resources in water

from novel concepts to business

IWA Resource Recovery Conference Special

in this issue

Perspectives from around the world

Lessons learned and bottlenecks

How to build markets for recovered resources

Nutrients, biomaterials, energy & water

and much more!

wetsus
european centre of excellence for sustainable water technology

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IWA Resource Recovery Conference Special

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colophon

A Wetsus initiative

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Circular opportunities for all

by Kala Vairavamoorthy, IWA Executive Director

As we look around the world, the International Water Association (IWA) sees that the coming decades could be a golden age for sanitation and wastewater. More specifically, this means a golden age in low- and middle-income countries. Why? Because the current lack of infrastructure combined with the huge unmet need – both in terms of those lacking access to sanitation but also the vast quantity of wastewater that today is untreated – presents an opportunity to do things differently.

Without a legacy of expensive, centralised wastewater systems, there is a freedom to pursue other approaches. That does not mean centralised systems should be discounted, but we are already seeing an upswell of interest and activity across low- and middle-income countries in decentralised options.

Importantly, what is driving these solutions to take root is not only that they feature technology options scaled and tuned for decentralised use; there is an alignment of end user needs and operator – typically entrepreneurial – interests. And the vital ingredient here is resource recovery, with the operator tapping into circular economy opportunities to sustain its business.

This bridges the precise gap captured by the theme of the latest event of the IWA Resource Recovery Cluster, which IWA is pleased to support. 'From novel concepts to business' gets to the heart of the resource recovery challenge and it is why we should anticipate looking towards the experiences of low- and middle-income countries for inspiration and options.

In the meantime, innovative and far-sighted thinking means exciting advances are being made in high-income countries, not least those in Europe, increasingly unlocking practical resource recovery opportunities. This includes taking advantage of the upsides of centralised systems, which by concentrating resources potentially support the economic viability of solutions. It also means working to align circular economy aspirations with net zero ambitions, mitigating the sector's contribution to climate change.

These challenges and opportunities demonstrate precisely why IWA established its Resource Recovery Cluster. This move recognised the need to connect the various specialist topic areas across the used water spectrum and at the same time provide a platform to plug in the wider stakeholders crucial for taking technological advances to wide practical application.

The key action of this platform has been to provide a mechanism for the staging of a series of events, of which the edition in the Netherlands forms a part. These provide a precious opportunity for all the different interests and potential contributors to come together and to craft and carve out pathways to make the circular economy a reality.

Our sector needs to lead society towards a change of direction in which the circular economy plays an essential role.

We need to be courageous in calling for that change. And we need to be persuasive, with our case built on insights gained from the best experiences.

The energy and expertise around the latest resource recovery cluster conference gives confidence on both fronts – that the case for resource recovery is getting stronger and that we have cause to be courageous.

'Without a legacy of expensive, centralised wastewater systems, there is a freedom to pursue other approaches.'

Kala Vairavamoorthy, IWA

Resource recovery from water: The future starts now

by Leon Korving, Wetsus

What is waste? This is the question that comes to mind when reviewing the huge array of resources which can be recovered and produced from waste streams: fertilisers, nutrients, precious metals, plastics, building materials, cellulose, chemical precursors and building blocks of hundreds of types of products, energy in various forms. This is all aside from the most basic recovered resource of all —reused water.

Across industries and municipalities, the push for resource recovery is gaining momentum, driven by economic, environmental, and strategic factors. Wastewater is an important carrier of spent or inefficiently used resources. Scarcity of water itself is an increasingly pressing concern. The water also contains other matter often considered pollutants that need to be removed before the water can be discharged or reused. In the current situation this removal generates waste material (such as surplus sludge) that needs to be disposed of.

There are also geopolitical drivers; as "de-globalisation" appears to be gathering pace, the increased trend for self-sufficiency of raw materials and supply chains means that the case for shifting to a local, sustainable source of resources is becoming more urgent.

And then there's the business case. Turning waste into a marketable product is no longer just a sustainability goal—in some cases, it can be a financial opportunity.

The great variety of materials available brings a host of individual technical challenges; how to solve discolouration—in bioplastic products; how to remove heavy metals in phosphorus. However, such puzzles are being tackled; as a sector, we have moved beyond the technology challenge stage – now, the task before us to bring the innovations to life in a commercial setting.

Anaerobic digestion plant

Unlocking the value in sewage

Every year, Europe's sewage contains an estimated 324,000 tons of phosphorus, equivalent to 55% of the total phosphorus found in food consumed on the continent. This is a staggering resource, considering that the EU still relies on imports for 23% of its phosphorus needs. This situation is not much different in other parts of the world. Phosphorus isn't the only element of interest. Sewage also carries significant amounts of nitrogen, potassium, and trace micronutrients like copper and zinc—all crucial for food production.

Beyond nutrients, sewage is a rich source of carbon. Right now, wastewater treatment plants across Europe produce 47 petajoules of biogas annually, capturing methane from organic matter. However, studies suggest that with improved techniques, this amount could be quadrupled, transforming wastewater plants into major bioenergy producers.

Another often-overlooked opportunity in sewage is heat recovery. The energy potential in wastewater effluent is immense—four to five times the chemical energy found in its organic content. On average, 15% of the total thermal energy in homes and up to 40% of energy in industrial buildings is discharged to the sewers. Heat pumps can extract this energy, repurposing it for district heating systems or industrial use. This means that even after treatment, sewage still has untapped value.

Industrial wastewater: a diverse resource pool

Industrial wastewater is even more varied than municipal waste, with recoverable resources differing by sector. The food and paper industries, for instance, generate roughly 20% of all industrial wastewater, with high concentrations of biodegradable organic material. This makes them a prime candidate for biogas production, a solution already being implemented by many companies, some of which now meet over 20% of their energy needs through biogas generated from wastewater.

Bioplastics recovered from industrial wastewater

But why stop at energy? Organic by-products from industrial effluents can be turned into higher-value biomaterials, such as poly-hydroxyalkanoates (PHA). As we cover later in this magazine, one Dutch paper mill is preparing to launch a full-scale PHA production facility, processing wastewater to create 1,500 tons of bioplastic per year—a material that could soon replace conventional fossil-based plastics in everything from coatings to packaging. By 2050, the pulp and paper sector alone could produce 40,000 tons of biopolymers annually, providing sustainable alternatives to fossil-based plastics.
The textile industry, too, holds potential. Right now, 30–50% of dyes lost during textile processing could be recovered and reused, significantly reducing costs and pollution while minimising reliance on virgin chemicals. In the mining and metal refining sectors, wastewater often contains high concentrations of valuable metals, including copper, nickel, and zinc.

Recovered iron sludge pellets used for colouring

Some operations are even beginning to extract rare earth elements, essential for electronics and green technologies. With advances in electrochemical and adsorption techniques, recovering these metals from wastewater is becoming increasingly viable, helping to reduce the environmental impact of mining while securing critical raw materials.

The role of drinking water

Drinking water production might not immediately come to mind when considering resource recovery, but it, too, generates valuable by-products. Treatment plants produce millions of tons of sludge every year, much of it rich in aluminum and iron hydroxides, which can be repurposed as coagulants in wastewater treatment or even as soil conditioners in agriculture.

Brine waste from desalination and softening processes also contains recoverable salts and minerals. Separating of mono- and divalent salts increases the potential of reuse of the salts in various applications. Emerging technologies are even demonstrating the ability to convert these salts into acids and bases, potentially reducing reliance on traditional suppliers from the chlorine and petrochemical industries.

With smarter approaches, drinking water facilities could cut waste disposal costs by up to 50%, generate additional revenue, and significantly reduce their environmental footprint.

From concept to reality

For decades, resource recovery has been an exciting concept, but today it is rapidly moving into real-world applications. The transition from waste to wealth requires not just new technologies, but also new business models and value chains. Industries that once operated in isolation must now collaborate, linking wastewater producers with industries that can use the recovered materials.

This magazine aims to spark inspiration and action beyond the traditional resource recovery community and to the wider public, helping to inform and encouraging everyone to think differently about the potential in waste streams. This returns us to that fundamental question – what is waste? It's all a matter of perspective.
In her 1966 book *Purity and Danger*, anthropologist Mary Douglas famously defines dirt as "matter out of place". As we look to further advance towards a true circular economy, perhaps the greatest shift we need to make is a psychological one.

The rainbow of resource recovery

One of the earliest rap songs to become a worldwide hit still sticks in my head. It came out during my graduate studies of environmental engineering in New Jersey and was performed by the local Sugarhill Gang: "...and I want to say hello – to the black, to the white, the red and the brown, the purple and yellow."

Working in wastewater treatment to recover the ingredients as valuable materials, I soon discovered that separating yellow water as fertiliser, as proposed by EAWAG in Switzerland 20 years ago in their "no-mix" toilets and using black water for direct energy production through anaerobic treatment could create sustainable solutions.

In addition, collaborating with University of Santiago in Galicia on harvesting sludge returns, we generated white struvite pellets, now used in Fertiberia´s plants - and used red Anammox bacteria to optimise energy balances. Developing an energy-autonomous water reuse process with green algae, we even explored purple phototrophic bacteria to increase the value of the biomass for fertiliser or bioplastics production. But colorful variety is not enough: viable commodities need to reach a critical mass and tight specifications - size does matter.

Often, it is a matter of policy; while gas companies in Spain require at least $500 m^3/h$ of biogas production from a wastewater treatment plant to connect to the grid, under France's "right to connect" half of the over 700 biogas plants connected to the grid in 2004 produce less than $200 m^3/h$.

Frank Rogalla, Aqualia

column

Anne Mieke van der Werf
Invest-NL

How financing and business support for resource recovery can build a functional and investable market

National Investment and Promotional Institutions (NPIs), such as Invest-NL in the Netherlands, are crucial in addressing water-related challenges through innovative financing solutions. Invest-NL's investments and development activities contribute to a carbon-neutral and circular economy, fostering resilience through access to critical materials, sustainable energy, water infrastructure, and a diversity of jobs. By addressing bottlenecks in the value chain, NPIs enable investors to finance future solutions today.

A good example of this is the development of Caleyda, a 100% biodegradable polyhydroxyalkanoate (PHA) biopolymer produced from organic waste streams developed by Paques Biomaterials. Invest-NL participated with € 2.5 million equity in a funding round that raised €14 million to build an extraction facility at a paper mill in Emmen, Netherlands (for more on the story of Caleyda, see page 12).

While the financial investment was critical, additional real value-add from Invest-NL came through business development support: the organisation collaborated in a study with Wageningen University & Research to create a market inventory for PHA. This was used to identify market and application opportunities to be targeted by PHA producers.

The challenge in building new value chains often lies in the dual risks of the technological development phase: the product acceptance and future offtake potential. This results in investors labelling these investments riskier than usual. However, entities like Invest-NL can play a crucial role, helping companies to navigate through this "valley of death" by providing both financial backing and market development support. This reduces both technology risk and market risk, increasing confidence for follow-on investors. For water-based resource recovery, where the products—such as recovered nutrients, biopolymers, or cellulose—often need to meet strict quality or safety regulations, such support is vital in developing user trust and securing offtake agreements.

Invest-NL has also worked in partnerships with various organisations. We worked amongst others on the implementation of the end-of-waste status that allows companies in Groene Chemie Nieuwe Economie (GCNE) to market recycled materials as products, ensuring regulatory compliance and opening new business opportunities. It also promotes sustainability by reducing the need for virgin raw materials and attracting investments through demonstrated commitment to environmental impact and to develop and test their technologies at demonstration plants. The key message from GCNE is the paradigm shift from end-of-waste declaration to feedstock declaration. This is a different approach to the 'raw material'. Equally important is the commitment to harmonisation in the European context. Meanwhile, we are working on practical solutions, such as the self-assessment tool."

Investing in the value chain

Invest-NL emphasizes the transition towards a circular economy in the agrifood sector, by supporting projects that aim to recycle nutrients and reduce waste throughout the food production chain. This is done via two goals: efficient use of resources (promoting technologies that enhance the efficiency of nutrient use in agriculture), and waste reduction (supporting innovations that minimise food waste and recover valuable nutrients from waste streams).

With this experience Invest-NL can offer valuable lessons for other NPIs and development banks seeking to accelerate circular economy solutions. A key takeaway is that public investment can have outsized impact not only by de-risking technology but by convening and coordinating the actors needed to create a functional and investable market.

> 'National promotional institutes have a unique role to play—not just as financiers, but as strategic enablers, connecting the dots'

column

Bernhard Truffer
Eawag/Utrecht University

Why transforming utilities into 'mining' companies is a social science challenge

Wastewater treatment is one of the biggest historical success stories of industrialised societies. Without it, cities would still be the poisonous draining pits they were far into the end of the 19th century. That success relies on a very particular technological and organisational paradigm, which has not changed much since the beginning. It is largely based on collecting as much polluted water as possible in a single treatment plant, because treatment efficiency increases with volume. As the output has (traditionally at least) had little or no market value, utilities are considered to be providing public services, mandated, managed and controlled by public entities. Economists would say that wastewater utilities are granted a local monopoly, which allows them to charge cost-covering tariffs for their services, while accepting regulatory oversight for not abusing their privileges.

What happens when such organisations try to engage in market-oriented activities, like producing and selling resources recovered from the wastewater stream? Sociologists will immediately predict manifold problems due to conflicting institutional logics that utilities have to follow. The managers will have to veer between providing reliable public service with one eye, while looking for increasing market shares and price competition with the other.

We know from the literature in organisational studies that competing institutional logics are hard to handle. This is because the conflict means that decision makers will always be at risk of failure in one dimension or the other: either not adequately fulfilling their public service mandate or failing to realise commercial ambitions. Being successful in resource recovery, therefore, is a very fundamental challenge that cannot be fixed by incrementally transforming utilities.

In general, public utilities are notoriously weak in managing innovation. Novelty is mostly managed by sector associations and their related research institutes. Innovation management is then happening in networks, where utilities can engage selectively depending on their interests, capabilities and resources. Resource recovery represents many different technical procedures, cost recovery models and market demands depending on the specific resource to be recovered. It therefore does not represent one alternative development trajectory – it is a whole gamut of potential pathways.

This forces a decision on utilities. They must selectively decide on a pathway and pick which resource recovery innovations to pursue, and therefore which technological innovation system they will engage with. Innovation systems typically consist of various actors that collaborate in targeted networks to make a new product or technology grow and mature. Growth and maturation of these networks requires a systemic understanding of the innovation challenge, coordination among different actors, and often initial policy support.

If this engagement is successful, dedicated businesses may emerge, which master the technology, know their specific markets and are able to run the operations at a profit without jeopardising any public service mandate.

Therefore, resource recovery transitions should not be seen as the substitution of one utility model by a new one, but rather as an expanding and flourishing ecosystem of organisations, services, products and business forms. In this ecosystem, utilities may play the role of new "mining companies", which provide the raw materials for the development and prospering of the ecosystem. Achieving such a multifaceted transition needs dedicated coordination efforts to combine the traditional public mission with the more market-oriented ambition of increased resource recovery.

> 'Being successful in resource recovery is a very fundamental challenge that cannot be fixed by incrementally transforming utilities'

Resource recovery: from vision to scaled practice –a Dutch perspective

Sander Mager
Amstel, Gooi & Vecht Water Board

In the Netherlands, the 21 regional Water Authorities play a vital role in managing one of our most precious resources: water. While wastewater treatment is a core responsibility, it is only part of a much broader task. In a country where 60% of the land lies below sea level, water authorities are also responsible for flood protection, maintaining dikes and pumping stations, regulating water levels, and ensuring clean and sufficient surface water.

In recent years, our mission has expanded—not as a showcase of what we can do, but as a logical and necessary response to growing challenges. Seventeen years ago, the Dutch Water Authorities joined forces in establishing the Energy and Raw Materials Factory (EFGF), a national initiative to explore how to extract energy and raw materials from wastewater. The journey has required technological innovation, regulatory changes, scientific research, and new forms of collaboration between government, academia, and business.

Success Story

Today, we are approaching a turning point. The Dutch Water Authorities have already made significant progress. Eight wastewater treatment plants across the country now operate full-scale struvite recovery systems, reclaiming over 300 tons of phosphorus per year. Cellulose is another success story: extracted from toilet paper in sewage, it is now being reused in insulation, asphalt, and other sustainable products.

The production of biogas from sludge digestion is also gaining ground, with more facilities upgrading biogas to green gas, suitable for injection into the natural gas grid. In some cases, CO_2 separated from the biogas is even being sold for industrial or agricultural use.

Of course, technology alone is not enough. The current economic and legislative systems are still largely based on a linear model: take, make, use, and discard. To truly shift toward circularity, we need change on multiple levels—policy, market incentives, and organisational culture. First of all, this means tackling pollution at the source.

Source control—especially for substances like PFAS, microplastics, and other hazardous chemicals—is far more cost-effective than trying to remove these pollutants once they enter the water system.

Accelerate

From policymakers, we ask for recognition of wastewater and phosphate as strategic resources within European raw materials policy. If Europe wants to accelerate the circular transition, we need a quicker, standardised and widely accepted assessment method for granting end-of-waste status—one that enables recovered materials to move freely across borders and find markets throughout the continent.

Just as crucially, we strongly support the introduction of mandatory minimum percentages of recycled or biobased content in relevant product categories.

But we must also look inward. If we want to move from concepts to business, we as water authorities need to work differently. That means organising ourselves to achieve scale by pooling resource flows, jointly investing in infrastructure, and spreading risk. It requires a commercial orientation, a focus on quality control, and a long-term view on supply and demand.

Communicate

Perhaps the most important lesson we've learned is that collaboration is not optional—it is essential. Internally, among the 21 Dutch Water Authorities, we have built a robust network that allows us to share knowledge, align investments, and create scale. But we also depend on external partners: entrepreneurs who can develop applications, knowledge institutions that provide insight and innovation, governments that shape enabling policy, and even creative professionals who help communicate the value of circularity to the wider public.

WEF's perspective on resource recovery: priorities, opportunities, and bottlenecks

The Water Environment Federation (WEF) has been a leader in the water sector since 1928. With more than 31,000 members globally, a knowledge base of more than 21,000 books, papers, fact sheets, reports, and articles, a broad network of partnerships, and a portfolio of leading water conferences, WEF has been at the forefront of advocating for resource recovery in the water sector, transforming wastewater treatment plants into hubs of sustainability and efficiency.

This approach not only enhances environmental stewardship but also drives economic benefits by recovering valuable resources such as water, nutrients, and energy. WEF's ReNEW Water Project revealed significant potential for resource recovery. For instance, the baseline recovery rates showed that approximately 2.2 billion gallons of water per year, 350 megawatts of energy per year, and 172,400 dry metric tons of nutrients per year could be recovered from wastewater treatment processes in the United States alone.

Addressing the bottlenecks in resource recovery

Resource recovery is driven by market forces. If conventional alternatives like chemical fertilisers and municipal water supplies are cheaper, only passionate innovators or companies aiming for sustainability will engage in recovery activities. Crossing this hurdle requires significant reductions in unit costs.

There are current bottlenecks such as technical barriers, where unmet technological hurdles exist, and scale, which means that average treatment plants need to meet consistency and volume requirements. The regulatory environment is another issue, with inconsistent regulations across federal and state levels, especially regarding PFAS, hindering reuse and biosolids management. PFAS impacts include persistence and health risks that lead to regulatory scrutiny. Regulatory inconsistency creates planning challenges with unpredictable costs, and there is limited federal appetite for additional regulation or funding for resource recovery.

Many of the regulatory bottlenecks are primarily state-level issues. While WEF currently does not carry out state-level advocacy, we contribute to EPA's Water Reuse Action Plan, which just celebrated 5 years of action on water reuse. Our state member associations (MA) and members participate in state-level development of legislation, regulation, and policy development. We are actively looking to identify how WEF can advance resource recovery through the cooperative federalism framework and through our educational programming.

WEF is looking to EPA to better quantify the risk of PFAS on biosolids to the general public. WEF's members have concerns with EPA's recent draft risk assessment of PFAS in biosolids, which derives risk from a modelled scenario that is not reflective of the general public and utilises a number of assumptions that are not consistent with real-world biosolids application scenarios. WEF is advocating for a more robust review of the risk of PFAS in biosolids that includes analysis of the risk management options and is based on more recent research and real-life data. Fertiliser products like Bloom from DC Water and Milorganite from Milwaukee are good examples of how biosolids can be safely and sustainably reused.

Finally, collaboration is at the heart of WEF's approach to resource recovery. By leveraging its convening power, WEF connects public- and private-sector partners with mutually beneficial interests. This collaborative effort supports market-building activities and fosters a culture of innovation and sustainability within the water sector. Additionally, WEF's technical communities play a crucial role in advancing resource recovery practices through research, education, and advocacy.

WEF's commitment to resource recovery extends to educational programming and outreach effort, offering a range of training materials, workshops, and events designed to build circular economy knowledge and skills among water professionals. Conferences and summits, such as the Residuals & Biosolids and Innovations in Treatment Technology (RBITT) conference and the Industrial Water Solutions summit, provide platforms for knowledge exchange and collaboration.

John Ikeda
WEF

Getting into Business

Drinking water

Setting the standard: from building a market to leading it

Iron sludge pellets

While the main focus of resource recovery is often on wastewater, drinking water also shows significant potential. AquaMinerals, a Dutch organisation, has a 30-year history of turning water treatment by-products into a portfolio of viable secondary materials. Its journey offers vital lessons for scaling resource recovery across Europe and beyond, in terms of navigating the complex mesh of regulation, logistics and bringing innovations to market.

Iron sludge basin
Aquafer is also available in pellet or granulate form. The iron is a suspension of ferric (hydr)oxide that results from the process of iron-removal from groundwater. The pellets/granulates are made by adding carboxymethyl cellulose (CMC), drying the sludge and then transforming it into pellets/granulates

Iron sludge: from rust to revenue

Take iron sludge: once considered to be a low-value, bulky by-product of drinking water purification, it is now a prime example of resource recovery success. Iron sludge forms when dissolved iron from groundwater is oxidised during treatment. Traditionally, this reddish-brown sludge was used for backfilling ditches or landscaping—hardly high-value reuse. But AquaMinerals changed that narrative.

Today, the company is the market leader in supplying iron sludge as a sulphur binder for anaerobic digesters used in biogas production within the Netherlands – and exports significant volumes of iron sludge to Belgium, Germany, France and Denmark. The sludge binds sulphur, preventing it from forming hydrogen sulphide—a corrosive and toxic gas—in the biogas production process. Not only does this improve the safety and longevity of the digesters, it helps farmers and energy producers avoid costly maintenance and emissions issues. Crucially, the recovered product is priced competitively with virgin iron chloride, ensuring economic feasibility.

The key to success? Standardisation and ensuring security of supply. By investing in dewatering, silo infrastructure, and quality control, AquaMinerals offers consistent, predictable product specifications—an essential condition for industrial users. This alignment of supply and demand built trust and opened a stable market.

Falling through the gaps: when innovation isn't enough

However, not every resource recovery attempt hits the mark. One example is sievings— the waste captured in the very first filtration steps of municipal water treatment, containing items like wet wipes, wood chips, and other solid debris. Less than 1% of total plant waste by weight, sievings are typically incinerated.

In a promising pilot in Rotterdam, AquaMinerals partnered with students and entrepreneurs to transform sievings, in particular the wet wipes, into a moisture-retaining substrate for green roofs. The environmental fit was excellent, supporting urban cooling and water retention. But despite technical feasibility, the project failed to scale. Quality varied across treatment plants, precluding a stable product offering. Logistics were inconsistent. The market needed 30,000 tonnes a year—far more than AquaMinerals could supply at that time. Without standardisation and volume, even the best ideas can flounder.

Staying focused

With over 20 different recovered materials in play—from calcite and activated carbon to sand and lime pellets—one might wonder how AquaMinerals stays on course. CEO Olaf van der Kolk credits a clear hierarchy of priorities: ensuring continuity of waste removal and disposal for water utilities, financial viability, sustainability (short logistics, clean energy use), and above all, circularity.

In AquaMineral's model, true circularity means reusing recovered materials within the water sector itself. A prime example is calcite, used as a seeding material in softening processes—a loop that keeps valuable materials circulating in the same ecosystem. Similarly, trials are underway to repurpose CO_2 from wastewater plants for pH control in drinking water treatment.

Match-making

One of the most demanding aspects of resource recovery is matchmaking: aligning recovered materials with industrial or commercial end users. The process is often part detective work, part diplomacy. Searchable databases and trade fairs help identify leads, but every new material requires a period of testing, dialogue, and trust-building.

For calcite, a well-understood product, AquaMinerals can simply pick up the phone. For newer materials, like organic polymers or specialised sands, market development takes years. In many cases, the smallest, family-owned businesses with 10 staff or fewer have proven to be the most ideal partners—flexible, long-term oriented, and capable of adapting their processes. Large multinationals, by contrast, are often slow-moving and risk-averse.

Standardisation: the hidden bottleneck

A recurring theme in the resource recovery story is standardisation—or rather, the lack of it. While EU legislation provides high-level criteria for defining something as "no longer waste"—positive value, functional market, safe use—the implementation is anything but harmonised.
In The Netherlands, companies can self-declare compliance, while in France the 96 regional authorities play an important role in the implementation and enforcement of the End of Waste (EoW) legislation and often even in the judgement if a material is EoW or not.

Olaf highlights this challenge: "If the Netherlands gives material X End-of-Waste status for application Y, why should Belgium repeat the whole process?" The resulting cost is steep: duplicative testing, delayed market entry, and high transaction costs that deter new players.

Infrastructure, networks – and trust

Given the clear environmental and economic rationale, why aren't there more organisations like AquaMinerals across Europe? Partly, it's culture. The Dutch water sector operates on a principle of collective responsibility: "We are all used to collaborating together – we have a saying: if one dike fails, everyone gets wet feet," as Olaf puts it. This fosters a spirit of co-operation that is hard to replicate in more fragmented or privatised systems. In countries like the UK, where water is privatised, or France, where 10-year concessions discourage long-term investments, creating a central recovery body is a hard sell.

Building the necessary infrastructure, networks, and trust takes time—often three to five years of groundwork before results appear. For many utilities or private firms, that's a hard proposition without clear funding, mandates, or institutional support.

The way forward

What would Olaf do differently, if the last 10 years could be repeated? "Perhaps to have been more self-confident", he considers. "Not aggressive, but we could in hindsight have been faster and more entrepreneurial given the strong proposition we have – we were very cautious and careful to involve and persuade all the stakeholders and bring them along with us." But that collaborative instinct soon resurfaces: "On the other hand, I don't regret much, because our prudent approach meant we were successful in recruiting a critical mass of utilities."

Olaf van der Kolk
AquaMinerals

Getting into Business

Biopolymers

A vision for a bio-based future

Polyhydroxyalkanoate (PHA) is a naturally occurring polymer made by certain microbes as an energy store. Unlike traditional plastics, PHA biodegrades in soil, freshwater, marine, and composting environments, making it a strong candidate for sustainable plastic alternatives.

René Rozendal (l) and Joost Paques of Paques Biomaterials

Italy's pioneering role in PHA recovery

Italy began exploring PHA in the early 1990s through pilot projects using municipal and industrial waste. A key milestone was the Horizon 2020 "SMART-Plant" initiative, led by Professor Francesco Fatone at Università Politecnica delle Marche. This involved a large pilot plant at the Carbonera treatment facility in Treviso, which could recover up to 1.5 kg of PHA daily.

"This project was among the largest at its time," says Prof. Fatone. "We demonstrated not just PHA recovery, but also integrated nitrogen and phosphorus removal."

This evolved into the Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR) system, which merges short-cut nitrification/denitrification with PHA production. The result is an integrated process that enables nutrient management and bioplastic production within wastewater treatment plants.

Good on paper: PHA extraction in the Netherlands

In the Netherlands, Paques Biomaterials produces PHA from wastewater and organic waste using mixed microbial cultures. This contrasts with most commercial methods, which rely on food-based feedstocks and pure cultures. "Our process uses waste—not food—which makes it more sustainable and robust," says René Rozendal, Co-founder and CTO of Paques Biomaterials.

The outcome is Caleyda, a versatile PHA used in a wide range of products – from plant pots to leather alternatives. It's recyclable, compostable, and degrades safely in the environment, leaving no persistent microplastics.

End product: **Caleyda**

From pilot to first commercial plant

Despite promising pilots, scaling wastewater-based PHA production is challenging. To overcome this, Paques partnered with ESKA, a Dutch paper company with a strong sustainability track record.

"The hardest part is finding that first customer willing to take a risk," Rozendal admits. The partnership began in 2014 and evolved into a joint venture with shared risk and ownership. At the ESKA site, process water from paper production—rich in fermentable starches—feeds the PHA-producing microbes. The plant aims to produce 1,500 tons of PHA annually.

Given the complexity of standardising municipal wastewater processes, Prof. Fatone also sees industrial waste—especially from food and wine industries—as key. Projects like the partnership between Caviro, the University of Bologna, and the B-Plas demo plant are using winery sludge to produce PHA. "The idea is to close the loop—for example, by using recovered PHA to make wine packaging," he says.

Technical breakthroughs

One technical hurdle has traditionally been the PHA extraction process. For Rozendal, one of the biggest engineering milestones was converting the process from batch to continuous operation. "Industry works continuously. So, if we wanted to be taken seriously, we had to adapt," he says. The challenge was replicating the "feast and famine" cycles that microbes need to produce PHA in a continuous flow—a problem the company ultimately solved, and which now underpins the company's core IP.

Another breakthrough has been in downstream processing: transforming the microbial biomass into a usable, market-ready bioplastic. This required novel extraction methods and robust quality control to ensure the final product met industrial standards.

Finding a competitive edge

In a rapidly expanding PHA market—forecast to grow from 100,000 tons to over 1 million tons in five years—Paques Biomaterials aims to stand out by focusing on true circularity. Unlike other producers that rely on genetically modified microbes and sterilised sugar feedstocks, their mixed culture process thrives on real-world variability.

"Waste-based production isn't just greener—it's more resilient," Rozendal argues. The company's approach skips the step of converting waste to biogas before turning it into products. In the end, this translates into much higher product yields.

And unlike other "drop-in" biodegradable plastics like polybutylene adipate-co-terephthalate (PBAT), Caleyda offers full-spectrum biodegradability. "This is one of the many reasons we believe in PHA. If it ends up in the ocean, it breaks down naturally. That's the ultimate insurance policy," Rozendal says.

Choosing the right investors

Scaling any new technology in water and wastewater is notoriously slow—and capital intensive. Rozendal is candid about the hurdles: "You're entering a market dominated by cheap fossil-based plastics. Investors expect quick returns, but water tech timelines don't fit that model."

His advice to fellow innovators? Choose the right investors. "Look for funds that understand long-term horizons—family offices, public-private partnerships, or sustainability-driven VCs." He also advocates for aligning public funding with core business goals, rather than chasing every grant opportunity.

Having matured under the umbrella of its parent company, Paques, the spin-out benefited from a decade of R&D before seeking outside investment, avoiding the equity dilution many startups face.

Beyond the technology

Despite visible technical success, commercialisation is still an uphill battle. One of the primary issues is the lack of "end-of-waste" criteria specific to PHA recovered from sewage sludge.

"Public perception plays a big role," says Fatone. "A helpful development would be if we had a specific chapter in the EU sewage sludge directive about material recovery and to have a kind of "brown certificate." A risk-based regulatory approach would help to drive large-scale adoption."

For Rozendal and his team, "It's about building a real material transition—away from fossil-based plastics, toward bio-based, biodegradable alternatives," he says.

As regulatory pressure mounts and microplastics become a mainstream concern, PHA is poised to become more than a niche. Already, bans on single-use plastics and new Extended Producer Responsibility (EPR) rules are opening doors for alternatives like Caleyda. But Rozendal cautions that even the best material won't change the world alone.

"It's not just the technology—it's the partnerships, policies, and public support that make the difference," he says. "We're not just recovering resources from wastewater. We're redefining what waste means."

As Prof. Fatone concludes, "We've proven the science. Now we need to unlock the business model."

Prof. Francesco Fatone
Università Politecnica delle Marche

resources in water magazine

China's resource recovery journey and reflections on IWARR2023

With contributions from
Dr. Troy Y. Tao, IWARR2023
Yujia Shen, Global Water Intelligence

The 5th International Water Association Resource Recovery Conference (IWARR2023) was held in Shenzhen from November 1–3, 2023. Attracting over 700 delegates from 30 countries, the conference explored water reuse technologies, nutrient recovery, and energy recovery from wastewater. Conference Chair Professor Aijie Wang called it "a new beginning," sparking collaborations to advance resource recovery from water globally.

The focus of resource recovery in China is around water reuse. The current 14th Five Year Plan (2021-2025) mandates that water-scarce cities—around two-thirds of China's urban areas—increase their wastewater reuse rate to over 25% by 2025. In even more water-stressed regions such as Beijing, Tianjin, and Hebei, the target is higher: 35%.

These targets, though ambitious, are unevenly distributed. "The reuse efforts are very much focused in northern China, where water scarcity is severe," says Yujia Shen, Senior Technology Analyst at Global Water Intelligence. Cities like Beijing have made considerable strides, reaching high reuse rates primarily through the adoption of advanced wastewater treatment technologies like membrane bioreactors (MBRs).

Despite this localised emphasis, there are flagship projects even in less water-scarce regions. One example is the Yixing Wastewater Resource Concept Plant, a water resource recovery facility near Shanghai in Eastern China which can treat 200,000 tons of sludge per day. Completed in 2021, the facility reclaims nutrients, biogas and water, while doubling as an educational site.

Stronger nutrient regulations

Despite impressive projects like Yixing, and many more similar planned facilities, when it comes to nutrient recovery—particularly phosphorus and nitrogen—the focus is driven by tighter discharge standards rather than circular economy goals.

In 2015, China significantly strengthened its wastewater discharge regulations, compelling utilities to reduce nitrogen and phosphorus levels before effluent enters natural water bodies. All municipal wastewater treatment plants will have to ensure that discharges do not exceed Level 1A standard limits: 15mg/l for Total Nitrogen and 0.5mg/l for Total Phosphorus – and these limits will apply to all natural water bodies, not just reuse applications. However, challenges linger. In 2021, 12% of urban sewage treatment capacity fell short of Grade I-A standards, signalling infrastructure and efficiency gaps. Addressing these issues necessitates technological advancements and heightened public awareness.

The sludge challenge

China is committed to enhancing resource recovery from wastewater, with ambitious targets such as treating 95% of urban wastewater by 2025. However, in most of the country, dewatered sludge is primarily landfilled. A sludge-to-energy facility was built by Veolia for its wastewater project in Urumqi, Xinjiang Uygur Autonomous Region, which treats sewage sludge and captures methane by applying its anaerobic digestion solutions, with co-generation as the disposal method. However, Shen notes that while a few larger, wealthier cities like Shanghai and Beijing have adopted incineration or anaerobic digestion technologies, these remain the exception rather than the rule.

Decentralised momentum: industrial parks and pilot projects

Where progress is happening, it is often within government-led industrial parks. However, infrastructure remains a major barrier. "You need a whole separate network of pipelines to deliver reclaimed water from treatment plants to industries," Shen points out. "It's slow-moving, but it is happening."

That said, there are sparks of potential. "Reuse is a focus—particularly where water is scarce. And as technologies mature and economic conditions improve, we may see more pilot projects pushing into recovery," Shen suggests.

Global lessons from China's experience

The effectiveness of structured approaches to water management and urban planning, exemplified by the Concept WRRF Yixing, underscores the importance of public participation and education in achieving high recycling rates.

As resource recovery continues to evolve worldwide, China's model reminds us that sustainable innovation must adapt not only to technical hurdles, but also to the socio-economic and geographical realities of each region.

The global transition to resource recovery will not be uniform—but every journey, including China's, offers lessons for us all.

Unearthing value from urban mining in Japan

Fumiki Hosho
Kubota Corporation, Japan

Kubota's Surface Melting Furnace

Japan provides an example of successfully recovering resources from sewage sludge via thermal processes, which separate and concentrate elements under high temperatures (1,250–1,400 C°). Kubota's Surface Melting Furnace (KSMF) technology is turning sewage sludge ash from low-grade industrial residues such as automobile shredder residue (ASR), as well as electronic waste into sources of high-value metals and nutrients. While high-value electronic waste—circuit boards, copper wiring, and batteries – already have established recycling routes, KSMF is able to upgrade lower-quality residues that leak from existing recycling systems.

Urban mining is no longer a fringe idea; it is becoming a central pillar of modern resource management. Pilot and commercial-scale deployments in Japan have demonstrated the economic feasibility of extracting trace amounts of precious metals such as gold, silver, and copper from these materials. For instance, slag produced from incineration ash has yielded metal values equivalent to 38,000–72,000 JPY (approx. €230–440) per tonne, depending on the prevailing market. Similar returns have been achieved from shredder residue (SR), largely driven by copper recovery. These figures put KSMF's outputs in competitive territory with conventional sources—but with the added advantage of closing waste loops and reducing landfill burden.

Kubota's technology also allows for more than 90% of phosphorus in sewage sludge to be recovered into a slag product, in which the phosphorus is citrate- and neutral ammonium citrate-soluble—indicators of bioavailability for plants. In Japan, the slag from commercial sewage sludge melting plants has been recognised as meeting fertiliser standards in terms of effectiveness and safety by MAFF (Ministry of Agriculture, Forestry and Fisheries), and it has been registered as a byproduct fertiliser. The process also eliminates contaminants such as PFAS, microplastics, and pathogens during the high-temperature treatment.

The challenges to roll-out of this technology are primarily economic and systemic. Compared to traditional landfill or incineration, resource recovery processes can carry higher upfront costs. To drive adoption, three key conditions must be met: First, policy incentives: regulatory frameworks must favor recovery over disposal. Examples include the EU's End-of-Life Vehicle (ELV) Directive and mandates for phosphorus recovery. Secondly, transparent markets: a fair and stable market for secondary materials is essential.

Finally, economic viability: Without the above conditions, resource recovery technologies may struggle to compete. However, the inclusion of feedstock subsidies, tax breaks, or premium pricing for recovered materials could tip the balance. Kubota has proven that with market support, KSMF can meet both economic and environmental performance targets.

Local loops, global gains

In Japan, Kubota's success has been underpinned by several favorable factors including a nationwide network of non-ferrous smelters capable of processing recovered metals; established fertiliser regulations that facilitate the registration of recovered phosphorus products, and government support for strategic resource recovery following price shocks in the global phosphorus market. In addition, there is a domestic market for recycled aggregates from furnace slag, which in some cases can replace sand used in the construction and civil engineering sectors.

To export the success of KSMF to other regions, partnerships are key—from engineering firms and municipal waste operators to smelting facilities and fertiliser manufacturers. Financial mechanisms such as public-private grants, subsidies for capital investments, and operational incentives for users of recovered resources are also critical. As resource constraints and regulatory pressures mount, investment in urban mining technologies is poised for growth.

Getting into Business

What brine mining reveals about the global circular economy

by Christos Charisiadis
Brine Consulting

In the global push for resource recovery, brine mining, extracting valuable minerals such as lithium, magnesium, and potassium from saline waters, emerges as both a cautionary tale and a source of inspiration.

Sodium crystals

Technically, brines are complex chemical cocktails. A lithium-bearing salar (salt flats or brine lakes, often found in high-altitude areas like the Andes), for instance, may contain just 500 to 1,000 milligrams of lithium per litre, dwarfed by sodium, magnesium, and potassium concentrations exceeding 10,000 milligrams per litre.

Extracting lithium selectively from this ion-rich soup is a formidable task, requiring advanced solvent extraction, ion exchange, or membrane separation processes. Despite promising laboratory results, commercial-scale applications remain difficult: membranes foul, reagents degrade, and energy inputs escalate.

While Latin America often dominates discussions, the Middle East is quietly positioning itself as a future player. Countries like Saudi Arabia, the UAE, and Oman generate millions of cubic metres of concentrated brine daily through desalination. Unlike brines from salars, which can either be affected by drought or be diluted by rainfall, desalination streams are stable and year-round, containing significant quantities of magnesium, lithium, and potassium. This presents a unique opportunity to integrate mineral extraction directly into existing desalination plants, transforming waste into resource. However, the energy-water nexus here is acute: desalination itself is energy-hungry, and additional extraction processes risk exacerbating this burden. Nevertheless, projects such as Saudi Arabia's NEOM are actively exploring how brine valorisation could support broader sustainable development, with a 500,000 m³/d reverse osmosis desalination plant planned at the site.

If successful, NEOM's brine mining project could become a global model for integrating resource recovery into the circular economy. A 2022 presentation at the Saudi Water Forum outlined plans to recover 21,000 tons/year of bromine, which could generate $96.4M USD in North America or $186.4M USD in the Asia-Pacific region based on Q1 2022 prices. By 2030, NEOM aims to expand desalination capacity to 1.5 million m³/d, potentially tripling bromine output.

Brine mining offers benefits such as reducing desalination costs and achieving zero-liquid-discharge (ZLD) waste reduction. However, challenges remain, including high feasibility costs for pilot testing, complex seawater chemistry requiring advanced modelling and bench-scale experiments, and market uncertainties for recovered products. Seawater mining projects are more profitable due to higher-value minerals but require substantial capital investment. NEOM's large-scale approach—targeting 1.5 million m³/d by 2030—aims to address these barriers through economies of scale.

Beyond technical difficulties, the business case for brine mining is precarious. Mid-sized operations demand capital investments of $500 million to $1 billion, while lithium prices have fluctuated wildly, ranging from $6,000 to $80,000 per tonne over the past decade. Brine deposits often lie in remote areas lacking infrastructure, driving up costs.

Promising answers to the brine mining puzzle are beginning to emerge. Direct lithium extraction (DLE) technologies aim to bypass evaporation ponds entirely, selectively recovering lithium with much lower water use and improved yields. Electrochemical separation and selective solvent systems are showing potential to enhance efficiency while reducing the energy footprint.

In the Middle East, coupling extraction to desalination infrastructure could turn waste brine into a steady, valuable feedstock without significantly increasing environmental harm. The pairing of extraction with renewable energy, especially solar and geothermal, is helping some projects tackle the water-energy-material nexus head-on.

column

Korneel Rabaey
Ghent University

Should we recover CO_2 from wastewater?

Utilities worldwide are putting major efforts into decreasing their greenhouse gas (GHG) footprint. The focus of the moment is mainly on nitrous oxide (N_2O) emissions from wastewater treatment plants (WWTPs), which are estimated to make up three quarters of emissions from wastewater treatment processes. The other quarter of GHG emissions comes from methane (CH_4) emissions which leak from both WWTPs and sewer systems.

For nitrous oxide, based on IPCC calculations (2019), the estimated emissions are about 1 g N_2O per m_3 of wastewater treated, which equates to some 275 g carbon dioxide (CO_2) equivalents. In other words, one cubic meter of wastewater emitting 1 g of nitrous oxide (N_2O) is estimated to have as much global warming potential as 275 grams of CO_2.

For methane (CH_4), the numbers vary significantly as this depends on both measurements and CO_2 equivalents assumptions (28 or 80 times CO_2). In the Netherlands the current standard of 28 leads to an assumed emission of 86 g CO_2 equivalents per m³ wastewater. In the US, a recent study (Moore et al. 2023) found the warming potential of methane from wastewater to be significantly stronger, leading to 1,370 g CO_2 equivalents by assuming a figure of 80.

Utilities are investing in mitigating technologies including better control systems, covers for the bioreactors and catalysts to remove nitrous oxide – but strikingly, efforts on dealing with the third emission, CO_2 itself, seem to be lacking.

One can estimate that about 60% of carbon (about 200 g/m³) in wastewater becomes CO_2 during aeration. Adding in the weight of the oxygen means that this 200g of carbon becomes roughly 450 g/m³ CO_2 emitted. The sludge generated in a WWTP is increasingly converted through anaerobic digestion. Burning the resulting biogas adds 150 g m³ of CO_2 emissions, and incineration of the residual sludge to create ashes gives a further 150 g. Added together this means 700 g of CO_2 emissions per m³ which together with the other emissions gives very roughly more than 2,300 g CO_2 equivalents per m³.

Even if we cover the WWTP and improve mixing and aeration to solve the N_2O and CH_4 emissions we still have 700 g of CO_2 emissions per m³ remaining. To put it in perspective, for a WWTP serving 250,000 people (approximately the population of the City of Ghent in Belgium), we are looking at over 11,500 tons of emissions per year.

There are no efforts today to deal with these emissions, as they are considered biogenic (although it is known that at least part of it is not, Tseng et al. 2016). As we advocated in the past (Martens et al. 2016) creating a distinction between different types of CO_2 makes no sense. For chemists and for the climate, CO_2 is CO_2 and irrespective of its origin it should be captured – ideally prioritising sources from which CO_2 is straightforward to capture.

I am thus advocating that we should capture CO_2 from wastewater treatment plants or avoid its emission by doing something better with the sludge. Aeration in the WWTP already does the work of stripping CO_2 and with the potential to cover plants enabling collection we have a far more attractive setting than the direct air capture plants which are currently discussed.

Biogas plants can create biomethane while capturing the CO_2. WWTPs thus offer a unique opportunity to capture CO_2 and either sequester it, or put it to good use for example greenhouse fertilisation, fuel production or other options.

'CO_2 is CO_2 and irrespective of its origin it should be captured'

Getting into Business

Phosphorus recovery

From sewage sludge ash to food security

Marissa de Boer SusPhos (r) and **Silvester Bombeeck** SNB

EasyMining, a subsidiary of Ragn-Sells, is deeply involved in this shift with its Ash2Phos technology, which extracts high-purity phosphorus, aluminium and iron from sewage sludge ash (SSA). The company is moving from demonstration to industrial scale with its first commercial facility under development in Schkopau, Saxony-Anhalt, Germany.

Christian Kabbe
EasyMining Germany

Pumping up the volume

But recovery alone is not enough. As Christian Kabbe, MD of EasyMining Germany says: "There's no point in recovering material and ending up in a market that doesn't exist. Volume, quality and reliability are everything." This principle has shaped EasyMining's strategy from the ground up. The Schkopau plant is designed as a volume hub: sourcing SSA from across the country during its demonstration phase, and later from regional sources as additional Ash2Phos plants come online.

With growing concerns about the depletion of phosphorus sources, the global phosphorus market has changed substantially in recent years, and Europe in particular faces a resource reality check, importing almost 90% of its phosphorus – an increasingly vulnerable supply chain. The European Union is aiming to encourage phosphorus recovery in Europe, and one key source is the ash of incinerated sewage sludge. In the coming years, phosphorus recovery from sewage sludge ash is projected to increase and overtake struvite, in terms of volumes recovered.

Turning ash into products—and value

The Ash2Phos process begins with acid leaching, dissolving phosphorus, aluminium, iron, and heavy metals from the ash. The solution is separated from the inert sand residue—destined for use in construction—and undergoes chemical separation to isolate the valuable metals.
The recovered phosphorus is extracted as a high-quality product suitable for fertiliser and even feed production.
The sodium aluminate (8,000–9,000 tonnes/year from a 30,000 t/y plant) is particularly valuable, often overlooked in resource recovery projects but pivotal in EasyMining's business case. "Aluminium recovery is not just a bonus—it's a core driver of the plant's economics," Kabbe notes.

Ash2Phos separates heavy metals which end up in a concentrated filter cake, containing e.g. copper, zinc, and nickel. While current volumes (1,000 tonnes dry solids/year) are too small to interest smelters, EasyMining's target capacity of 300,000 tonnes of ash/year would yield 10,000 tonnes of metal concentrate—crossing the commercial viability threshold for secondary metal recovery.

Phosphorus pioneers

Several other companies are developing innovative technologies to push forward the sludge ash route. While expectations are always high, there are often challenges on the way. Early pioneers included PHOS4Green – the first technology to transform ashes into fertiliser at full scale in Germany. A plant in Haldensleben, Saxony-Anhalt, started operating in spring 2021, and was designed for a yearly production of 60,000 tons of fertiliser, but shut down in 2022 due to high gas prices. Another example is TetraPhos, a technology from Remondis Aqua, which opened its first full-scale plant at the Köhlbrandhöft WWTP in Hamburg Germany. That facility faced technical issues, and after a pause, restarted operations after some important modifications.

Another example is SusPhos. The company is currently developing a commercial scale plant for NV Slibverwerking Noord-Brabant (SNB) which processes sewage sludge for Dutch utilities, taking in around 430,000 tonnes of dewatered sewage sludge annually, at Europe's largest mono-incineration plant in Moerdijk, the Netherlands.

Marissa de Boer, founder and CEO of SusPhos explains: "We expect to complete the basic engineering in 2025. The phosphate recycling plant, operational in 2028, will be located next to the existing mono-incineration plant." Silvester Bombeeck, managing director of SNB, says: "We selected the SusPhos technology for several reasons. With this technology, the sludge fly ash is completely converted into a phosphate fertiliser and a cement substitute. No waste remains. Furthermore, this technology requires relatively little energy and chemicals." Marissa adds: "In addition to these benefits, a large CO_2 reduction per year will be achieved."

In the Netherlands, there is no legal obligation to recover phosphate from wastewater, but SNB opts for this anyway. "Sustainable processing of sewage sludge is essential. In addition to the benefits that this brings to the environment, the current method of processing is no longer economically feasible in the long term. Therefore, we have agreed with the shareholders to fully commit to the recovery of raw materials. We are also working on the recovery of nitrogen, metals and sulphur from sewage sludge. Our goal is to achieve a reliable, circular, and affordable treatment of sewage sludge, now and in the future," Silvester says.

These projects pose quite a few challenges for SNB. Silvester: "As an organisation, we are not set up to run large projects and all the aspects that come with it. That's why we are making a number of changes to the organisation this year. But we also have to rely on input from partners. With SusPhos, we do that in a joint venture called S&S Feniks, to make the phosphate recycling plant a success."

Moving beyond land-spreading

Recovering phosphorus from ash first requires producing the ash, which depends on mono-incineration—a process of burning sewage sludge in dedicated facilities. Despite a reputation shaped by outdated notions of pollution, modern mono-incinerators are highly efficient, producing energy and destroying organic pollutants like PFAS and microplastics.

Germany leads the way here, alongside Austria and Switzerland, but adoption elsewhere has lagged due to cost, outdated perceptions of incineration, and fragmented policy. Yet Kabbe believes the tide is turning: "PFAS and microplastics are changing the narrative. Land spreading of sludge is increasingly seen as unsafe, and mono-incineration is gaining momentum."

Regulatory tailwinds and strategic timing

Germany's regulatory framework mandates phosphorus recovery from sludge, which, as Kabbe points out, is a key enabler: "Without regulation, utilities wouldn't prioritise this—there are too many competing investment demands. But once you show that plants like ours work and have a viable business case, it becomes a no-brainer."
More than just compliance, Kabbe sees this as a question of resource sovereignty. With phosphate rock controlled largely by a few exporting nations—and with additional pressure from its use in lithium-iron-phosphate (LFP) batteries—the strategic need for a European phosphorus source is becoming urgent.

Scaling the model: quality, volume, reliability

Kabbe is clear-eyed about what it will take for the circular economy in wastewater to succeed: "Quality matters. Volume matters. Reliability matters." Without all three, recovered resources remain boutique solutions—interesting, but not impactful.

The sewage sludge ash recovery model represents more than just a clever use of technology—it's a blueprint for how resource recovery can integrate with industrial ecosystems, close critical nutrient loops, and secure Europe's place in a materials-hungry future. "We're not trying to make a niche green product," Kabbe says. "We're trying to build a real and future proof industry."

A design drawing of the Ash2Phos commercial facility under development in Schkopau, Germany

resources in water magazine

column

Mark van Loosdrecht
Delft University of Technology

What's needed is a cultural shift in our sector

I've seen first-hand the transition from lab-scale discoveries to full-scale applications, having worked on the development of, for instance, granular sludge and Nereda technology for more efficient wastewater treatment and more recently Kaumera, a versatile byproduct of the Nereda process suitable for agriculture as well as industrial applications such as fire retardants. A persistent misconception in the resource recovery field is the belief that once a valuable resource is extracted, the market will naturally come calling. The reality is more sobering.

Unlike Nereda, which operated within an established market and was easily embraced by environmental engineers, products such Kaumera or biodegradeable plastics such as PHA (polyhydroxyalkanoates) enter unfamiliar territory. These are not merely recovered substances—they are potential ingredients for new materials and products. And that makes all the difference. Here, we're not selling into existing markets—we're trying to create them.

That's where many fall short. Technical feasibility doesn't equal commercial viability. Without a clear application and a committed end user, it's extremely difficult to design an extraction process or refine a product to the standards needed. Whether it's the smell, colour, or performance characteristics, if you don't know what your customer wants, you can't tailor your solution. And yet, in too many cases, the product journey stops at the wastewater treatment plant gate.

There are often complaints about regulation being the main barrier. Certainly, there are significant challenges in standardisation and legislative harmonisation. But often, the real bottleneck is product development. Regulations are often used as a scapegoat when the actual problem is that the recovered material simply isn't good enough or lacks a defined use case. Let's be honest with ourselves: without a compelling product, we can't expect to scale.

It's important to recognise the effort required; look at the chemical industry, and the sheer number of people who are assigned to development of, for example, a new washing powder. If you have a product from a recovered resource, you really need to find applications that are compelling enough to justify that level of R&D and commitment of time and resources.

What's needed is a cultural shift in our sector. We must actively engage the chemical industry, polymer markets, construction sector, agriculture—and all the other places where these recovered resources can truly make a difference. That means startups, multidisciplinary partnerships, and people willing to take on the risk and reward of true product innovation.

The future? I hope by 2040 we will see a fully functioning value chain for wastewater derived resources, akin to what we already have for metals like scrap iron. Recovery should become a routine part of how we manage waste—economically, not just environmentally. That future won't arrive on its own. It needs us to do the hard work now: develop real products, define real markets, and engage real users.

We are making progress. I'm encouraged by startups founded by students around Kaumera, and by others taking on the challenge with PHA. These are the pioneers. But if we want to scale, we need more of them—and a lot more support from investors, policymakers, and industry players willing to take a bet on a sustainable, circular economy.

> 'Recovery should become a routine part of how we manage waste—economically, not just environmentally'

Getting into Business

Nitrogen recovery
The commercial link in the nitrogen cycle

While nitrogen makes up 78% of the atmosphere, is a component of all proteins and can be found in all living systems, uncontrolled release of nitrogen within treated wastewater leads to eutrophication of water bodies. Meanwhile, it is vital to agriculture, and conventionally produced nitrogen fertilisers require natural gas as a feedstock.

The ingredients are all there to create momentum for more circular practices – however, globally, while nutrient discharge limits are getting stricter, there are still legislative barriers which prohibit the use of resources from waste streams for food production. This was addressed to a certain extent by the EU's Regulation 2019/1009, also known as the Fertilizing Product Regulation (FPR) which passed in 2022, and which introduced an end-of-waste status for fertiliser from waste streams (such as wastewater).

However, there are forward-looking utilities which have long established commercial operations selling recovered resources for fertlizer. This approach is exemplified by Veas, Norway's largest wastewater treatment plant which serves approximately 800,000 people in the Oslo metropolitan area. Veas removes nitrogen from wastewater and converts it into mineral fertiliser: it has been active in recovered nitrogen markets for over 20 years. So what has been holding others back?

A solid business case

Veas currently produces around 5,000 tonnes of ammonium sulphate solution annually, using a stripping column and an absorption column, both designed in collaboration with the Norwegian University of Science and Technology (NTNU). What were the biggest hurdles in establishing a steady customer base? Per Torp, CEO of Veas Marked, a subsidiary of Veas explains: "As a small producer, the main challenges have been ensuring consistent sales, securing sufficient storage capacity, and competing with the low prices in the larger international bulk market." However, Torp also notes that Veas's 2025 production is already sold out, indicating a healthy demand.

Does this produce a challenge in expanding production further? "Our primary focus is selling the entire volume of ammonium sulphate produced - rather than scaling up production for revenue purposes, our goal is to optimise the product's value while ensuring a stable and reliable sales pipeline", explains Torp. In fact, the market value of the ammonium sulphate is too low for it to be considered a profitable commodity on its own. "However, ammonium stripping is financially more viable than alternative technical solutions for nitrogen removal at the plant."

Per Torp
photo: Torbjørn Tandberg

Environmental and regulatory benefits

By utilising ammonia from wastewater, Veas eliminates the need for fossil-based ammonia synthesis, reducing greenhouse gas emissions whilst generating a more sustainable fertiliser alternative. Additionally, the sulphuric acid used in the process is a by-product of copper production, further enhancing its overall sustainability. The ammonium sulphate produced at Veas is CE-certified, ensuring it complies with European safety, health, and environmental standards. This certification not only guarantees the product's quality and traceability but also facilitates its acceptance on the open market within the EU, positioning it as a sustainable alternative to conventionally produced fertilisers.

The primary driver for making ammonium sulphate from wastewater financially competitive is the growing demand for sustainable, non-fossil-based products. However, further mechanisms would boost the circular economy still further: Torp suggests that certification schemes that provide a "proof of sustainability" will help differentiate the market into fossil-based and non-fossil alternatives. "Over time, this distinction is expected to improve the competitiveness of our product as sustainability becomes an increasingly important factor in purchasing decisions", he points out.

Leaning into the circular economy

The nitrogen recovery process is just one aspect of a broader strategy to minimize climate impact and optimise resource utilisation at Veas, however. Additional initiatives include supplying over 100 GWh of heat from untreated wastewater to district heating, producing Bio-LNG from biogas for energy applications, and establishing a CO_2 upgrading facility to remove 8,000 tonnes of CO_2 annually for carbon capture and storage.

Through advanced nitrogen recovery and other resource optimisation efforts, Veas continues to demonstrate how wastewater treatment facilities can transition from waste processors to resource producers, contributing to a lower-carbon, circular economy.

Advocating for nutrient circularity: a decade of ESPP action

Cooperl site visit: digestate processing, organo-mineral fertiliser production from manure and animal by-products

European Sustainable Phosphorus Platform (ESPP), established as a not-for-profit association in Belgium in 2014, has seen significant policy advances towards phosphorus sustainability.

ESPP was born from the convergence of diverse stakeholders – ranging from the water sector and fertiliser industry to national governments and technology providers – all sharing the common goal of advancing phosphorus sustainability. This remains core to ESPP's identity today, with over 50 member organisations across sectors including waste and water management, agriculture, chemicals, recycling technologies, research institutions, and public bodies. The platform is 100% funded by membership fees, enabling it to act consistently for long-term objectives.

Policy shifts in a changing world

Since its inception and supported by the Netherlands Nutrient Platform and the German Phosphorus Platform, ESPP has helped shape the policy landscape for nutrient recovery in Europe.

Major milestones include the inclusion of phosphorus recovery in the revised EU Urban Waste Water Treatment Directive (2024), the recognition of phosphate rock on the EU Critical Raw Materials list, and provisions in the EU Fertilising Products Regulation (FPR) for the use of struvite, recovered phosphates, and ammonia salts from waste streams, as well as mandatory phosphorus recovery in Switzerland, Germany, and Austria.

These achievements also reflect broader drivers: the 2008 global phosphorus price spike, persistent eutrophication challenges accentuated by climate change, the Russian invasion of Ukraine and resulting fertiliser crisis, and rising concerns about food and raw materials security.

Phosphorus recovery, once a niche environmental concern, is now increasingly seen as a strategic necessity for circular economy and food sovereignty goals.

Dialogue, data, and demonstration

What distinguishes ESPP is not just its advocacy, but its function as a neutral, technically grounded platform for dialogue. By convening targeted workshops and site visits – on topics ranging from nitrogen recovery and aquaculture nutrients (Bergen Norway 10-12 June 2025 with UNEP) to phosphorus in intensive livestock systems or the future EU Circular Economy Act – ESPP fosters trust and knowledge exchange between researchers, regulators, investors, and practitioners.

Site visits to initiatives such as Brittany's Cooperl cooperative, which produces 50,000 tonnes per year of organo-mineral fertilisers from manure biogas digestate, or TIMAC Agro's facilities for valorising secondary organic resources in fertilisers and biostimulants, help translate practice into policy. These examples show what's possible – but also highlight the hard realities of logistics, economics, and public acceptance.

Recent developments include the integration of phosphorus recycling into EU green finance taxonomy, and the emphasis on the Nutrient Circular Economy in the 2025 EU Clean Industrial Deal.
Over €750 million has been invested in EU-funded R&D on nutrient recovery over the past decade, including over 150 Horizon and LIFE projects.

Meanwhile, ESPP's communications – through eNews newsletters (115,000 email circulation), LinkedIn (2,500 followers and 115,000 views/year), and its extensive online catalogue of nutrient recovery technologies – enable objective and factual communication of regulatory, technical and scientific information.

ESPP membership is open to all organisations with activities related to phosphorus management or nutrient recycling in Europe: **phosphorusplatform.eu**

column

Olaf van der Kolk
AquaMinerals

It's the organisation & logistics, stupid!

'Together, we can move smarter, stronger, and faster'

The goal of the valorisation efforts of our resource recovery community is clear: stable, reliable, safe, sustainable, and financially attractive raw material chains. As a sector, we often focus on the technical side: research, pilot projects, and innovation. But when it's time to scale up to full-scale operations, many in the water/wastewater treatment sector hesitate. Why? In most cases, it comes down to uncertainty.

To move forward, we need to build confidence by creating solid propositions that reduce risks—not just for the water utilities, but for all players in the value chain. To do that, we must collaborate. Working together around a specific material flow or theme allows us to create volume, scale, and ultimately impact.

Collaboration brings multiple advantages. For example, it enables us to jointly address legal and regulatory barriers, conduct more efficient research, standardise and certify products and processes, and offer continuity to contractors. Without this collective approach, building and maintaining a stable chain becomes nearly impossible.

Let's take logistics as a concrete example. Transport is often a key cost factor in any value-chain case. Compare a setup with one supplier and one customer to a situation with 25 suppliers and 25 customers. The larger system will typically enjoy lower transport costs due to economies of scale. It also spreads the risk: in a one-to-one setup, if one party drops out, the entire chain is disrupted.

Mitigation through stockpiling in this one-to-one situation is possible, but inefficient and costly. Furthermore, logistics in a one-to-one relationship are often tailored and inflexible, making future expansion challenging. With more partners involved, logistics planning becomes more efficient and adaptable. We see this in practice with iron sludge produced at 80 drinking water treatment plants and supplied to 120 customers (digesters), giving the sector procurement power, scale to standardise, flexibility and continuity.

This same logic applies beyond logistics—to procurement, sales, R&D, lobbying, administration, and certification. By jointly building in safeguards in these areas, we make it easier for stakeholders to commit.

Yes, this approach requires a new way of working. It means that parties in the supply chain hand over some control to a coordinating organisation—one that has the capabilities to initiate and maintain new material chains. That may sound like a big step, but it's already happening.

AquaMinerals is a good example, but we're not alone. Across the globe, there are successful collaborative models around themes like energy (e.g., biogas) and specific material streams (e.g., Kaumera).

The bottom line: technical innovation alone will not get us there. Without strong organisation, smart logistics, and robust partnerships, promising ideas will remain stuck at the pilot stage.

Getting into Business

Water reuse Innovation meets urgency in South Africa

The Water Research Commission (WRC) of South Africa has been instrumental in promoting water reuse through research, policy advocacy, and capacity building, having recently hosted the 14th International Water Association (IWA) International Conference on Water Reclamation and Reuse in Cape Town.

In a candid interview, Jay Bhagwan, Executive Manager: Water Use & Waste Management, paints a picture of a country navigating structural limitations, climate variability and aging infrastructure—and responding with some of the most forward-thinking approaches to resource recovery and water reuse in the global South.

A mindset shift

"The first thing we need to change is the terminology," says Bhagwan. "We don't talk about wastewater anymore. We call it used water—because it's a used opportunity." This linguistic shift is more than semantic. It reflects a deeper realignment in South Africa's strategy: away from linear models of water extraction, use, and disposal, toward a resource-based view of the urban water cycle.

One of the key players in this transition is industry. Chemical giants like Sasol and beverage companies such as Heineken are pushing for zero effluent footprints—not out of corporate altruism, but necessity. "In cities like Johannesburg, water allocations are maxed out. You can't grow unless you find a new water source—and reuse is that low-hanging fruit," says Bhagwan.

The economics are shifting too. Bhagwan cites examples where reused water, treated to advanced standards with ultrafiltration and reverse osmosis, is now cheaper than municipal supply—particularly for high-volume industrial users who face increasing tariffs and restricted allocations.

The power of decentralisation and the toilet revolution

One of the WRC's most radical innovations comes in the form of off-grid, non-sewered sanitation systems—toilets that don't flush, don't require sewers, and don't produce wastewater. "We are entering the age of the air-fryer toilet," Bhagwan quips. "Like flat-screen TVs, these technologies are still niche—but within a few years, costs will plummet, and adoption will explode."

Through initiatives like SASTEP (South African Sanitation Technology Enterprise Programme), these systems are being scaled up from pilots to public policy. Some models use combustion to process human waste, producing minimal residue and zero effluent.

Jay Bhagwan WRC

This is not theoretical. Bhagwan references working with global leaders such as Cranfield University. He notes: "There's a need to decouple sanitation from centralised, water-intensive systems and move towards something more flexible, resilient, and circular."

Meanwhile, fecal sludge management is undergoing a renaissance. With landfill space shrinking and incineration facing emissions hurdles, South Africa is embracing pyrolysis and other thermal treatment systems. These not only sanitize sludge but also recover energy and nutrients, contributing to a truly circular sanitation economy.

Water security as a business imperative

Bhagwan advocates for a national reuse platform—a centralised initiative akin to South Africa's renewable energy IPP model. Municipalities could list their underused treatment assets, and the government could facilitate private investment to retrofit and operate them for reuse, bypassing fragmented municipal approvals.

"This isn't about luxury or climate ambition. It's survival," Bhagwan states. "Reuse is not optional. It's the only way forward."

The WRC is now modelling scenarios where 90% reuse becomes standard, with industry as the primary offtaker and municipalities redirecting fresh water to households. Human consumption of reused water remains politically sensitive, but that debate is fast approaching.

Jay Bhagwan is unambiguous: innovation must meet urgency. And while South Africa is already charting bold new territory—from combustion toilets to industrial water compacts—the challenge now is scale, regulation, and public trust.

Getting into Business

Cellulose CirTec's mission to mainstream cellulose recovery

A pioneering technology

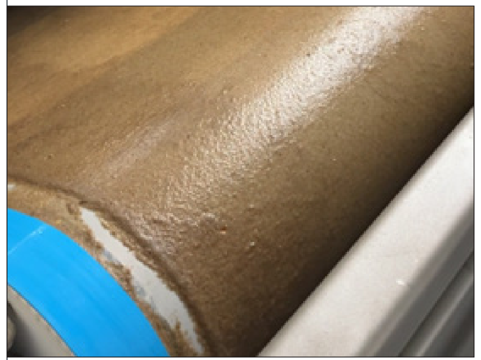
The average European uses approximately 10-14 kg of toilet paper per year, and it is estimated that 30-50% of the suspended solids in the influent of a wastewater treatment plant can be attributed to this. CirTec, a Dutch innovation company and part of Nijhuis Saur Industries (NSI), Saur's Industrial Water Division, is pioneering a technology that turns flushed toilet paper into a high-quality, carbon-negative resource for industrial reuse.

A valuable resource in the waste stream

CirTec's CellCap and CellPro technologies intercept the waste stream during primary treatment. Cellulose fibres are separated, sanitised, and dried, producing a clean, hygienised material that can be completely repurposed in a wide range of industrial applications. Adding the Cellvation technology, the fibres are transformed into a widely used functional additive for asphalt production or biobased composite for building materials.

In partnership with Severn Trent Water, AtkinsRéalis, and JN Bentley, and Cranfield University, CirTec is now constructing the world's first large-scale cellulose recovery plant at Strongford STW in the UK—a facility that will demonstrate how cellulose recovery can be implemented at scale.

This isn't just upcycling for the sake of it. "When cellulose is removed from the incoming sewage, the plant capacity increases, and sludge production is reduced resulting in lower chemical use and lower energy consumption," says Marit van Veen, CirTec's Sales Manager. "That's a huge OPEX benefit for water authorities. Plus, it reduces CO_2 emissions—each ton of recovered cellulose offsets two to three tons of CO_2."



Cellulose

From fibres to fine chemicals: industrial potential

Beyond construction materials, asphalt and insulation, CirTec and partners are investing in a value-added clean-technology called Cellforce, breaking cellulose down into industrial sugars. These (non-food) sugars can serve as a building block for bioplastics production, green chemical applications and advanced bio-fuels. "It's a high-value application with a more uniform quality requirement," van Veen explains. "And potentially a game-changer in how these recovered materials support the resource and energy transition away from fossil origin."

Cirtec's **Marit van Veen**

Know your market —or risk losing it

Pioneers often face bumps in the road, and in this case, the largest is regulatory fragmentation. Despite the EU's circular economy ambitions, there is no harmonised "end-of-waste" status for cellulose.

For CirTec, understanding the market has been key to success. "We always start by asking: what does the market need? Then we work backward," says Marit van Veen.

Ironically, one of the biggest surprises didn't come from regulators or engineers, but from consumers. At a technology symposium, CirTec handed out drinks and cake on plates labelled "Made from toilet paper." Despite being water professionals, most attendees chose traditional dishes. But when CirTec repeated the same experiment at a local market, the public had no issue choosing the plates labelled "Made from toilet paper".

A study by the University of Groningen confirmed that emphasising the origin of recycled material can reduce consumer acceptance—even if the material is perfectly safe. The takeaway? Focus on quality, not origin.

Building a scalable system

With a demonstration plant now operational in the UK, a flagship plant upcoming in The Netherlands and new markets opening in France and beyond, the company is laying the groundwork for a pan-European value chain of bio-based materials derived from wastewater.

In a world striving for circularity, CirTec is showing that what goes down the toilet doesn't have to go to waste. It is a valuable resource—if we're smart enough to recognise it.

Getting into Business

Struvite recovery: a business, maintenance and food security case

Struvite installation

Most of the phosphorous the world uses for growing crops comes from rock extraction technology in Morocco and China. Using alternative phosphorous sources such as struvite from wastewater will not only boost its availability, but it will also help to democratise access to phosphorous, and to open up new markets to help future proof supply.

Defining the challenge

According to Alex Veltman, senior wastewater technologist and researcher, Waterschap Hollandse Delta, the South Holland islands water authority, the biggest challenge he has encountered so far has been legal obstacles. Veltman's research and development while at Waternet Amsterdam helped to adjust the wastewater treatment process to capture struvite crystals.

"The key is to think in terms of business models, rather than simply what's possible, which is not always a normal way for water authorities to think," Veltman said. After building a pilot reactor, (using an AirPrex approach, in which struvite is collected from sludge) he took some of the struvite it had produced to a large, local fertiliser company with experience of struvite from the potato industry. "They told me that if I can make it, they can sell it."

However, despite this strong interest, he found that although struvite was admitted as a fertiliser in the Netherlands, it still had a waste status, which meant it was difficult for him to sell it. It took seven years to get a government opinion on the end-of-waste status for struvite. In the meantime, it was already brought on the market based on self-declaration. As required for all chemical products, the struvite was REACH-registered. The legal opinion and the risk assessment carried out for this purpose ensure that struvite is accepted as safe for use as a fertiliser.

A shift towards revenue? The US perspective

Currently, the main driver for struvite recovery is operational cost savings, for example, dewatering and reduced maintenance. However, the future looks brighter for revenue generation, both in Europe and in North America.

For example, around 19,000 tons of struvite are recovered annually in the US, almost entirely by Ostara, which produces Crystal Green fertiliser using its patented nutrient recovery technology. The product can sell for between €250-300 a tonne.

Ron Restum, chief commercial officer at Ostara, the producers of Crystal Green and Crystal Green Pearl, believes that there has been a change in attitude in the agricultural sector: "We've experienced a shift in the market to be interested in products that will give crops the nutrients they need while also protecting the environment."

A growing demand

Veltman suggests that struvite prices are only going to go up as demand continues to grow. He adds: "A business case I put forward for a waste treatment plant in Amsterdam, for example, showed that it was possible to achieve a return on investment in approximately six years.

This was largely based on lower maintenance costs and improved dewatering of the sludge – so before the value of the struvite was factored in. This is based on an initial investment of €3 million, annual costs of €700,000 and benefits of €1.5 million, giving a cost saving of €500,000 a year."

Showing a way forward

Globally, it is assumed that approximately 10% of the total mass of phosphorous goes through WWTPs with enhanced biological phosphorus removal (EBPR) facilities, which means struvite processing can recover approximately 5% of that phosphorous. However, Veltman believes these facilities show a way forward: combining struvite processes with other methods has the potential to scale phosphorous recovery from to as much as 80%.

Veltman concludes: "Like most things, once the legislation is in place then the techniques will develop."

Transforming Singapore's water resource recovery efforts

PUB, Singapore's National Water Agency, is pursuing an ambitious agenda of resource recovery that extends far beyond water recycling. With a commitment to achieve net-zero emissions by 2045, PUB is reimagining the entire water loop, turning what was once considered waste into valuable resources.

NEWater: The foundation of Singapore's water circularity

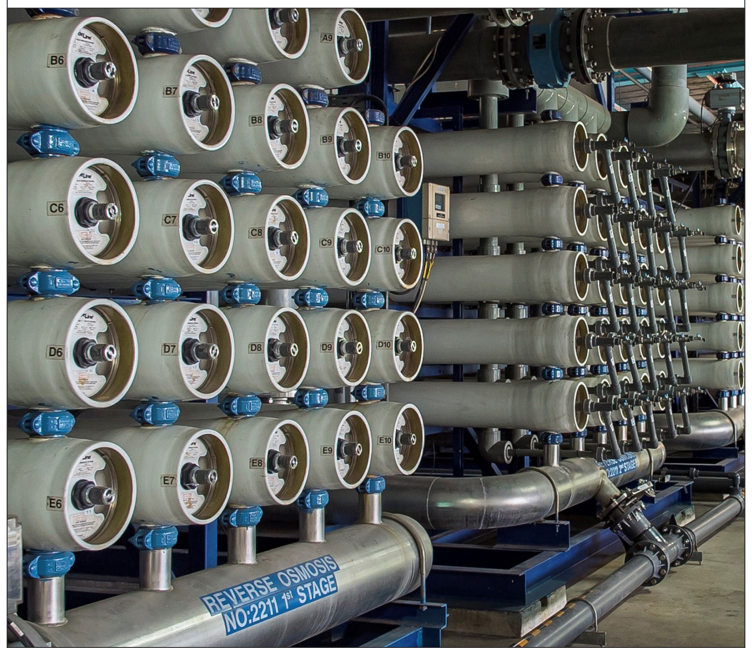
A cornerstone of Singapore's success in water sustainability is the internationally acclaimed NEWater programme, launched in 2002. NEWater transforms used water into ultra-clean, high-grade recycled water through a robust treatment process involving microfiltration, reverse osmosis, and ultraviolet disinfection. NEWater is extensively used in the industrial sector, such as for industrial cooling and semiconductor manufacturing and also to top up our reservoirs and blended with raw water to supplement our potable water supply during dry weather.

Turning waste into power

Going beyond our efforts to close the water loop through water recycling, PUB is also leveraging anaerobic digestion at water reclamation plants (WRPs) to convert sludge into biogas for power generation. This move toward energy-positive water treatment is exemplified by the Tuas Nexus, a groundbreaking facility that co-locates water and waste treatment infrastructure.

Recovery of valuable resources: building the circular chain

In line with Singapore's Zero Waste Masterplan, PUB is piloting nutrient and mineral recovery technologies to extract value from used water and seawater. Launched in 2019, the masterplan underpins a national vision to reduce landfill waste by 30% by 2030 and move towards a circular economy across food, packaging, electronics, and industrial waste streams—including water.



NEWater reverse osmosis installation

PUB plans to implement technologies for capture of ammonia from digestate using stripping technologies and investigating the extraction of minerals from seawater reverse osmosis brine—transforming what was previously discharge into marketable materials.

One of PUB's most ambitious ventures lies in advanced thermal treatment of sludge, using slagging gasification and pyrolysis. These technologies convert sludge into construction-grade materials such as slag for concrete and biochar for lightweight applications. By avoiding landfill and producing valuable end-products, PUB's approach exemplifies circular economy principles in action.

These technologies also demonstrate the value of long-term investment. PUB's approach includes de-risking innovation through government support, with agencies like the National Research Foundation (NRF) and Enterprise Singapore co-funding R&D. This framework helps accelerate promising technologies from lab to full-scale deployment.

The role of policy and finance

Singapore's policy ecosystem has been instrumental in catalysing innovation. To finance our ambitions in the area of sustainability, PUB has established a Green Financing Framework, enabling access to green bonds and sustainable investment instruments that align with the Singapore Green Plan 2030. Singapore's regulatory agility has been key. Coordinated engagement with local environmental and health authorities ensures that resource recovery innovations are not stymied by outdated or overly rigid regulations.

Challenges and cultural shifts

Despite good progress, PUB faces familiar challenges: retrofitting infrastructure, building public confidence in recycled materials, and overcoming roadblocks in scaling up nutrient and mineral recovery. In Singapore's dense urban setting, land for soil-based agriculture is limited, posing barriers to local nutrient reuse.

The solution lies in collaboration and culture. PUB works closely with industry, academia, and regulators to co-develop market pathways and explore non-traditional uses for recovered materials—from fertilisers to building products.

As PUB continues its journey toward energy-positive and zero-waste operations, it stands as a compelling case of how even the smallest nations can lead the way in transforming waste into opportunities.

Getting into Business

Energy from wastewater
Unlocking the energy value in sludge

Globally, about 45 million metric tons of dry solids are produced annually. Sludge and biosolids hold the potential to be transformed into fuel, fertiliser, or other marketable products, while management costs for sludge and biosolids range between 30-50% of a wastewater treatment plant's OPEX. Under these imperatives, wastewater treatment is rapidly evolving into a circular economy engine, and among the pioneers in this space is Cambi, a Norwegian technology company known globally for its thermal hydrolysis process (THP).

Speaking with Harald Kleiven, Cambi's Sales Director for Emerging Markets, it's clear that the conversation around wastewater treatment has matured. "It's not just about treating water anymore. It's about extracting value—energy, nutrients, biosolids—while reducing the overall environmental footprint," Kleiven says.

The case for sludge

Cambi's THP technology pre-treats sludge under high temperature and pressure, breaking down complex organic molecules and making them more digestible in anaerobic digesters. The results are increased biogas yields, pathogen-free biosolids suitable for agricultural use, and a significant reduction in sludge volume.

By increasing biogas production—often by 30–50%—THP contributes to energy self-sufficiency or even net energy production. Some plants are now generating excess electricity or biomethane, feeding it back into the grid or using it as vehicle fuel.

Transparency, data, and success stories

But it's not just about the technology. As Kleiven emphasizes, the broader ambition is to integrate wastewater treatment into the circular economy. "We need to move beyond compliance and see treatment plants as resource optimisation hubs," he says.

This involves rethinking planning, finance, and policy. One of the recurring challenges is that sludge treatment is often treated as an afterthought—budgeted last and least. "If you want real sustainability gains, you can't just focus on the clean water part. Sludge is 50% of the operating cost and 90% of the headache," Kleiven jokes—but the point is serious.

Thermal hydrolysis is a two-stage process combining high-pressure boiling of waste or sludge followed by a rapid decompression. This combined action sterilises the sludge and makes it more biodegradable, which improves digestion performance

Catalysing change through collaboration

Kleiven sees growing interest from not only utilities, but also industrial users, EPC contractors, and investors looking for impactful sustainability opportunities. One area of particular opportunity lies in co-digestion—using THP to treat a mix of municipal sludge and food or industrial waste. This can unlock even higher energy yields and solve organic waste challenges for cities and industries alike.

As the conversation shifts from wastewater treatment to resource recovery and circularity, Kleiven encourages industry media, including conference publications, to broaden the audience. "We need to stop talking only to ourselves," he says. "The message should resonate with urban planners, regulators, food producers, and even the public."

He suggests that stories focus not only on technical details, but on human and environmental impact—how a project helped a city reduce carbon emissions, lower energy bills, support local farmers with fertiliser, or produce biofuel. "People care about outcomes, not inputs," he adds.

Looking ahead

With over 90 thermal hydrolysis plants worldwide, Cambi's footprint is growing. However, Kleiven sees much more room for adoption. "There are thousands of plants out there still doing digestion the old way, still hauling wet sludge to landfill or incinerators," he says. "We need to accelerate change."

Part of that acceleration involves a cultural shift—from compliance-based thinking to opportunity-driven strategies. The economics are aligning, the technology is proven, and the climate imperative is only getting stronger.

"In the next decade, the question won't be 'should we do resource recovery?' but 'why didn't we do it sooner?'"

'We need to move beyond compliance and see treatment plants as resource optimisation hubs'

Wastewater as bioenergy: a Spanish perspective

Water moves energy – whether in hydropower or steam turbines, it is one of nature's most valuable resources and key in a green, decarbonised economy. Wastewater even more so, as its treatment offers an opportunity to produce cleaner energy—its organic content can be harvested as an energy source, as Aqualia's projects show.

Domestic wastewater (WW) contains substantial energy—about 2 kWh th/m^3, yet conventional aeration consumes 0.5 kWh el/m^3 to convert this energy-rich matter into sludge. Through anaerobic digestion (AD) and co-generation, about 30% of plant electricity can be recovered.

With optimised aeration, or intensified AD with pre-treatment, co-digestion or temperature phasing, up to 50 % can be covered internally, but full energy neutrality requires external renewables, as contemplated in the new EU UWWT Directive.

Beyond energy, wastewater carries nutrients: each European citizen contributes on average 4.5 kg of nitrogen, 1 kg of phosphorus, and 2 kg of potassium annually. If recovered, these can replace artificial fertilisers – their production consumes 10–15 kWh/kg N of fossil fuels.

Across Europe, innovative projects drive a vision of circularity forward, converting WW into energy or harvesting subproducts. A challenge to recovery is dilution by flushing waste with clean water. Horizon2020 projects such as **run4life-project.eu** explore decentralised treatment of concentrated streams.

In Nigran, Galicia, blackwater from an office is converted directly into biogas using anaerobic membrane bioreactors (AnMBRs). This combination of AD and ultrafiltration cuts biosolids by a factor 4, and produces nutrient-rich disinfected water for irrigation, cooling or flushing.

This sewer mining concept is further explored in **LifeZeroWasteWater.com** and **Rewaise.eu,** where AnMBRs placed on sewer lines or in industrial parks yield reuse water with a positive energy balance, reducing costs to irrigate golf courses or public parks, and recovering water, nutrients and bioenergy.

An All-gas car powered with algae biomethane

Energy autonomy was demonstrated with **all-gas.eu** where algae grow on WW nutrients in raceway ponds, converting sunlight into oxygen. This feeds bacteria converting carbon to CO_2, fuelling the algae, while both organisms clean the water.

Algae and bacteria yield high sludge production, and the biogas generated by AD is used to fuel vehicles. As no electricity for blowers is needed, a positive energy balance is achieved while producing reuse water, digestate as fertiliser, and biofuel.

A demo plant in Chiclana/Cadiz treats 1,000 m^3/d and produces 100 t/yr of biomass per hectare, yielding 14,000 kg CH_4 (methane) per year. Modern compressed natural gas engines consume 4.5 kg CH_4/100 km and typically run 15,000 km/yr—thus, 20 cars can be powered from a wastewater plant serving a population of 5,000.

Viability was shown with vehicles run on algae biomethane for 70,000 km over two years, meeting all EU standards without engine stress. Since the 2017 scale-up of All-gas in Chiclana, municipal vehicles are fuelled there exclusively by biomethane.

Another pathway to harvest WW energy is microbial desalination cells (MDC). To avoid the high electricity use of reverse osmosis (up to 4 kWh/m^3), bioelectroactive bacteria like *Geobacter* take up WW's organic energy and generate electric currents. This potential difference between electrodes causes salt separation through ion-exchange membranes, allowing desalination without external energy. From a WW and saline stream, the MDC produces treated reuse water and a desalinated output, as shown by the MIDES project in two prototype units treating up to 4 m^3/d.

'Innovations like these show that sustainable desalination, water reuse and resource recovery are technically feasible'

Innovations like these show that sustainable desalination, water reuse and resource recovery are technically feasible. The next step is clear: aligning regulatory frameworks and investment strategies to mainstream these solutions within Europe's policy landscape.

column

Ana Soares
Cranfield University, UK

With contributions from:
Sergio Lima, Jason Askey-Wood & Mark Douthwaite, Green Fuels Research, UK; David Inman, Anglian Water, UK; Ideh Heidari, Firefly Green Fuels, UK

Why sewage could boost sustainable aviation fuel

Across Europe, bioresources from wastewater treatment plants (also called biosolids, stabilised sludge or anaerobic digestion cake) are managed in various ways. The European Sludge Directive (86/278/EEC) promotes the safe use of bioresources in agriculture, setting limits on heavy metals and requiring treatment to protect human health and the environment.

Nevertheless, current unknowns and political pressures concerning residual amounts of microplastics, PFAS and the presence of antibiotic-resistant bacteria/genes in bioresources are raising real concerns around bioresources-to-land approaches, and these concerns are reaching the public via sensationalist media coverage.

These factors, coupled with nutrient (nitrogen and phosphorus) saturation in farmed and natural environments, have supercharged the development of innovative approaches to manage bioresources safely. One of these approaches uses hydrothermal liquefaction (HTL) as conversion technology.

HTL mimics the natural geological formation of fossil fuels but accelerates the process. What takes nature millions of years can be achieved in mere minutes by applying high pressure in a water-rich environment. In the HTL process, biocrude is produced, which can be further refined into sustainable aviation fuel (SAF).

UK company Firefly Green Fuels (flyfirefly.uk) is currently developing a solution to produce sustainable aviation fuel (SAF) from sewage biosolids using HTL as key enabling conversion technology. Work on Firefly's first-of-its-kind commercial-scale facility is currently underway and the facility is expected to be in operation by 2028/29. Firefly's sewage biosolids-to-SAF process is a game-changing innovation in sustainable aviation, which promises to make a significant contribution towards the UK government's SAF mandate (10% by 2030).

SAF is gradually being adopted in the UK as part of national efforts to decarbonise the aviation sector. Several UK airports, including Heathrow and London City, have begun using SAF blends in commercial flights, and the UK government is supporting this shift through its Jet Zero Strategy and a planned SAF mandate from 2025. The potential for SAF in the UK is significant, with estimates suggesting it could meet up to 50% of aviation fuel demand by 2050, especially if produced from domestic feedstocks such as waste oils, agricultural residues, or sewage sludge via technologies like hydrothermal liquefaction.

As a by-product of the HTL process, an aqueous effluent is also produced, together with a solid co-product (biochar) and an off-gas stream, mainly composed of biogenic CO_2. The aqueous effluent is rich in nutrients and carbon that can be further valorised for products such as biogas or bioplastics. Alternatively, the nutrients can be made into new fertilisers and chemicals, closing the waste loop even further.

The potential impact of these technologies is already being felt across many industries and sectors. UK water companies, for example, are excited about Firefly's technology and its potential for safe management of biosolids whilst lowering costs and creating new value. Several have already partnered with Firefly and have committed to supply biosolids to the company's facility. Sustainable aviation fuel technology is an extremely positive development for the UK and has potential to become a significant global bioresources and energy production solution.

'Sustainable aviation fuel could meet up to 50% of UK aviation fuel demand by 2050, from feedstocks such as waste oils, agricultural residues, or sewage sludge'

resources in water magazine

column

Wilbert Menkveld
Nijhuis SAUR Industries

Closing the loop: how service-driven circularity can unlock the true value of wastewater

In recent years, I've spoken with many people in the water sector – utilities, industrial operators, and policymakers – and I keep hearing the same thing: "We want to reduce our carbon footprint, be more circular, but how do we organise this?"

The ambition is there. The technology is ready. But time and again, the real stumbling block is turning that ambition into day-to-day operations, especially when it comes to recovering valuable resources such as nitrogen, phosphorus, cellulose from wastewater and calcite and ferric sludge from drinking water production.

What I've learned is that the real challenge isn't just technical, it's practical. It's about giving people the confidence, the tools, and the operational support they need to make circularity work. That's why I'm convinced that the future of resource recovery isn't just about selling technologies, it's about offering resource recovery as a service.

Why the service model matters
Let's be honest: most companies or municipalities don't have in-house experts in selecting the right proven technology, the operations of these new type of technologies, or in how to bring the recovered product back as product with value in the market. They're focused on their daily business: delivering clean water, meeting regulations, and keeping operations running. Expecting them to manage complex recovery systems and figure out how to sell recovered products is unrealistic.

So instead of handing over a piece of machinery and walking away, we need to stay at the table. By offering fully managed, performance-based services, we take away the complexity and give our clients what they really need: full service!

How it works in practice
Here's what this looks like in real life:

1 **Modular, standardised plug-and-play systems**
We use standardised, proven solutions like ammonia, phosphorus and cellulose recovery solutions that can be dropped into existing infrastructure. No major overhauls. No endless pilot projects. Just straightforward integration with a quick path to value.

2 **Performance-based service contracts**
Rather than expecting clients to master dosing or deal with operations, we operate and optimise the systems for them. Everything is monitored remotely. We're responsible for performance, and we share in the value that's recovered. It's a true partnership.

3 **From waste to product: valorisation and sales**
One of the biggest roadblocks I see is that many organisations don't know what to do with the recovered materials. That's where we open doors partnering with companies like Recell for cellulose applications via our joint venture Cellvation and AquaMinerals to turn nutrients into fertilisers. It's not just about recovery; it's about real-world impact and market access.

4 **Smart systems, real-time insights**
All systems are controlled through real-time monitoring and digital twins. This isn't just tech for tech's sake – it's about making the entire recovery process smarter, more resilient, and more efficient. The result? Less downtime, better yields, and more transparency.

Enabling action through partnership
We often talk about the circular economy in big-picture terms, but implementation is where most people get stuck. What I've seen is that when we offer resource recovery as a service, we move from theory to practice. From complexity to clarity. From hesitation to action.

It's especially powerful for industries and water boards that are under pressure to lead on sustainability, but don't always have the internal capacity to make that leap alone. This approach gives them not just tools, but trusted support and the confidence that they're not navigating this transition by themselves.

Because in the end, we're not just helping clients recover resources from wastewater, we're helping them reducing the carbon footprint and creating value with wastewater. Not a problem to be managed, but a solution waiting to be unlocked.

'And that's a future I'm proud to be building together with many others!'

resources in water
from novel concepts to business

IWA Resource Recovery Conference Special

“One of the most demanding aspects of resource recovery is matchmaking: aligning recovered materials with industrial or commercial end users. The key to our success? Standardisation and ensuring security of supply.”
Olaf van der Kolk AquaMinerals

“Perhaps the most important lesson we’ve learned is that collaboration is not optional—it is essential.”
Sander Mager Amstel, Gooi & Vecht Water Board

“Being successful in resource recovery is a very fundamental challenge that cannot be fixed by incrementally transforming utilities.”
Prof. Bernhard Truffer Eawag/Utrecht University

“Presenting recycled products based on quality rather than origin helps adoption.”
Marit van Veen CirTec

“It’s not just the technology—it’s the partnerships, policies, and public support that make the difference... We’re not just recovering resources from wastewater. We’re redefining what waste means.”
René Rozendal Paques Biomaterials

“Quality matters. Volume matters. Reliability matters. We're not trying to make a niche green product—we’re trying to build a real and future-proof industry.”
Christian Kabbe EasyMining Germany

“The real challenge isn’t just technical, it’s practical. It’s about giving people the confidence, the tools, and the operational support they need to make circularity work.”
Wilbert Menkveld CTO Nijhuis SAUR Industries

“Sustainable aviation fuel could meet up to 50% of UK aviation fuel demand by 2050, from feedstocks such as waste oils, agricultural residues, or sewage sludge.”
Ana Soares Cranfield University

“I hope by 2040 we will see a fully functioning value chain for wastewater derived resources, akin to what we already have for metals like scrap iron. Recovery should become a routine part of how we manage waste—economically, not just environmentally. That future won’t arrive on its own.”
Mark van Loosdrecht Delft University of Technology

“The case for resource recovery is getting stronger... we have cause to be courageous.”
Kala Vairavamoorthy IWA Executive Director