider changes to the Clean Air Act (CAA) section 129 regulations pertaining to pyrolysis and gasification, saying: "The agency believes there is considerable confusion in the regulated community regarding the applicability of CAA section 129 to pyrolysis and gasification units." The EPA is considering removing the reference to pyrolysis and gasification.

Incineration facilities are regulated pursuant to 40 *CFR* parts 60, 61, and 62 (commonly referred to as the Sewage Sludge Incinerator [SSI] Rule) and Title V Permit requirements. To date, pyrolysis and gasification have been determined exempt from SSI Rule requirements by federal and state regulatory agencies.

Incineration systems have demonstrated compliance with the 2016 mandate per EPA §40 *CFR*, Parts 60, 61, and 62.

Bioenergy recovery. The energy balance for thermal processes is an important consideration and depends principally on the calorific value of the biosolids (VS content) and dewatered cake dryness.

Because incineration converts nearly 100% of the VS and fixed carbon, it produces the most amount of heat. There is usually enough heat generated to allow the process to be autogenous after it is up to operating temperature. Data from

operational installations show that incineration can be autogenous at about 28% to 30% TS and 75% to 80% VS. Excess heat can be recovered to produce electricity or provide building heat.

In pyrolysis and gasification, there is enough heat generated by syngas oxidation to keep the reactor autothermal after it reaches an operating temperature. Excess heat is used to offset the dryer heat demand. Pyrolysis can offset 50% to 75% percent of a thermal dryer's heat demand, or up to 100% with a BioDryer. BioDryers use the exothermic heat from biological growth coupled with excess heat from pyrolysis to dry the dewatered cake. Gasifiers have demonstrated the ability to satisfy 100% of a thermal dryer's heat demand, thus no additional external fuel is required when the bulk of the fixed carbon is converted to syngas. Gasifiers may also generate excess heat depending upon the moisture content and fuel value of the dewatered biosolids, and the conversion efficiency of the gasifier.

All three thermal processes require external fuel during reactor start up to heat the reactor to operating temperature.

Carbon sequestration. Pyrolysis can sequester most of the biosolids fixed carbon in the biochar rather than release it as carbon dioxide. From an environmental viewpoint, biochar production and incorporation into agricultural soils is attractive because the process is carbon negative. Biochar is a stable means of sequestering carbon in the ground for hundreds to thousands of years.

Gasification converts a portion of the fixed carbon to syngas, so its carbon sequestration in biochar falls between pyrolysis and incineration proportionate to the amount of carbon converted.

PFAS. PFAS molecules have carbon bonded to fluorine, which is one of the strongest molecular bonds in nature. PFAS are extraordinarily recalcitrant to biological degradation and persistent in the environment, hence the nickname "forever chemicals." One of the known ways of destroying PFAS is by thermally breaking them into smaller molecules and ultimately elementary atoms.

EPA has stated thermal processing of biosolids "shows great promise" in the destruction of PFAS and related compounds. Research is underway by our industry to address PFAS. Initial research shows that incineration, pyrolysis, and gasification eliminate PFAS and related compounds in the final product thereby mitigating current biosolids disposal risks where PFAS is or may soon be regulated.

Other opportunities. Pyrolysis and gasification require pre-drying the biosolids. This two-step approach allows for diversification of end-product management risk. Beneficial use of dried biosolids can be a secondary or backup management approach if the thermal reactor is unavailable or the local market for biochar is not yet developed.

Other opportunities for pyrolysis and gasification of biosolids include co-management with municipal solid waste feedstocks, such as yard waste and wood waste, as well as creating new beneficial uses of the product.

Equipment suppliers. Pyrolysis and gasification equipment suppliers that can utilize municipal biosolids as feedstock are highlighted in the attached information boxes. Pyrolysis and gasification of biosolids is an expanding market and other manufacturers may be available.

What's Right for You?

As utilities consider their environmental impacts and biosolids program risks, thermal processing remains a sustainable and economically feasible option. Pyrolysis and gasification are new tools available for the biosolids manager's toolbox. Their advantages and disadvantages are site-specific and depend on the desired balance between mass reduction, energy, and product quality. For these thermal technologies, it is important to characterize the fuel value of your dewatered cake. Your trusted biosolids professional can offer advice and support decision-making as to whether pyrolysis or gasification can address the risks in your biosolids management program.

***Stan Chilson**, P.E., is a technical director and senior project manager and **Charles Winslow**, P.E., is a senior engineer in the North Wales, Pennsylvania, office, and **Jeremy Kraemer**, Ph.D., P.E., is a Wastewater Technical Director in the Whitby, Ontario, Canada, office of GHD. **Ian Piro** is manager of business development at Anaergia Inc. (Burlington, Ontario, Canada). **Joseph Regnery** is the Director of Business Development, West Region, at Aries Clean Technologies LLC (Franklin, Tennessee). **Valentino Villa** is the Chief Operating Officer of Bioforcetech Corporation (South San Francisco, California). **Andrew Friedenthal** is the Director of Business Development at CHAR Technologies (Toronto). **Chris Holcomb** leads project and business development at Ecoremedy, LLC (Pittsburgh).*

CharTech Solutions

Pyrolysis

Global head office: Toronto, Ontario, Canada

CHAR Technologies Ltd. is a cleantech development and services company with three operational groups: CharTech Solutions (CharTech) specializes in delivering turnkey High Temperature Pyrolysis (HTP) systems for organic waste management; CHAR Biocarbon manages biocarbon market development/offtake, and oversees the research and development of new biochar products; and Altech Environmental Consulting is a full-service environmental engineering and consulting firm focused on resource efficiency, remediation solutions, and environmental compliance. CHAR's partnership with Anergy based in Singapore/Australia brings a total of 30 years of pyrolysis expertise and equipment manufacturing experience.

TECHNOLOGY FEATURES

CHAR's HTP Technology, which operates in a temperature range between 500° to 850°C (930° to 1,560°F), produces a high calorific value syngas and high purity biocarbon, limits tar and oil formation by cracking hydrocarbons at temperatures above 750°C, thereby reducing downstream syngas treatment requirements, and offers high thermal efficiency compared to an indirect fired kiln. The syngas passes through a cleaning train to produce clean syngas. CHAR Biocarbon has developed several innovative value-added biocarbon products including SulfaCHAR™, a cost-effective and zero-waste activated carbon replacement for cleaning hydrogen sulfide from biogas, and CleanFyre™, a biocoal replacement for traditional fossil coal.

TECHNOLOGY STATUS

CharTech's HTP Technology is commercially available. Their partner Anergy has delivered more than 100 pyrolysis kilns over 30 years. CHAR announced two commercial-scale projects in 2021 and plans to announce up to five in 2022. CharTech has developed a 3-to-12-month small-scale, containerized HTP system available for on-site pilot testing of dried biosolids.

HIGHLIGHT PROJECT

Completed in 2018, CHAR Biocarbon operates a High Temperature Pyrolysis facility in London, Ontario, Canada, co-located within an organics processing biogas facility with 750 kg/hr of feed comprise of digestate, biosolids, compost, and wood chips. This facility has an air, noise, and odor emissions approval issued by the Ontario Ministry of the Environment. Financing was through Sustainable Development Technology Canada, Ontario Centres of Excellence and CHAR.

Contact: Andrew Friedenthal M: 647-926-6144 E: afriedenthal@chartechnologies.com

Anaergia Inc.

Pyrolysis

Global head office: Burlington, Ontario, Canada
US headquarters: Carlsbad, California

Established in 2010, Anaergia (Burlington, Ontario, Canada) focuses on recovering value from waste for the municipal, industrial, and agriculture sectors while also reducing greenhouse gas emissions and generating revenue for its clients. With 10 regional offices around the world and two manufacturing facilities, Anaergia delivers complete, integrated solutions that provide value to clients in the form of clean water, renewable energy, and high-quality fertilizers while reducing the costs of waste management. Anaergia has a portfolio of more than 220 patents granted or pending, with 12 specifically related to pyrolysis of biosolids. Anaergia has been developing biosolids pyrolysis technology for almost a decade. Anaergia has delivered more than 1,700 biogas facilities on four continents. These facilities feature some combination of Anaergia-sourced financing, proprietary and third-party equipment, market-building, process engineering, project delivery methods, and operations.

TECHNOLOGY FEATURES

Anaergia's pyrolysis technology provides precise control of the biosolids residence time and temperature to create

high-quality biochar. Biochar production is typically 40% of feed dry solids with a carbon content of 40% by weight. The syngas treatment and heat recovery system is designed around a two-stage thermal oxidizer. The first stage operates at high temperature with a reducing atmosphere and the second stage operates with excess oxygen. Each stage utilizes flue gas recirculation for precise temperature control in each stage, allowing

for nitrogen oxide emissions below 200 ppm_{vd}. Heat is recovered via flue gas to thermal oil heat exchanger for the biosolids dryer. Emissions control includes reducing sulfur oxides by greater than 95% or optional selective catalytic reduction system can further reduce nitrogen oxide emission to below 30 ppm by volume dry. The furnace is designed for ultra-low nitrogen oxide emissions, making it suitable for air district in North America.

TECHNOLOGY STATUS

Anaergia's technology is commercially available. Anaergia deployed a 12 tons per day (TPD) full-scale demonstration pyrolysis system at the Encina Wastewater Authority's Water Pollution Control Facility in California. With support from the California Energy Commission, the pilot began operation in April 2015 and concluded in early 2016. The Rialto Bioenergy Facility is scheduled to be commissioned in Q1 2022 and online in Q2 2022.

HIGHLIGHT PROJECT

Rialto Bioenergy Facility, California, is the largest organic waste-to-energy facility in North America using anaerobic digestion of food waste and generation of renewable natural gas for pipeline injection. It is designed and permitted to process 1,000 TPD of organic wastes, consisting of 700 TPD of food waste separated from municipal and commercial solid waste and 300 TPD (75 DTPD) of dewatered biosolids from municipal WRRFs. Digestion and drying is operational; pyrolysis is being added in 2022.

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Aries Clean Technologies LLC

Gasification

Global head office: Franklin, Tennesee

Established in 2010, Aries (Franklin, Tennessee) focuses on designing, building, operating, and maintaining biomass processing facilities using its patented fluidized bed gasification technology for biosolids and its patented downdraft gasification technology for wood residues. Aries Bio-Fly-Ash™, produced from fluidized bed gasification of biosolids, is a renewable additive for concrete, asphalt, or soil amendments. Aries GREEN®, produced from downdraft gasification of wood residues, is a high carbon biochar that is certified by the U.S. Department of Agriculture and the International Biochar Institute. It is available through Amazon and The Home Depot as an all-natural soil conditioner and soil amendment.

TECHNOLOGY FEATURES

The Aries fluidized bed gasifier operates at temperatures greater than or equal to 675°C (1,250°F) with solids residence times greater than 20 seconds and gas residence times greater than 8 seconds. The Aries downdraft gasifier operates at temperatures greater than or equal to 980°C (1,800°F) with solids residence times greater than 60 minutes and gas residence times greater than 6 seconds. The thermal oxidizer runs at temperatures greater than or equal to 980°C (1,800°F) with gas residence times greater than 1 second to control air emissions. Independent testing indicates these conditions are sufficient to destroy PFAS.

TECHNOLOGY STATUS

Both Aries gasification technologies are commercially available. The Aries fluidized bed gasification technology was originally commercialized on biosolids by MaxWest in 2009 at its facility in Sanford, Florida, where it operated periodically until 2014. Aries acquired the technology in 2015 and scaled it up by a factor of five. Aries fluidized bed gasifiers for biosolids come in two sizes: 25 and 100 dry ton/d. Aries has one operational biosolids fluid bed gasifier and three additional systems planned to come online in 2023. Aries downdraft gasification technology has been operating on wood residue since 2016 in Lebanon, Tennessee. The facility has a 32-ton/d capacity, diverting 8,000 ton/yr of wood waste, to create Aries GREEN® biochar. Syngas is combusted and the thermal energy used in three Organic Rankine Cycle generators rated 420 kW that offset electrical usage at the Lebanon WRRF.

HIGHLIGHT PROJECT

The Aries Linden Project (New Jersey) fluidized bed gasifier became operational in December 2021. At full capacity, the facility will divert 430 tons of biosolids daily (130,000 tons per year) from local landfills while producing 22 tons per day of Bio-Fly-Ash™ that will be sold as an additive to local concrete companies. The system is within a re-purposed building at the Linden Roselle Sewerage Authority complex. The project uses Aries' Build-Own-Operate model and financing was provided in part through $61.5 million USD of "green" tax-exempt bonds. The facility brought 16 new, high-paying, clean tech jobs for the people of Linden.

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Bioforcetech Corporation

Pyrolysis

Global head office: South San Francisco, California

Established in 2013, Bioforcetech has been rethinking each step of biosolids treatment. Bioforcetech's patented BioDryer and P-Series Pyrolysis machines work together to reduce material volume and weight by 90% and produce OurCarbon™ biochar at net zero thermal energy. The P-Series system can process digested or undigested biosolids, manure, green waste, wood waste, food waste, agricultural waste, or any combination.

TECHNOLOGY FEATURES

The unique BioDryer reduces external heat demand by 50% and electricity by 30% compared to typical thermal dryers using a three-phase batch process: (1) the dewatered solids are self-heated by cultivating thermophilic bacteria, which raise the temperature to 65°C (150°F), (2) airflow is modulated to maximize bacterial growth, which generates large amounts of heat to evaporate moisture without any external heat source, (3) passive heat has evaporated so much moisture the bacteria are not able to proliferate further, reducing their heat output. The BioDryer then introduces an external hot airflow using heat from the pyrolysis reactor to finish off the drying process. This batch-wise process will dry biosolids to 80% TS in as little as 48 hours. The P-Series "plug-and-play" pyrolysis system can grow as the plant grows by simply adding more units. The units are compact, modular, skid-mounted, and self-contained for easy installation and integration.

TECHNOLOGY STATUS

The Bioforcetech system is commercially available worldwide, with 35-plus operating full-scale facilities (7 on biosolids only feed stock) including the first biosolids pyrolysis system in North America (discussed below), a second system designed by GHD for Ephrata Borough Authority, Pennsylvania, under construction in 2022, and a third system designed by Waterworks Engineers for the City of Redding, California, under construction in 2022. A fourth system will be installed in the Mid-Atlantic area in 2023.

HIGHLIGHT PROJECT

In 2017, the first full-scale operational biosolids pyrolysis installation in North America began operation at Silicon Valley Clean Water in Redwood City, California. This pyrolysis system, rated for 3,000 wet tons per year at 20% solids with an output of 250 tons per year of OurCarbon™ biochar, is comprised of three BioDryers and one P-FIVE pyrolyzer. This system received an SSI Exemption from the EPA and is permitted to operate in the Bay Area Air Quality Management District, one of the most stringent in the U.S.

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Ecoremedy

Gasification

Global head office: Pittsburgh, Pennsylvania

With more than 30 years of experience, Ecoremedy LLC is dedicated to its Fluid Lift Gasification (FLG) system for converting dewatered biosolids, animal manure, and other waste feedstocks to renewable energy and beneficial products. The innovative FLG system allows operators to make real-time adjustments to the gasifier to optimize the balance between energy and biochar: target carbon content can range from 1% (maximum mass reduction and maximum energy recovery) to more than 50% (maximum biochar production and minimum energy recovery beyond drying).

TECHNOLOGY FEATURES

A unique feature of Ecoremedy's process is that the gasifier receives blended biosolids (+/- 60% TS) instead of greater than 90% TS biosolids. The dryer is highly integrated into the process, following the gasifier rather than proceeding it. The oxidizer operates at over 1,090°C (2,000°F) to achieve complete combustion of syngas and

a high level of pollutant destruction. As an added benefit for WRRFs, the gasifier can operate on grit and screenings mixed with the dewatered biosolids. All energy to sustain the process is recovered from the biosolids without the need for supplemental fuels, even if the biosolids are digested. FLG has the flexibility to balance thermal energy recovery by various means with resource recovery in the form of >90% TS granular Class A biosolids or FlexChar™ biochar with selectable carbon content (low to high as required). The FLG has been determined by the EPA to prevent sewage sludge combustion and therefore is not an incinerator. Ecoremedy is part of WEF's LIFT Technology Scan program.

TECHNOLOGY STATUS

FLG has been commercially available since 2001 to the agricultural, renewable natural gas (RNG), municipal biosolids, wood waste, green waste, and industrial sectors. Ecoremedy has completed two biosolids projects (Morrisville, Pennsylvania, 25,000 wet tons per year full-scale pilot and Edmonds, Washington, currently under construction discussed below) as well as four facilities with other feedstocks (manure and wood waste).

HIGHLIGHT PROJECT

Ecoremedy is honored to provide a 14,250 wet tons per year Fluid Lift Gasifier to the City of Edmonds, Washington, for biosolids, grit, and screenings under its Carbon Recovery Project. Ameresco is providing an energy service contract for the replacement of the city's sludge incinerator which was past its service life, unreliable and high operating cost. Ecoremedy's FLG was selected in part because it fits within the existing incinerator building and provides a more sustainable solution that provides carbon recovery through FlexChar™. Reduced electricity consumption will save ratepayers an estimated $341,000 USD per year. The incinerator was demolished in 2021 and the FLG is being installed in 2022.

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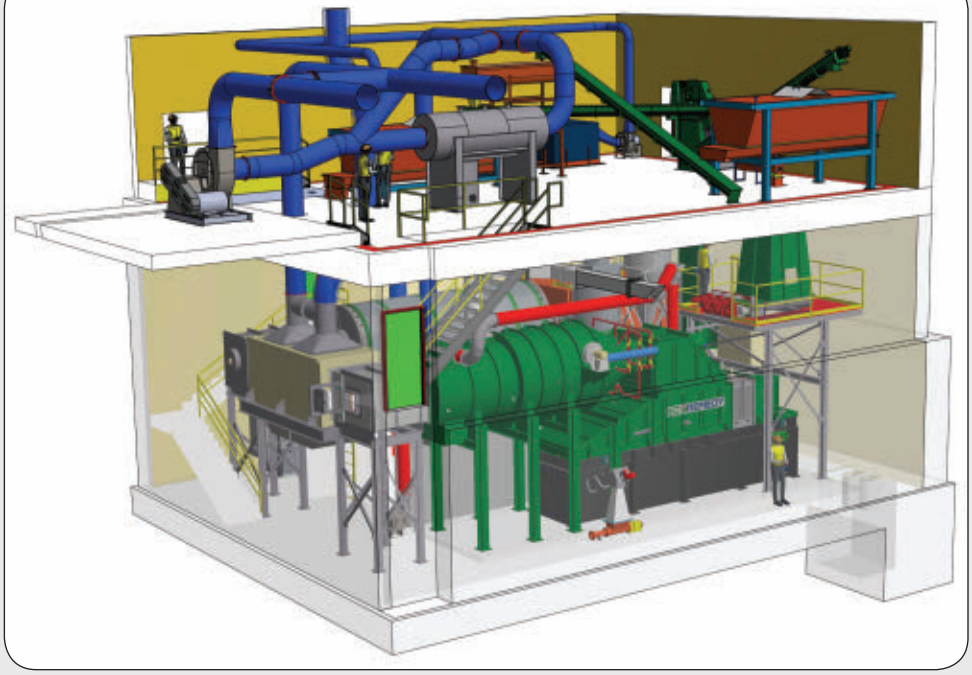


Nuisance Odors:

No Longer Such a Mystery

Philadelphia's experience with odor monitoring advancements

Gary A. Burlingame and
Xianhao Cheng

The Philadelphia Water Department (PWD) has a water resource recovery facility (WRRF) that borders directly on a residential, urban neighborhood. From the 1970s and into the 1980s, the WRRF upgraded to secondary activated sludge treatment with rotating biological contactors followed by final settling, as well as anaerobic digestion followed by conversion to biosolids. During this time, the WRRF was odorous but so was the neighborhood, which consisted of a multitude of commercial and industrial sources of odors. By the later part of the 1980s, many neighborhood sources of odors had closed down for one reason or another. Yet the community remained, and residents adjacent to the fence line complained about nuisance odors from the WRRF.

A local community organization representing 135 residents filed a civil action against the City of Philadelphia in U.S. District Court for Eastern Pennsylvania concerning the nuisance odors. In 1986, a court order required the city to hire experts to conduct an independent evaluation of the odor conditions and identify potential controls. The evaluation identified several sources of offsite odors. Obvious conditions that promoted the release of nuisance odors were identified, such as the accumulation of scum in open-air troughs in the primary tanks; lower-than-reported dissolved oxygen conditions throughout the activated sludge process; and the escape of anaerobic digester gas. PWD responded with a plan of action for more

Aeration in the activated sludge, secondary treatment process released DMS to the air. Courtesy Bureau of Laboratory Services/ Philadelphia Water Department

DMS was sampled throughout the WRRF processes. Courtesy Bureau of Laboratory Services/Philadelphia Water Department

than 100 remedial measures that were ultimately completed.

Beginning in 1988, an expert in nuisance odor evaluations along with treatment chemical manufacturers and suppliers assisted in developing a more thorough odor control plan. This expert conducted odor surveys and olfactometry measurements and to assessed controls. The traditional technique that involved measuring hydrogen sulfide emissions and dissolved sulfide in wastewater as indicators of the conditions that would produce nuisance odors was not addressing the issues. The consultant was asked to take a broader look at the situation. The novel application of analytical methods for detecting and monitoring the chemicals that cause nuisance odors required the specialized services of experts who could employ such odor assessment tools and procedures.

In 1994, the community's attorney reported to the federal judge that the odor problem had more or less disappeared, and PWD had met all of its obligations. However, in 2002, PWD reinitiated an internal Odor Control Committee to develop strategies for mitigation because some nuisance odors were still being reported and these nuisance odors were now part of PWD's Title 5 Air Pollution Control permit. A renewed attack on the nuisance odor problem began in 2003 with the help of odor control experts.

The Pennsylvania Code Title 25, Chapter 123.31 and the City's Air Management Code Chapter 3-200, section 3-201(a)(3) stated, "A person may not permit the emission into the outdoor atmosphere of any malodorous air contaminants from any source, in such a manner that the malodors are detectable outside the property of the person on whose land the source is being operated." The City of Philadelphia Department of Public Health's Air Management Services (AMS) maintains authority under Pennsylvania's Air Pollution Control Act. AMS issued Notices of Violation for detecting odors beyond the WRRF's property line, which resulted in a new Administrative Order and Consent Agreement between AMS and PWD.

Understanding Nuisance Odors

During the 1980s, PWD developed a successful taste and odor control program for its drinking water using flavor profile analysis and had trained experts in sensory analysis. PWD applied these resources to help with the evaluation of odors at the WRRF to better understand the situation using in-house expertise. This led to collaboration with other researchers internationally to develop an odor quality classification scheme along with an odor survey procedure for characterizing odor sources at WRRFs. It was a challenge to move from evaluating odors over water contained within a flask to evaluating odors outdoors in the open atmosphere.

During the early 1990s, PWD routinely began monitoring for odors that crossed the fence line of the WRRF. Odors were profiled downwind of the various processes within the facility, and hydrogen sulfide readings were collected using a portable hydrogen sulfide gas analyzer. However, hydrogen sulfide odors were not crossing the fence line. One of the most problematic odor sources did not have high hydrogen sulfide levels being released to the atmosphere. Wastewater contains a mix of sulfur-based and nitrogen-based chemistries that come from the natural decay of proteins and amino acids. These volatile organic chemicals, after they escape into the air from the treatment processes, change and dissipate as they cross the fence line. Some will dilute out more quickly than others. Therefore, characterizing the odors at the sources of emissions can be misleading for predicting odors downwind in the community.

Because odor profiling identified that hydrogen sulfide was not indicative of nuisance odors crossing the fence line, efforts were made to identify other volatile organic chemicals. Work that had been done on drinking water sources of odors showed that, for example, decaying vegetation produces a mix of organic sulfides (such as dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide) and wastewater contains these plus others (such as carbon disulfide, allyl mercaptan, methyl mercaptan, ethyl mercaptan, etc.). These volatile organic chemicals were not being measured because, at the time, the sample collection and laboratory testing technology was not widely available. In addition to the organic sulfides, such compounds as

n-butylamine, ethylamine, dibutylamine, ammonia, diisopropylamine, methylamine, trimethylamine, skatole, and indole could also occur. This complex makeup of wastewater odors, and the sulfur-based and nitrogen-based chemistry required a different approach.

The analytical instruments that were needed to detect and identify the low-level volatile organics in wastewater and in the atmospheric emissions from wastewater were the gas chromatograph (GC) and the mass spectrometer (MS). During the 1950s, scientists at Dow Chemical demonstrated how GC and MS could be combined to separate molecules in a mixture and identify the components. This led to the production of GC-MS equipment, which became affordable and available to environmental chemistry researchers during the 1970s, along with the development of mass spectra libraries. This analytical methodology was operated by highly trained chemists who could interpret chromatograms, operate the equipment, and make their own separation columns. Today, the GC-MS is a standard instrument that most chemists learn to operate in environmental, organic chemistry laboratories. In addition to developing the analytical methods, there was a need to develop methods for sampling organic chemicals in air instead of in wastewater; organic chemicals that are not very stable at very low levels. These sampling techniques advanced quite steadily during the 1990s.

During the late 1980s and into the 1990s, research on volatile organic chemicals in various natural media identified a variety of organic sulfides. Into the early 2000s, literature greatly increased on studies detecting organic sulfides in various environments. Literature about wastewater volatile organic chemicals and odorous emissions became numerous during this time. Therefore, at the same time that PWD odor surveys were determining that the characteristics of the nuisance odors were more complex than hydrogen sulfide, the science was moving forward in understanding how volatile organic sulfides play an important role and how these could be sampled and analyzed at WRRFs.

DMS can have an odor similar to that of canned corn. Courtesy Bureau of Laboratory Services/ Philadelphia Water Department

Identifying Dimethyl Sulfide

Downwind of the WRRF, under atmospheric conditions that promoted odorous emissions to stay low to the ground and travel into the community, PWD's odor survey team identified an odor that

Analytical methods for trace organics in wastewater have greatly advanced since the 1970s. Courtesy Bureau of Laboratory Services/ Philadelphia Water Department

Odor surveys were conducted downwind of the processes and the WRRF. Courtesy Bureau of Laboratory Services/Philadelphia Water Department

was not occurring at other WRRFs. The odor was described as being like one that comes from opening a can of corn. This odor was able to travel for a mile or more into the community under certain atmospheric conditions. It was not present all of the time.

The approach to determining the cause of the canned corn odor came from PWD's research to identify the source of a cucumber odor in drinking water. The causative chemical was found by referring to agricultural and food literature on flavor chemicals. A chemical standard of *trans 2-cis* 6-nonadienal, which is found in cucumbers, was found to be a very good match for the odor that was causing customer complaints about the drinking water. Following this identification, the analytical GC/MS method was applied by PWD's Organics Analysis Laboratory to confirm that nonadienal was present in the cucumber-smelling water of a supply reservoir, thus confirming that this chemical was the cause. Therefore, this same approach was used to identify the chemical cause of the canned-corn odor at the WRRF. Standards for the various organic sulfide chemicals expected to be found in wastewater were obtained and smelled. Dimethyl sulfide was found to have an odor very similar to the odor coming from the WRRF.

Dimethyl sulfide (DMS) can travel long distances in the atmosphere, as it is part of the odor of the seashore, which has been known since the early 1980s. DMS is important in the cycling of sulfur in the oceans. DMS also is found in foods and beverages, such as beer and wine. In fact, DMS can be used to enhance the flavor of canned corn as it has been known since the 1960s to be an important flavorant in heated corn. In wastewater, DMS would be expected to be found as part of a mixture of organic sulfides. Here, at this WRRF, it appeared to stand out. The next step was to confirm its presence in the wastewater and correlate it to the canned corn odor crossing the fence line. PWD's laboratory focused on its detection in the wastewater.

PWD employed odor experts and researchers to help study DMS formation in Philadelphia's WRRF. The studies showed DMS formation was proceeding by at least two routes. First, it was occurring by the typical, slower route of protein breakdown and formation of sulfur compounds such as hydrogen sulfide, DMS, dimethyl disulfide, and methyl mercaptan that occurs every day. Second, a faster and more predominant reaction was taking place with a compound in the influent waste stream that was not always present but when placed under biological reducing conditions, formed DMS.

PWD's Organics Analysis Laboratory took on the challenge to employ a laboratory method for determining the concentration and presence of DMS in wastewater, which led to monitoring the treatment processes and incoming waste stream. DMS was found to vary in the wastewater and to be at higher levels than would be expected compared to other organic sulfides. DMS was shown to carry into the secondary wastewater treatment process wherein aeration resulted in significant emissions and the release of DMS such that it would travel out into the community and be noticed by residents.

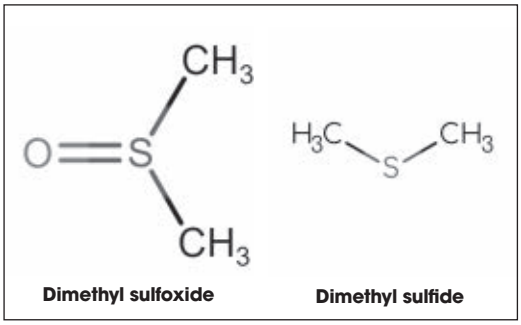
Odor control experts developed atmospheric dispersion models and odor mapping, using air emission rates and odor strengths, to predict downwind occurrences of odors by which to prioritize source emissions. Hydrogen sulfide concentrations and dilution factors were the usual way to prioritize odor nuisance emission sources. However, when DMS was substituted for hydrogen sulfide in the model, the prioritization of odor sources changed significantly. The secondary activated sludge process, which was aerated, though lower in odor strength for its emissions, covered a wider area, which led to a much higher total air emission rate, which made it the major source of DMS in the community. PWD's odor survey team, over 2 years, detected 14 common odor descriptions downwind of this process, and, at the source, the process typically smelled oniony, decaying vegetation-like, and earthy. DMS was hidden within the stronger odors but it became the more persistent odor out in the community.

Identifying DMSO as the Precursor for DMS

A review of permitted wastewater dischargers that handled sulfur-based chemicals revealed that one discharger, not far from the WRRF, used dimethyl sulfoxide (DMSO) in its industrial process. DMSO is a common solvent, widely used, and is not an odor problem by itself. DMSO is used by the semiconductor, pharmaceutical, refinery, paint, coatings, and solvent sectors. It is very soluble in water, thus making its way into the WRRF where, under low oxygen, biological conditions it is changed to DMS. After its discharge to the sewer, it converts to DMS under anaerobic conditions with the help of DMSO reductase, which removes the oxygen double bonded to the sulfur (see figure).

The Organics Analysis Laboratory adapted a method to monitor for DMSO in the wastewater. Achieving satisfactory reproducibility using published analytical techniques was a challenge. For one reason, the complicated matrix of wastewater made the separation and concentration of low levels of DMSO more difficult to obtain. With reconditioned purging equipment and perdeuterated DMSO as an internal standard, the laboratory achieved a reproducible detection limit. Optimizing the analytical method further achieved good precision with recoveries between 95% and 105% at a level as low as 2 µg/mL. The method was then used to look for DMSO in Philadelphia's three WRRF influents. The two WRRFs without the canned corn odor had no detectable DMSO, but it was detected as high as 12 mg/L when the industrial discharger was releasing it to the WRRF that had the nuisance odor problem. The DMSO began converting to DMS in the collection system even before the WRRF and continued its conversion under reducing conditions within the WRRF. Working with the industrial discharger, controls were applied to minimize the discharge of DMSO to the sewer. This alleviated the decades-long, canned-corn odor nuisance caused by DMS.

Chemical Structure of DMSO Compared to DMS



Review

It took two decades of study to mitigate a unique nuisance odor problem. The solution came with characterizing the odors crossing the WRRF's fence line followed by narrowing the odors down to the most problematic one, identifying the odor's chemical cause, then identifying the source and resolving the problem. A good part of the delay was due to the lack of technologies and methods to identify odorous chemicals, other than hydrogen sulfide. Since the 1990s, however, research and applications have greatly advanced the understanding of the variety of odorous chemicals found in wastewater and biosolids. This was possible through the application of both sensory and analytical chemistry methods used for water and wastewater. For example, between 2003 and 2015, seven projects were completed under the Water Environment Research Foundation (now The Water Research Foundation) on odorous emissions monitoring and control for wastewater and biosolids. Today, odor control and odor characterization address a variety of volatile organic chemicals in addition to the sulfur-based chemicals that are typically found in sewer systems and WRRFs.

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PART TWO

Passing the Sniff Test

Common odor and corrosion control misconceptions corrected

Rob Gaylord, Mark Smith, David McEwen, Laura Woodbury, Milton Rodriguez, and Jason Parrillo

Odor and corrosion control have become more than buzzwords in wastewater utilities. Around the sector, specialized odor and corrosion groups within wastewater utilities have become ubiquitous. These groups have affected management programs, regulatory compliance, capital planning, development requirements, and daily operations. Increasing interest in nearly all facets of odor and corrosion control have led to several myths and misconceptions about correctly identifying, assessing, and applying cost-effective methods that address odor and corrosion control in varying functions.

There are 10 common myths encountered during odor and corrosion projects from around the country. Those myths are debunked in this two-part series. The first part appeared in the February 2022 issue of *WE&T*.

Myth 6: The location of the odor complaint and the location of the cause of the odor are the same.

Busting Myth 6. When odor complaints occur, the information is typically tracked at the specific complaint location. Projects often become exercises in futility when utilities focus their analysis solely on odor complaint locations, when the problem could very well be caused elsewhere in the collection system. Addressing the odor at the complaint location can sometimes result in a successful localized solution to the problem. However, the reality is that the causes of collection system odor complaints can and often do lie in areas of the collection system far from where the complaint is called in. This is analogous to treating the disease rather than solely focusing treating the symptoms.

Some examples of where the cause of odors is not in the same location as the complaint include:

- A headspace constriction in a sanitary sewer that causes a back pressurization effect in the upstream reaches of the collection system (the problem is downstream of where the odorous air exits).
- Long force mains with long detention times that generate high liquid-phase sulfide concentrations (the problem is developing throughout the entire force main length and not just at the point of odor escape).

- Wet wells that have long periods between pump starts (sulfide accumulates at the pump station upstream of where odors escape).
- High-strength side-stream discharge contributions, such as from an industrial or commercial facility, that make the environment more conducive to sulfate reducing bacteria (SRB) proliferation (an upstream change in water quality parameters, such as pH or biochemical oxygen demand, results in increased liquid-phase sulfide accumulation and associated odor emissions further downstream).

Myth 7: 1+1 = 2... The solution to an odor problem will either be a liquid-phase or a vapor-phase approach, but not both.

Busting Myth 7. Depending on conditions, sometimes the most cost-effective approach to solving an odor problem in a sanitary sewer system is incorporation of both a liquid-phase treatment technology (often chemical addition at an upstream pump station) and a vapor-phase approach (often headspace air extraction from a downstream gravity line or pump station). Individual elements and pipe segments in problem areas of a collection system that carry common flows should be studied both independent of one another and collectively to determine the most cost-effective treatment solutions. There are cases where both types of odor control have used to, for example, both protect a gravity sewer from corrosion and reduce downstream odor emissions or reduce stress on a vapor-phase odor control unit. The combination of liquid- and vapor-phase technologies provides greater overall effectiveness than either solution incorporated on its own (1+1>2).

Myth 8: Odor and corrosion chemical dosing controls are well-established.

Busting Myth 8. Sulfide generation patterns often have a diurnal signature in a wastewater collection system, which means that higher liquid-phase sulfide quantities can be generated at different times of the day (and night). Because of this, the most cost-effective approach to chemical treatment would be to pace the chemical dose rates to match the diurnal sulfide generation patterns, so that the system is neither under-dosed (potentially causing odor emissions) or over-dosed (wasting chemical and increasing cost).

Chemical dosing variations using a wastewater flow-pacing algorithm can be effective to some extent in collection systems where there are large flow increases over the course of the day and/or with multiple large side-streams, which imparts large sulfide increases in the wastewater that must be matched with increasing chemical dose rates. However, in many collection systems, the inverse is true. *Lower* wastewater flow rates (such as during overnight hours) can result in higher sulfide accumulation because the wastewater detention time has increased, and anaerobic conditions have been created. In these cases, wastewater flow-pacing alone is insufficient for chemical dosing, and under-dosing may result. This can cause issues both with odor emissions and corrosion potential.

Alternatively, a chemical dosing control system can be set based on the sulfide concentration, rather than the wastewater flow. However, this requires liquid-phase sulfide concentration measurements in real time, which is expensive, difficult, and potentially inaccurate due to interferences in the wastewater, such as solids deposition on probes. Chromatography, electrochemical microsensors, spectrophotometry instruments, or a combination of the above would be required to flow pace, as well as programable logic controllers and supervisory control and data access integration. However, these devices and sensors are prone to performance disturbances due to the wastewater contents and are sensitive to varying conditions, requiring frequent calibration.

Measured vapor-phase hydrogen sulfide measurements can be converted into liquid sulfide concentrations to attempt to dial in chemical

10 Odor & Corrosion Control Myths

Odor and corrosion control specialists frequently encounter these misconceptions in the industry:

1. Odor and corrosion control are the same thing.
2. We only need to address vapor-phase hydrogen sulfide.
3. We know everything about odor and corrosion control.
4. Odor complaints and hydrogen sulfide concentrations have a direct correlation.
5. The performances of chemical addition and innovative odor control technologies are predictable.
6. Location of odor complaint and location of the cause of the odor is the same.
7. 1+1 = 2: The solution to an odor problem will either be a liquid-phase OR a vapor-phase approach, but not both.
8. Odor and corrosion chemical dosing controls are well-established.
9. The simplest and quickest odor control solutions are the best choices.
10. Future collection system odor release locations cannot be predicted.

dose rates; however, there are many variables (ventilation, stripping, pH, unknown substances, etc.) that make this conversion challenging. While hydrogen sulfide data loggers can be effective at setting chemical dosing *locations* and approximate dose ranges, daily and even hourly modifications using these loggers can be difficult.

Simpler operational modes attempt to accomplish a more efficient chemical dosing schedule. When liquid-phase sulfide concentrations consistently peak around the same time every day (or in a recognizable pattern), a higher dosing rate can be programmed by a timer to coincide with the travel time between the dosing point and where the sulfide peak is measured. The same concept is then implemented during periods when low liquid-phase sulfide concentrations commonly occur (or in a recognizable pattern) by programming a lower chemical dosing rate using a timer. This method is typically an iterative approach, in which dosing rates and vapor-phase hydrogen sulfide response is observed over time, with tweaks to the system made until an acceptable level of service is achieved. Currently, this is the most economical and reliable method for optimizing odor and corrosion control chemical dosing patterns.

Myth 9: The simplest and quickest odor control solutions are the best choices.

Busting Myth 9. Odor control programs may utilize a "one-size-fits-all" approach, where a single technology (for example activated carbon adsorption) is implemented at all odor complaint locations. This may be done to be cost-effective, to streamline the project schedule, or so that the utility works with only one vendor. This may be deemed necessary because engineering costs for odor and corrosion control designs often exceed the 10% engineering design/10% construction fees (as a function of construction dollars) that is typical to the industry. However, more times than not, odor and corrosion projects are most effective when they are custom-tailored for a specific application, which varies with each utility and each collection system location.

For example, for a collection system interceptor that accumulates a moderate amount of sulfide and releases relatively low hydrogen sulfide at a downstream lift station where there is a neighbor in the adjacent lot who is prone to complain, a carbon adsorber may be the most cost-effective solution. However, another interceptor in the same collection system may generate very high sulfides and release high amounts of hydrogen sulfide at its downstream lift station. In this case, the same carbon adsorber may be overwhelmed by the high hydrogen sulfide concentrations, which would result in undesirably frequent (and costly) carbon replacement and occasional impactful odor breakthrough. Such an interceptor may be better suited for a two-stage odor control system at the lift station and/or an upstream chemical injection system.

Additionally, some simple and quick solutions to odor and corrosion problems are reactionary to failed infrastructure, immediate needs, or repeated complaints from residents who want immediate relief. Short-term solutions to achieve the "quick fix" may be effective in achieving immediate goals, but in the long-term, these solutions may not be sustainable or budget friendly. Short-term solutions to an uptick in odor complaints may include increasing the upstream chemical dosing rate or installing a skid-mounted chemical dosing system to enhance the existing liquid-phase treatment system. This type of approach may be accomplished under a utility's maintenance budget, which would result in high operational costs, but the solution is easier to procure. Such a solution may be appropriate until a long-term solution can be decided upon and implemented. However, when the short-term solution is not replaced by a more effective long-term solution, the result can be unnecessary increases in yearly maintenance budgets, which could reduce funding for other utility projects.

Myth 10: Future collection system odor release locations cannot be predicted.

Busting Myth 10. Through innovative analytical techniques that have been implemented and refined over the last 25 years, locations of future odor release from a collection system can in fact be predicted with impressive accuracy. These tools allow for utilities to proactively identify and design odor control solutions to such issues when new sanitary sewer pipes are in the design stage. This saves the utility time and money that is not spent responding to odor complaints and correcting odor emissions issues that were created by the addition of new sewer pipe connections and other related appurtenances.

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What Every Operator Should Know About Biosolids Land Application

Jeanette Klamm

Knowledge	Principles	Practical Considerations
Regulations	• Title 40, Code of Federal Register, Part 503 • Possible state and local regulations	Land application of biosolids is regulated through Title 40 of the Federal Register Part 503, which was adopted in 1993. Support documents are available for further guidance at https://bit.ly/EPA-Part503. Some state and local jurisdictions also have regulations that may be more stringent than federal regulations.
Definition	Biosolids	Biosolids are primarily sewage sludge from wastewater treatment processes that have been processed to meet Part 503 regulations. They are mostly organic matter and nutrients. Sewage sludge is unprocessed, unstabilized, and generally unsuitable for reuse via land application. The term *biosolids* was established after the Part 503 regulations were passed, so 40 CRF Part 503 uses the term sewage sludge. Some guidance uses the term *biosolids* and recognizes the difference. It is important to make sure that the term *biosolids* is only applied to sludge that has been properly processed.
Biosolids quality	Part 503 regulations and guidance define the acceptable levels of metals allowed in biosolids. Pathogen reduction requirements and vector attraction reduction options (stabilization) are also defined in the 503 regulations.	Pollutant limits are defined for arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. A successful pretreatment program can help to decrease the metals concentrations to below regulatory limits. However, operators should always verify compliance with pollutant limits. Any biosolids that are applied to the land must meet the ceiling limits at minimum. Pathogen reduction requirements are classified as either Class A or B, depending on the treatment process used. Any biosolids that are applied to the land must meet a minimum of Class B treatment processes or criteria and must also adhere to the management practices to protect public health. The vector attraction reduction options are required to minimize odors during transport and land application activities and helps to minimize public complaints.
Management practices	Biosolids that meet the criteria to be considered Class B pathogen must also follow specific management practices and site restrictions. Class A biosolids are exempted from the management practices.	Class B biosolids: • cannot be applied to flooded, frozen, or snow-covered ground in such a way that the biosolids enter a wetland or other waterway considered a Water of the United States; • must stay at least 10 m (33 ft) away from Waters of the United States; • must be applied at the agronomic rate; and • must not harm or contribute to the harm of threatened or endangered species.

Knowledge	Principles	Practical Considerations
Agronomic application rates	Biosolids application rates must not exceed the amount of available nitrogen that the crop being grown needs. Although phosphorus is not limited by regulatory requirements, the amount of phosphorus provided by biosolids is an important number for farmers to know.	Available nitrogen is calculated to determine the pounds of nitrogen per dry ton of biosolids. To determine the application rate, the value is converted to wet tons or gallons per acre, based on the fertilizer recommendations for the target crop. Calculations are available in the Part 503 guidance to help with determining the correct amount. Application equipment is then calibrated to apply the correct amount of biosolids to the field.
Monitoring	Part 503 regulations (and generally state regulations, if they exist), outline the monitoring frequencies, parameters, and laboratory methods required.	Testing is required for the metals listed above. To verify nutrient values and to complete the application rate calculations, the nutrients tested generally include total Kjeldahl nitrogen, ammonia nitrogen, and phosphorus. To determine the moisture content of the biosolids, a percent total solids test is completed. Additional pathogen reduction may be necessary for Class A biosolids. Frequency of testing is determined by the amount of biosolids used in that year and may occur 1, 4, 6, or 12 times per year.
Reporting	Reporting must be completed annually. Major components of the annual report include: • project description and summary including amount of biosolids land applied; • site descriptions of where the biosolids were applied (including maps of the sites); • management practice compliance; • pathogen reduction and site restriction compliance; • vector attraction reduction compliance; • agronomic rate calculations; • pollutant metals concentrations; • cumulative pollutant loading; and • notice and necessary information, lab analysis results, and soil analysis results.	The *preparer* of the biosolids must submit an annual report to the U.S. Environmental Protection Agency for the previous year no later than February 19. In states that have primacy for biosolids regulations, the report may go to the state regulatory agency or to both the state and federal regulatory agencies. The preparer must certify that all regulatory requirements have been met. In the case where a contract *applier* has completed some of the requirements, it is important that the preparer verify that the applier has met all the requirements. Ultimately, the preparer or biosolids generator is responsible for meeting all of the requirements, even if they contract out some of the services. Federal regulations require that the records be kept for 5 years and may be requested for review at any time by the permitting or enforcement authority. State regulations may require records be kept for a longer duration.
Communication/ public education/ outreach	Public outreach and notification of neighbors can help avoid public opposition.	News releases to focus on program successes, public outreach programs into the neighboring areas around land application sites, and other means of public education can be the greatest asset for any land application program. The more that people know about wastewater treatment and land application processes, the better understanding and less opposition they will have to the practice based on hearsay and assumption.

Jeanette Klamm *has 30 years of experience in land application of residuals and biosolids and more than 25 years of experience in water and wastewater operations & maintenance and utilities management.*

What Happens With Biosolids in the U.S.?

Ned Beecher

Answering the title question has always been hard. It is complicated.

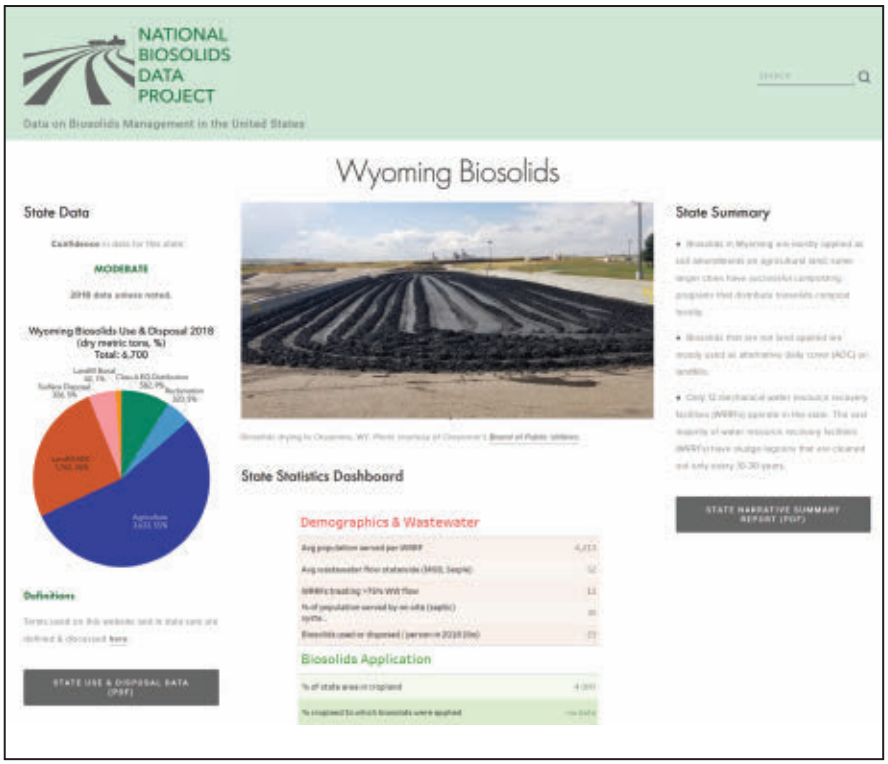
The National Biosolids Data Project (NBDP), first conducted on 2004 data, seeks to provide a comprehensive representation. Now, there is a new data set, compiling 2018 data, that you can take advantage of to help answer questions, benchmark your practices, and have some fun.

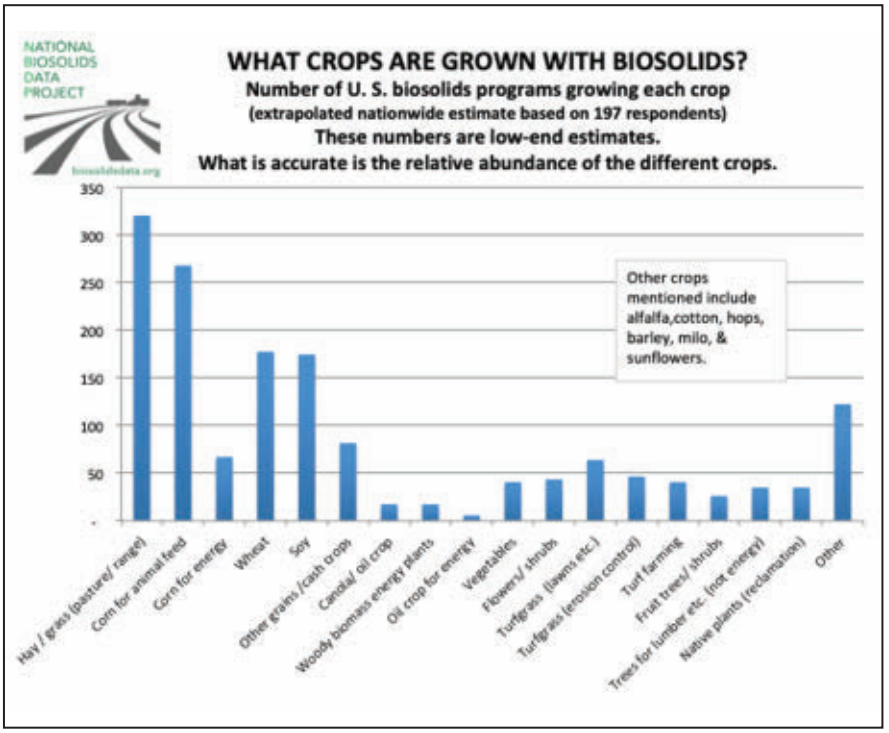
Data Collection and Complexity

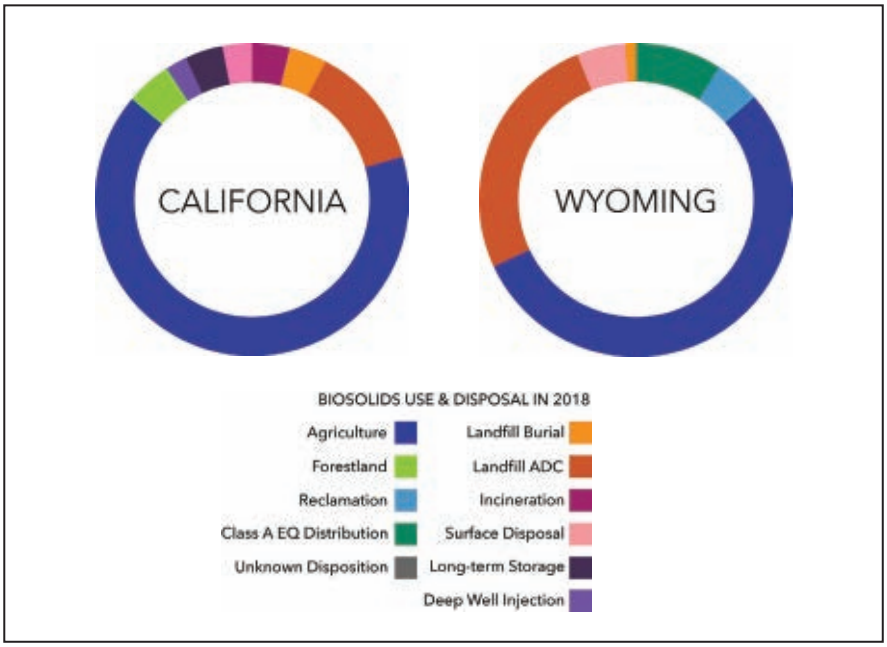
Compiling these data into comparable and contrastable format is no easy task. To start, the NBDP counts solids as they leave the gate of a water resource recovery facility (WRRF). In many cases, that's when the WRRF is paying someone, or filling their own truckloads, and are tracking what goes out.

But even this mode of counting has complexity. What happens if the trucks are just going to another WRRF for processing, where it becomes part of other truckloads leaving that facility? How is double-counting avoided? And then, if you want to know how much of a state's solids went to land application versus landfill, who counts those numbers and how?

That's where state biosolids coordinators come in. Most states — with U.S. Environmental Protection Agency (EPA) involvement, too — have regulatory programs for solids management. Sometimes these are part of National Pollutant Discharge Elimination System permits. Some states require regular reporting and have excellent data. Others don't. Some focus mostly on biosolids land applied and ignore landfill disposal. Others might rely on the solid waste branch of the regulatory agency for numbers regarding landfilled solids. These reports often lump together all "sludges," making it impossible to separate municipal from industrial.







EPA's data from the Part 503 program also exists from its inception in 1993; but, up until 2018, those are all in paper form. This makes them pretty much inaccessible. The new required electronic reporting has begun to create data sets of varied quality from state to state. But these data focus more on land application; landfilled solids often end up in the catch-all "other management" category.

New U.S. Nationwide Data

Over the past 2 years, the NBDP compiled and analyzed data for every U.S. state and territory. A separate online survey collected input from more than 450 major and minor WRRFs to provide a robust, representative sampling of biosolids management, with perspectives on technologies, trends, energy, and some of the economics.

These data are compiled into national tables and charts to paint the most detailed picture of what we, as a nation, do with our wastewater residuals. You can find all these analyses and summaries as well as the raw data to dig deeper yourself.

For example, have you ever wondered which crops are most commonly being grown with biosolids? Hay and grasses for pastures. (See the figure at the bottom of p. 56 for the entire story.) And how about how much final processed solids or biosolids we produce in the U.S. per capita? Find this factoid on the new website.

State Snapshots

Each state, district, and territory also has its own summary page broken into three columns. The first column shows a set of graphs and link to download a spreadsheet (PDF) with all the numbers. The second column provides a dashboard of key statistics. The third column presents a narrative summary that tells the story of what happens with solids in that state.

Seek Your Data

To get started, visit www.biosolidsdata.org.

Ned Beecher is Special Projects Manager at the North East Biosolids and Residuals Association (Tamworth, New Hampshire). He can be reached at ned.beecher@nebiosolids.org.

Thanks to U.S. EPA Region 4 for a grant to support the literature review and methodology for the 2018 NBDP as well as the National Association of Clean Water Agencies (NACWA; Washington, D.C.) and the Water Environment Federation (WEF; Alexandria, Virginia), and stakeholders nationwide who supported the collection, compilation, analysis, and publishing of the data.

Finding Cost Savings for Thames Water Blowers

New monitoring study shows big blower savings for United Kingdom's largest water and wastewater company

Problem: Thames Water has seven blowers operating at different sizes and delivering variable flow rates.

Solution: A weeklong test and analysis of the blowers revealed Thames Water could save as much as £107,000 (about $142,500 USD) with refurbishment and up to £111,000 (about $147,800 USD) with equipment replacement.

Following a highly detailed study with its proven FFi4 monitoring equipment, optimization experts Riventa (Truro, United Kingdom) identified these potential annual savings for nine blowers that serve aeration lanes for the Thames Water in England.

During a weeklong exercise, the performance of each of the blowers was monitored using the thermodynamic technique, with measurements taken every 5 minutes.

Blower Setup

The Thames Wastewater Treatment Works operates in tandem with another site to handle typically 32 to 35 million L/d as it takes the residual load within the catchment. As a result, the facility experiences a broad operating range, for which the aeration requirements need significant flexibility in blower output.

The facility's 20 aeration lanes are served by seven centrifugal-type blowers, split into two different sizes, that serve a common header to supply air. (Two additional blowers were not operational during this testing.)

All seven operational units can deliver variable flows individually using their inlet guide vanes. They all supply a common header that provides air at 450 to 500 mbar to the 20 plug-flow aeration lanes.

Air flows to the lanes vary widely between 20,000 and 95,000 m^3/h — that is, 7 to 27 tonnes of oxygen per hour. This equates to a system turn-down of almost 5:1.

Results

During the measurement period, all the blowers operated across their ranges, producing the need for solo operation to all seven blowers in parallel.

For 59% of the time, the blowers operated at more than 73% efficiency. The rest of the time was spent at efficiencies below 72%. This time included operation during disruptive periods when there were planned changeovers from grid power supply to onsite generation. This showed that the site's control of the process was relatively robust, with limited effect on overall average aeration performance.

The blowers overcame the differential pressure to deliver the desired flow of air to the aeration lanes. The height of the fluid above the diffuser heads led to frictional losses in the delivery pipework and diffuser head arrangement; static pressure played a role, too.

In this case, the full range of all the blowers was needed to provide a good relationship for the system pressure requirements for any flow. A static pressure of 445 mbar translated to an effective level in the lanes of 4.5 m above the diffuser heads, and approximately 512 mbar required at the maximum flowrate (90,000 m^3/h).

It was important to note that this system characteristic also encompasses all leakages and blockages — and any partially closed valves. It was known that a proportion of the diffuser heads had been identified for replacement. Greater oxygen transfer efficiency should occur with larger area of interface between air and liquor, reducing air demand per unit of biochemical oxygen demand. The control valves would operate more within their optimum operating ranges (usually 30% to 70% open).

As inlet guide vanes were closed, there was some sacrifice to efficiency. However, Blowers 1 and 2 could both achieve 80% efficiency — and so it is fair to expect that the other blowers, of the same manufacturer and type, should be able to achieve the same performance, through remedial works.

The electrical power for each unit of air or oxygen supplied to the aeration lanes had an average requirement of 0.018 kWh/m^3, which is equivalent to £6.81 per tonne of oxygen.

As air demand increases, so does the cost of oxygen supplied. Moving from the average flow of 18.5 tonnes of oxygen per hour at 62 kWh/T_{O2} to the most common operating conditions with six or seven blowers operating (22 tonnes of oxygen per hour), equated to an increase in specific power of 3.2%.

With clean lanes and new diffuser heads, the mass of oxygen needed should decline (for the same average biological load) as the oxygen transfer rate (OTR) increases through better bubble formation and distribution. It should be noted that OTR was related to the area of the interface between the liquid and the air. Smaller bubbles in greater density would address this.

Add Flowmeters, Address Valves

There are no flowmeters on Blowers 1, 2, and 3, but they are operating close to 13,000 m^3/h each. Flowmeters should be added to measure the combined output of these three blowers. This would enable operators to develop key performance indicators for benchmarking.

For the full range of flows measured over the logging period, using a variable speed drive throughout — instead of inlet guide vane control — would give Thames Water a potential saving of £20,000 ($27,500 USD) per year, a 1.8% savings.

When the diffuser heads have been replaced in each specific lane, the control valves need to be addressed. Twenty-nine of the 40 control valves operate outside the recommended 30% to 70% operational range — that is, not effectively — leading to greater than expected flows downstream, possibly due to burst diffusers or leaks. Replacement of the diffuser heads will remedy this — and greatly improve the control of lane-specific dissolved oxygen.

Looking at Savings

It is also noticeable that guide vanes are used where variable frequency drives could provide a similar effect. This change would only marginally affect isentropic efficiency, yet the blower shaft power would be substantially less.

For the full range of flows measured over the logging period, using a variable speed drive throughout — instead of inlet guide vane control — would give Thames Water a potential saving of £20,000 ($27,500 USD) per year, a 1.8% savings.

Given the additional costs surrounding 3.3-kV inverters, and the associated equipment, the costs to achieve this for Blowers 1, 2, and 3 could be prohibitive. However, blowers have a 250-kW rating, and generally demand an electrical load of no more than 230-kW. There could, therefore, be a comparison of 3,300-V inverter retrofit to 415-V electrical infrastructure replacement, making all equipment low voltage. This has advantages of its own: Safer operation, ease of spares, less cost to maintain, and lower capital cost.

Refurbishment Savings Analysis

The original equipment manufacturer's performance curves were not available. However, it is fair to assume that the same efficiency should be expected of all the blowers. Blowers 1 and 2 both achieved an average 80% to 81%, and both operated more than 95% of that time. If all the other blowers were able to achieve this same efficiency, Thames Water would see a total saving of £87,500 ($120,000 USD) per year.

Replacement Option

This system also includes a recently installed low-voltage, high-speed, turbo-type unit. At the time of this assessment, this unit was awaiting completion of final commissioning works and was not included in these figures. However, based on its rating, five such units could provide the air demand needed by the system, and require only 90% of the current energy used. This 10% savings on the current energy bill would equal £111,000 ($147,000 USD) per year.

PRODUCTS

Clamp-on Flowmeter

Endress+Hauser (Reinach, Switzerland)
▶ www.us.endress.com

1 The W 400 clamp-on and I 400 insertion units provide comprehensive process monitoring with long-term cost efficiency and extensive diagnostics. These sensors pair with Endress+Hauser's Proline 400 transmitter to provide a complete flow metering solution. They are suitable for low- or high-pressure applications, on pipes smaller than an inch in diameter, and up to 160 in., such as those encountered in water distribution. The flowmeter's IP68 Type 6P submergence-rated ultrasonic sensors provide long-term and reliable operation, requiring little maintenance. This makes them suitable for use in harsh process and ambient conditions, able to withstand temperatures from –40° to +266°F.

Continuous Jumpers

WAGO (Germantown, Wisconsin)
▶ www.wago.com

2 The TOPJOB S series of continuous jumpers have expanded with the introduction of new 3- and 5-way continuous jumpers. As with previous jumpers from WAGO, the TOPJOB S jumpers use an exclusive jumper retention spring designed into patented terminal blocks to ensure a vibration-proof connection. The jumpers provide additional options when circuit designs need to use the second row of jumper slots on other TOPJOB S terminal blocks for other purposes, such as testing. Combined with staggered jumpers, they are able to cover a wide variety of end-use commoning applications. Because of this flexibility, users can now continuously combine either adjacent or alternate jumpers (or both) in endless possibilities.

Fluid Equipment Training

AMETEK Spectro Scientific (Chelmsford, Massachusetts)
▶ www.spectrosci.com

3 The Fluid Management Academy is an online learning platform that offers customers a range of courses about Spectro Scientific's and Grabner Instruments' fluid analysis products. Academy users access 60- to 90-minute online courses that are taught and designed by subject matter experts. Customers can enroll in a series of learning modules covering instrument features, troubleshooting techniques, and instrument care. Each course is then followed by a short proof-of-concept exam. When a user completes a course and passes the exam, they receive a certificate of completion and a competency badge that is valid for three years.

Editor's note: *WE&T assumes no responsibility for claims made in product descriptions. Interested companies should send press releases and photos to prods@wef.org.*

AD INDEX

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WATER ENVIRONMENT & TECHNOLOGY
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OPERATIONS & ENGINEERING

Coming up in the May issue

Focusing on the Utility

Operating a utility requires keeping alert of a host of potential issues. The May issue will help you navigate some of the common pitfalls facing management. The issue packs a few surprises, too. Most notably, it will debut a special editorial section devoted to workforce issues. Additionally, WEF Past President Lynn Broaddus will offer a quick message. It is an exciting time to be in or joining the WEF community, and *WE&T* continues to highlight the great work being done.

3 Key Leadership Approaches

There are many types of leadership programs your organization can implement. Take a minute to review three that have been tested and labeled successful.

The Total Cost of Ownership

Major upgrades can lead to major financial headaches for facilities. Factoring the total cost of ownership into financing equations might be a necessary resolution.

Innovation & Collaboration

Water leakage reduction programs in the U.S. are getting a boost from collaboration. Utilities learn from one another how to maximize innovation and minimize losses from this common nuisance.

Resiliency & Sustainability

Winnemucca, Nevada, took a big step to stop using a lagoon for part of its operations. Instead, it took on a new treatment, disposal, and reuse program.

Also in this issue

- **Special Section.** Find out how to build a better workforce program to ensure knowledge transfer, sustainability, cybersecurity, and equity.
- **Small Talk.** Distributed, building-scale treatment systems can recover quickly by avoiding flood zones.

MARKETPLACE

MAINTENANCE ESSENTIALS

Effective maintenance programs are supported by operations and maintenance staff's knowledge and skill. Learning the underlying principles of equipment functionality aids in better decisions regarding time and resources for preventive and predictive maintenance activities. Additionally, it supports troubleshooting problems and brainstorming potential solutions.

Speed Reducers

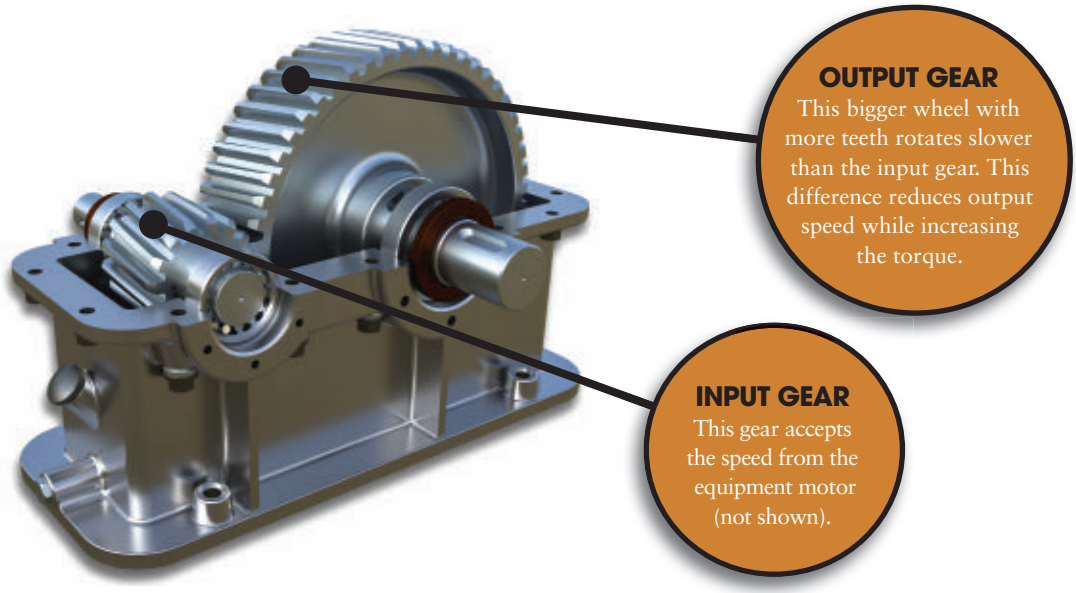
Speed reducers play important roles in water resource recovery facilities on equipment where slower speeds and higher torques are required. Some of their critical applications include clarifier solids collector mechanisms, influent screen rake mechanisms, conveyors, and belt filter presses.

BASICS

- Also called a gear reducer, this set of gears — installed between a motor and the equipment — reduces the speed from the motor and multiplies the torque proportional to the speed reduction, depending on the type of gears used.
- A single reduction gear (shown below) set can have 60:1 reduction ratio. A double-reduction gear set can have a reduction ratio up to 3600:1 (60 × 60 = 3600).
- Gear boxes are valuable because smaller motors can accomplish more work.

APPLICATION

- Important criteria to consider when choosing a speed reducer:
  - ❏ Horsepower requirements
  - ❏ Potential service factor requirements
  - ❏ Overload capacity
  - ❏ Torque capacities and limitations
  - ❏ Thermal horsepower requirements
  - ❏ Necessary gear ratio
  - ❏ Number of gears in a drive train
  - ❏ Reducer shaft sizes



MAINTENANCE TIPS

- Have a preventive maintenance schedule/inspection that aligns with the manufacturer's recommendations and lubricant specifications — or about every 3,000 hours or 6 months.
  - ❏ Remove condensed water from the oil reservoir at least weekly. Water can cause the gears and bearings to rust.
  - ❏ Many factors are involved in the determination of how often to change the oil, with the temperature of operation and the type of oil being the main ones.
- Consider performing a lubricant analysis.
  - ❏ Analysis verifies when an oil change is needed.
  - ❏ Knowing what metal particles are in the sample can help identify issues.
- Maintain the proper oil level. Check it when the reducer is not operating and has cooled.
  - ❏ Too little oil can lead to gear or bearing failure.
  - ❏ Too much oil can result in churning and air entrapment, which can lead to overheating because it is harder for the air and oil mixture to disperse heat.

***Joe Foster** is a Manufacturer Representative with Environmental Process Equipment Company (Olathe, Kansas).*

EGSW
Environmental Group Southwest

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