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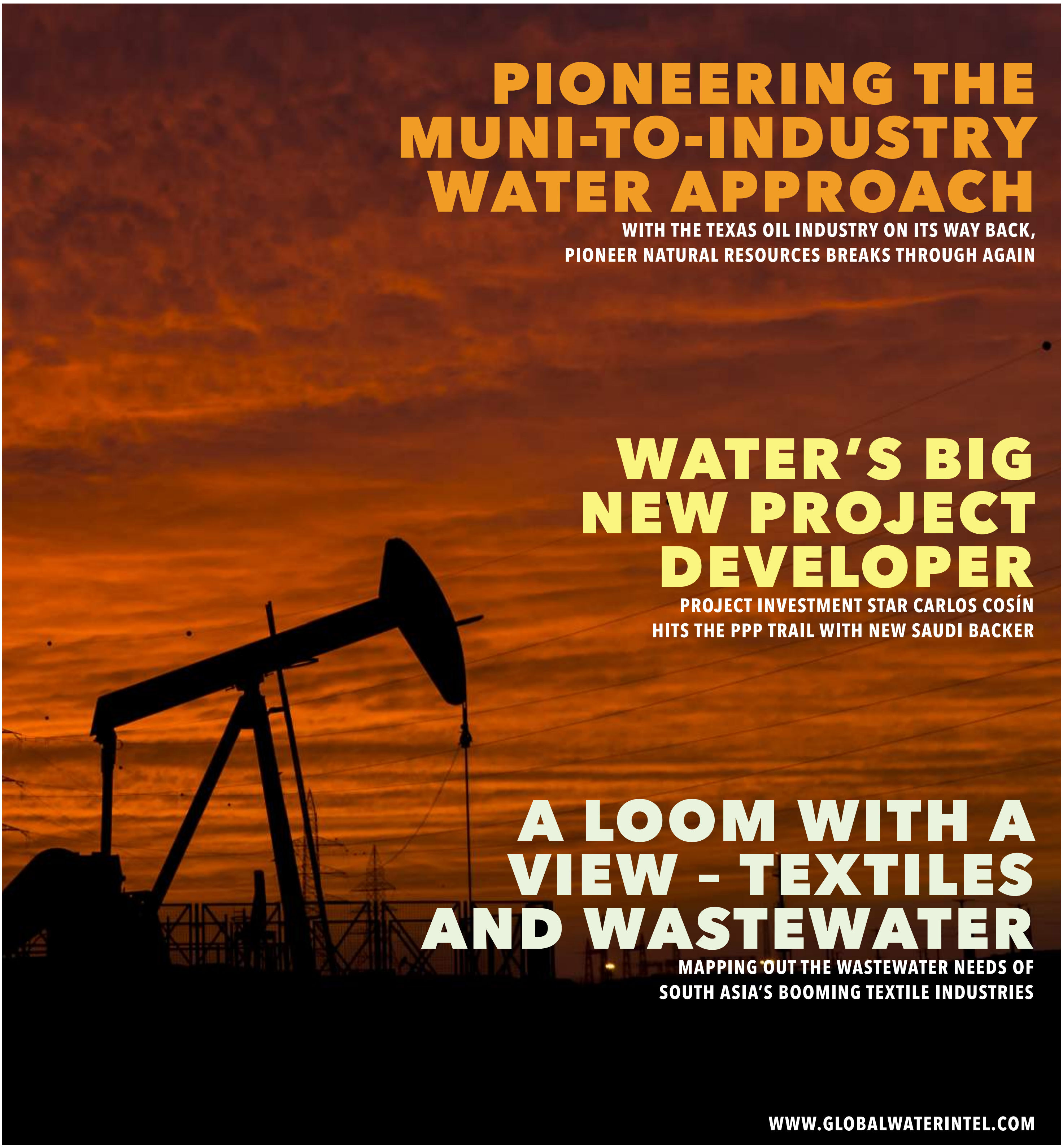

PIONEERING THE MUNI-TO-INDUSTRY WATER APPROACH

WITH THE TEXAS OIL INDUSTRY ON ITS WAY BACK, PIONEER NATURAL RESOURCES BREAKS THROUGH AGAIN

WATER'S BIG NEW PROJECT DEVELOPER

PROJECT INVESTMENT STAR CARLOS COSÍN HITS THE PPP TRAIL WITH NEW SAUDI BACKER

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MARKET MAP

Beating the burn rate for resource and energy recovery from sludge

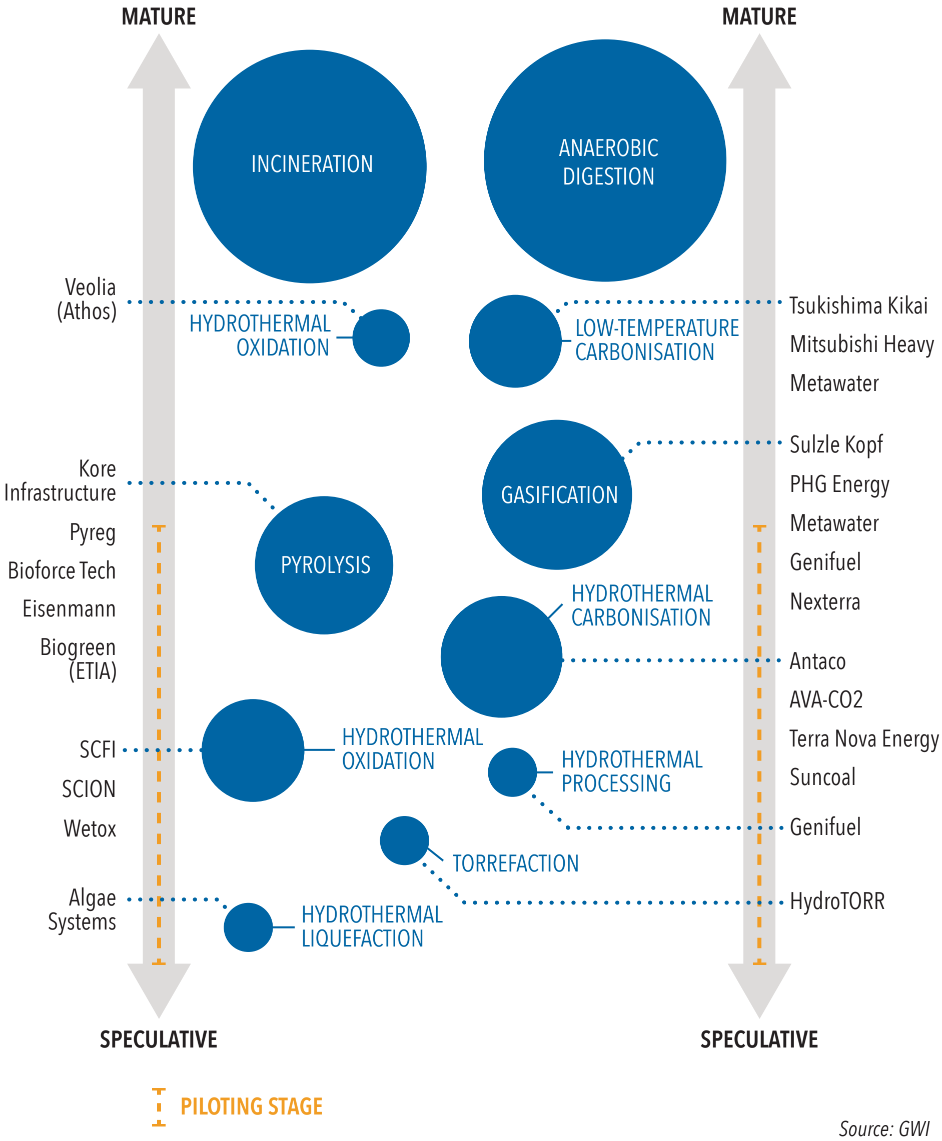
Traditional methods of managing sludge as a waste product are being challenged by technologies carrying the promise of sludge as a resource for energy and nutrients. What is fuelling the interest?

It has long been known that sludge is full of valuable commodities and energy potential, however the economics of realising these benefits has rarely added up. Recovery of biogas for energy generation is the notable exception, while recovery of phosphorus from both wet and dry sludge is an area where the economics are at a tipping point. This may be just the beginning: there is growing interest in turning sludge into a renewable energy source such as renewable natural gas, low-sulphur diesel, biocrude oil, or biocoal (an alternative to fossil coal), through modifications to thermal reduction processes traditionally employed on solid wastes (*see chart left*). Technologies specifically designed for wet wastes such as hydrothermal processing are also emerging. The interest "began to occur about ten years ago when the price of oil soared above $100 a barrel", according to Joe Zuback, president of consultancy Global Water Advisors. There is also growing interest from utilities to enhance their sustainability agenda.

Currently, the single most useful and valuable product to come from treating sludge is biogas, which is produced through a treatment process that has been employed at municipal wastewater treatment plants (WWTPs) for several decades - anaerobic digestion (AD). The most common form of recovering energy from sludge is converting the biogas into electricity to power other processes at a treatment facility in order to reduce the plant's energy footprint. The process can be tweaked and advanced in several ways to recover more biogas, notably with the inclusion of a thermal hydrolysis pretreatment step. Enhancing the AD process will be the subject of a later GWI Market Map.

MATURITY OF THERMAL REDUCTION TECHNOLOGIES

The practices of anaerobic digestion and incineration will continue to endure, but other technologies yielding valuable by-products are making a move. The size of the bubble roughly indicates the number of tech carriers.



Source: GWI

Reduce then plunder

Though recovering value from sludge to create another revenue source or push a plant further towards energy neutrality seems an attractive proposition, presenting the business case of a technology based solely on what it can recover can prove misguided. "The key driver for doing anything with sludge is getting rid of it for the lowest possible cost," explained Zuback. "The cost of disposal has gone up in the USA and UK, so anything you do to recover material, particularly energy, has got to reduce the volume [of sludge]."

Thermal processes, whereby sludge is subjected to high temperatures, are most effective at volume reduction, but have generally not been used on sewage sludge because it is a wet waste. Of these processes, incineration has gained the most ▶

traction, generally being used when sludge cannot be applied to land as fertiliser. It also does not require significant drying ahead of it, whereas many other thermal technologies need much higher dry solids content (e.g. over 50%). "The sludge must be taken at a minimum of 25% dry solids otherwise you have to add gas," explained Michel Bouvet, director at consultancy Inopex. "At 25% or more [dry solids] we achieve autothermal incineration, otherwise you need gas to burn it."

Incineration produces steam to generate electricity, which can be used to power a treatment plant or fed into the wider grid, as well as a solid ash residue that can be used in building materials or as a source for phosphorus. However, a waste product of incineration is poisonous flue gas, which needs to be cleaned up before it is released to the atmosphere. The process is increasingly coming under attack because of environmental concerns and growing regulation on air quality, particularly in the United States, and therefore alternatives are beginning to look attractive. As well as effective reduction of sludge volume (which remains paramount), such processes can yield valuable products such as biochar and syngas, a combination of carbon monoxide and hydrogen, that can be converted further into marketable products such as compressed natural gas.

Thermal reduction: value addition

One advantage of other thermal processes such as pyrolysis and gasification is that they convert the carbon in the sludge to products that have varying degrees of calorific value. Furthermore, they do not involve a direct burn (like in incineration) as oxygen is not involved in breaking down of the sludge.

Pyrolysis has been extensively used on dry feedstocks but has yet to garner much success treating sludge. However, interest in pyrolysis is growing because of the need to move away from land-based sludge management and to maximise energy recovery, according to Executive Vice President of Business Development for Kore Infrastructure, Steve Wirtel.

With its pyrolysis technology, California-based Kore Infrastructure is focusing on certain products. "We are focusing on converting the syngas into methane through a methanisation process to make a high purity renewable natural gas. That can be compressed for vehicle use or put into a pipeline," Wirtel told GWI. "We are also looking at taking the hydrogen portion out, compressing that into a renewable hydrogen source. Through talking to potential users of the energy, there's more of a drive for either renewable natural gas or ▶

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>
> Joe Zuback, Global Water Advisors

hydrogen. As a result, we are emphasising pyro-gas production over pyro-oil production."

Kore has developed a pyrolysis technology that is slightly different to others on the market, in that it operates at a higher temperature (over 500°C) to avoid the production of pyro-oil (which could be turned into biocrude to substitute fossil crude oil) that is traditionally produced within the process.

It is now developing a commercial demonstration facility for its high-temperature pyrolysis technology, following a six-year pilot project at the Los Angeles County Sanitation District (LACSD) 400MGD Joint Water Pollution Control Plant. The commercial facility – due to come online towards the end of 2017 – will demonstrate the technology for interested parties. "We've had a lot of interest from around the globe, and in particular China, wanting to see this technology when it's running," Wirtel said. Kore has won a performance-based contract to manage a portion of the biosolids produced at the LACSD facility.

By removing the technology risk for the client, Kore feels it can easier penetrate the municipal sector with an unproven technology. "It's a risk-averse industry when it comes to innovation," Wirtel said. "That's why today we're offering the market performance-based services agreements, a risk-free option to be next in line." If Kore's solution does not work, then there is no long-term obligation for the client.

> Undigested biosolids present a better opportunity than digested biosolids [for our pyrolysis technology].
>
> Steve Wirtel, Kore Infrastructure

Gasification takes pyrolysis to the next step, occurring at higher temperatures and converting more of the carbon embedded in the sludge to a usable form. PHG Energy has entered the final stages of commissioning of a gasification facility at the WWTP in Lebanon, Tennessee, which will convert thousands of tons of sewage sludge, used tyres and industrial wood waste into synthetic gas and biochar. It is its first such facility at a WWTP, but will rely on the more solid biomass such as wood waste to co-gasify. The feedstock will comprise of only 15% sludge, while wood waste accounts for 70%.

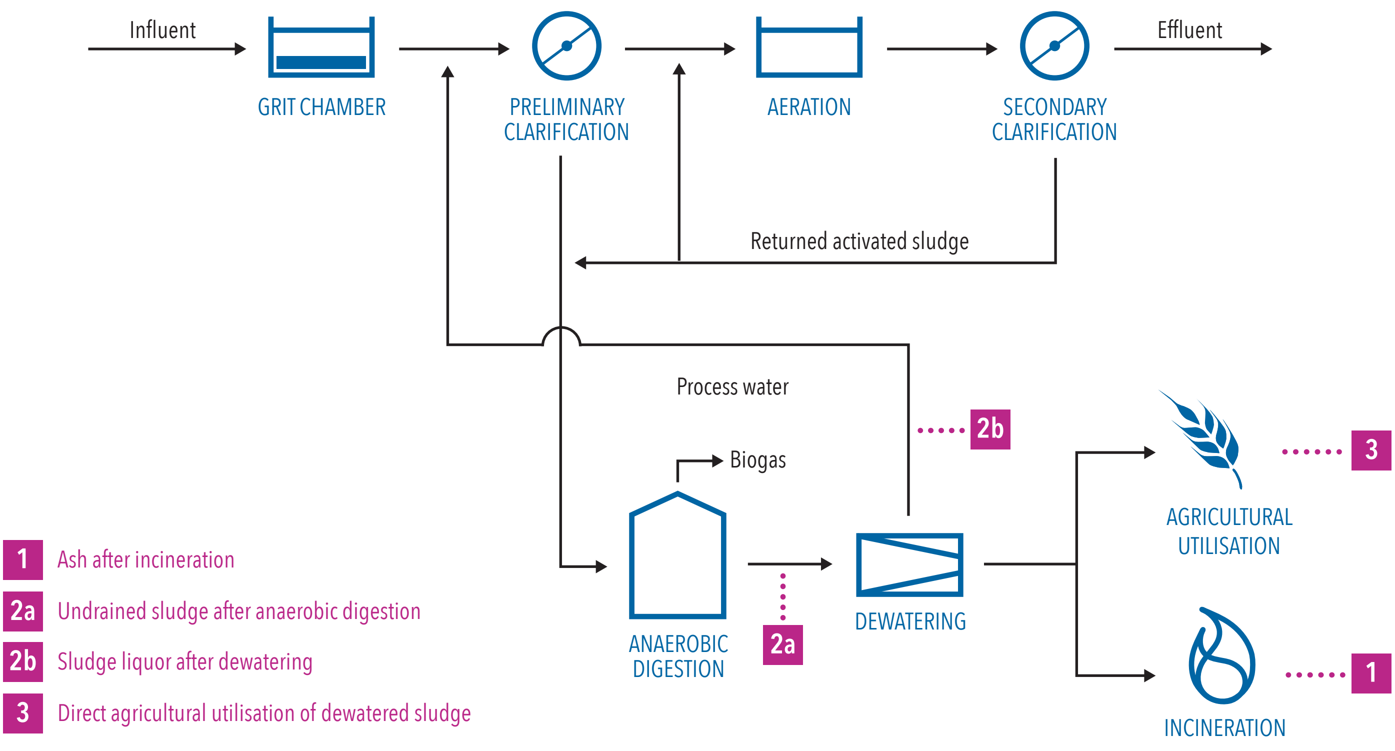
For all the hype surrounding biofuels, creating the gas by combusting the sludge is the easy part. That gas can be used to drive a turbine to generate electricity on site, but adding value to that product to be used off site can pose a further conundrum. "The trick is how to take that gas and upgrade it to where it has value as a natural gas or diesel fuel that meets pipeline specs [to sell to the local grid]," Zuback said. "That is the next level."

Furthermore, these processes still require significant amounts of energy. "The rub in all of these processes is that it takes energy to make energy – how much energy do you have leftover and is it in a form to add value?", Zuback pointed out.

To counter the amount of energy needed, a lower temperature conversion process has gained several references in Japan from companies such as Metawater and Tsukishima Kikai. The purported benefit of operating at lower temperatures is a higher calorific value of the end product, which is in this case a sustainable coal product for ▶

WHERE TO RECOVER P?

There are several places in the sludge treatment stream where phosphorus could be recovered. Currently the most chosen option is in the sludge liquor or in sludge directly coming out of the anaerobic digester.



Source: Kabbe

power plants.

Alternatives to anaerobic digestion?

Many thermal reduction technologies are used on the digestate from an anaerobic digester. However, Utah-based Genifuel Corporation is proposing to treat undigested solids (that have been thickened) with its hydrothermal processing technology to produce bio-crude oil. The company is in the design phase for two plants: one pilot facility at Metro Vancouver's Annacis Island WWTP, slated to begin testing in early 2018. The other will be constructed as part of the Water Environment & Reuse Foundation (WE&RF)-led consortium that was selected by the US Department of Energy in late 2016 to begin Phase 1 design and planning for a pilot plant near Oakland, California. This project will be undertaken with a view to replacing the existing incineration system at the Central Contra Costa Sanitary District's facility. In addition to the consortium, there are a dozen utilities that have sponsored the project.

"There are a lot of utilities monitoring this technology," James Oyler, president at Genifuel Corporation, told GWI. "Some [of the dozen] may be prepared to move ahead on their own without waiting to see what happens [with the pilot project]."

Using less energy than other thermal processes and yielding the production of biocoal is the relatively unknown technology of hydrothermal carbonisation. This technology specialises in treating wet wastes at low temperature (c.200°C) and between 10–20 bar of pressure to reduce sludge volume and create biocoal pellets. Because it is a wet process, no drying prior to the process is required, giving it an advantage over other thermal technologies, including the low-temperature processes advocated by Japanese players.

2016 saw UK-based Antaco win its first commercial project with the technology for a client in central Europe, while Swiss company AVA-CO2 commissioned a pilot plant in Germany converting sludge into biocoal with a view to recovering phosphorus from the final product. The market for biocoal is very young, but has strong prospects, according to Martin Bolton, director at Antaco. "There is appetite from major power producers [for the product] but the supply is not there yet. Once we are able to produce in greater quantities, that market will open up," he told GWI.

Kore also sees its technology being able to replace AD. "Undigested biosolids present a better opportunity than digested biosolids," Wirtel said. "We think they have the advantage of doubling the energy that could be extracted because digestion will take out a significant portion of the energy, and the sulphur content has not been reduced from the digestion process and that could end up in the biochar."

Non-thermal P recovery tech takes the lead

Phosphorus can be recovered from sludge ash produced by thermal reduction processes, but the leading technologies being implemented are recovering phosphorus in the form of struvite from the aqueous phase of sludge. The recovery of phosphorus from sludge is possible from different stages of the treatment process (*see diagram, previous page*). It essentially breaks down into two processes: either recovering nutrients from the aqueous phase or from sewage sludge ash. Recovering from each stage has its own merits, but some technologies are making much more progress than others.

Development of struvite-related technologies started in the late 1990s when ►

many WWTPs made a move to biological nutrient removal (BNR) for the main wastewater stream, switching away from iron or aluminium precipitation. Facilities with anaerobic digestion then began to encounter problems with struvite scaling in the sludge line, and so technologies to rectify this began to be explored. Indeed, the main driver for these technologies was not the recovery of phosphorus, but the ability to save operational costs that would be incurred from chemicals for controlling the struvite or unscheduled maintenance to deal with scaling. That phosphorus could be obtained to produce fertiliser was a secondary driver, but helped the business case significantly.

For recovering phosphorus from the aqueous phase, there are effectively three slightly different ways of proceeding. Firstly, precipitating phosphorus as struvite from the sludge centrate stream that results from the dewatering of the digestate. The leaders here are Canadian firm Ostara and Belgian company NuReSys, with Paques in third position.

The second is crystallising struvite from the sludge digestate prior to the dewatering step. Hamburg-based CNP is the ▶

> It will be a busy marketplace but what will take some time to get to the bottom of is what stage in the process is it most effective to recover P, and the recognition that the technologies are not mutually exclusive.
>
> Andrea Gysin, Ostara

CROWDED HOUSE FOR PHOSPHORUS RECOVERY

Many players have developed similar technologies to crystallise struvite from the sludge centrate, which can be upgraded into fertiliser. There are fewer carriers of technology for recovery of phosphorus from sludge ash so far, and the practice has not widely proliferated.

Company	Product	Recovery type	P form	Market presence
Ostara	Pearl and WASSTRIP	P recovery in centrate	Struvite	North America, Europe
NuReSys	NuReSys	P recovery in centrate/from digestate	Struvite	Europe
Paques	PhosPaq	P recovery in centrate	Struvite	Europe
Suez	PhosphoGreen	P recovery in centrate	Struvite	Europe
Veolia	Struvia	P recovery in centrate	Struvite	Europe
Remondis	Rephos	P recovery in centrate	Struvite	Europe
Naskeo		P recovery in centrate	Struvite	Europe
Multiform Harvest	Multiform	P recovery in centrate	Struvite	North America
Unitika/Hitachi Zosen	Phosnix	P recovery in centrate	Struvite	Japan
Royal HaskoningDHV	Crystalactor	P recovery in centrate	Struvite	Netherlands
Sustec	NutriTec	P recovery in centrate	Struvite/Diammonium sulphate	Europe
Nutrient Recovery and Upcycling	Phosphorus Recovery System	P recovery in centrate	Brushite	North America
CNP/P.C.S.	AirPrex	P recovery from digestate	Struvite	Europe, China
Swing Corporation	Rephos Master	P recovery from digestate	Struvite	Japan
Eliquo	EloPhos	P recovery from digestate	Struvite	Europe
Budenheim	Extraphos	Re-dissolution of P	Dicalcium phosphate	Germany
ASG	Gifhorn process	Re-dissolution of P	Struvite/hydroxylapatite	Germany
University of Stuttgart	Stuttgart process	Re-dissolution of P	Struvite	Germany
Ecophos		Sludge or ash leaching	Dicalcium phosphate/ phosphoric acid	Europe
Remondis	TetraPhos	Sludge or ash leaching	Phosphoric acid	Europe
BSH Umweltservice	LEACHPHOS	Sludge or ash leaching	Phosphoric acid	Europe
RecoPhos Consortium	RecoPhos	Sludge or ash leaching	Monocalcium phosphate	Europe
Metawater		Sludge or ash leaching	Hydroxylapatite	Japan
Ingitec	Mephrec	Thermal treatment	Slag enriched with P	Europe
Outotec	AshDec	Thermal treatment	Phosphate in form of CaNaPO4	Europe
Pyreg	Pyreg	Thermal treatment	P-rich biochar	Europe
Kubota		Thermal treatment	Slag enriched with P	Japan

Source: Kabbe; GWI

market leader with its AirPrex solution. The advantage of phosphorus recovery in the digestate is the improved dewaterability of the sludge, because phosphates help bind water to the sludge solids. Greater amounts of struvite can also be obtained, but it can be harder to then separate the final product. Ostara has countered this with development of the WASSTRIP technology that is placed upstream of its struvite crystallisation technology to release more phosphates prior to a thickening stage, and help reduce the volume of sludge further.

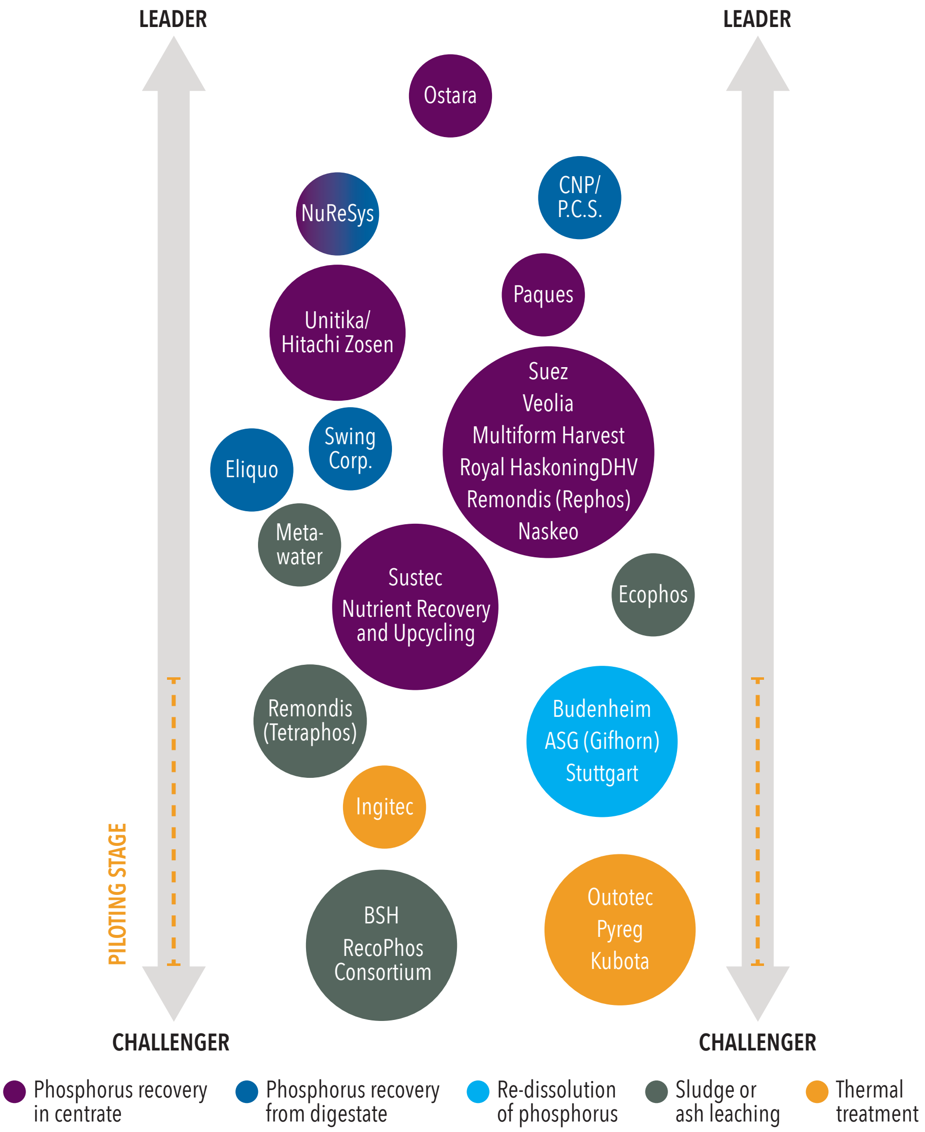
Market participants recognise that the market for these technologies is relatively limited, but still attractive. "The prerequisite for any technology recovering P from the aqueous phase is a well performing BNR plant," explains Andrea Gysin, managing director for Europe at Ostara. "It needs to be biologically removing phosphorus, which means that P is contained in the biology of the sludge., and from there it is released into the aqueous phase during anaerobic digestion"

The third method for the aqueous phase is acidic re-dissolution and precipitation of the phosphorus. Examples of these technologies are the Gifhorn and Stuttgart processes. Because of numerous chemical addition steps and the need to deal with other critical waste created with these processes, the economics do not currently appear to add up. Pilot projects for the technologies have been undertaken but have not made the transition to a commercial facility. "I don't really see a future or even potential for these approaches," said Christian Kabbe, Project Manager at Kompetenzzentrum Wasser Berlin. One technology that re-dissolves phosphorus and looks more promising is the ExtraPhos process developed by Budenheim. The immediate benefit over other processes such as Gifhorn and Stuttgart is that it applies carbon dioxide rather than chemicals for the re-dissolution of phosphorus. It could also compete with the struvite technologies. "The advantage of the Budenheim approach compared to the struvite approaches is that it is more flexible in terms of sludge," Kabbe told GWI. "So it can also deal with iron or aluminium rich sludge, whereas the others are limited to a biological P sludge."

These technologies will be located on the same site as a WWTP. If phosphorus is being recovered from sewage sludge ash, then the facility is more likely to be located away from a treatment facility. Technologies for the recovery of phosphorus from incinerated sewage sludge ash are much less developed, and many remain in the demonstration and pilot phase. EcoPhos and Remondis have technologies that are closest to the market: construction of a commercial plant at Dunkirk will see EcoPhos recovering value from the sludge ash, while Remondis is piloting in Hamburg with a view to upscale in the next couple of years. Technologies such as these are suited to large-scale dedicated incineration facilities. "I see more potential [for recovery from ash] in terms of very centralised logistics because you always have to cope with the economy of scale," said Kabbe.

STRUVITE IS KING

Companies recovering phosphorus as struvite are leading the way – Ostara now has 14 commercial facilities. Only Ecophos and Metawater have begun to commercialise recovering P from sludge ash.



Source: GWI

Scouting out the markets

Phosphorus recovery technologies are proliferating (*see table and chart, left*). "It will be a busy marketplace but what will take some time to get to the bottom of is what stage in the process is it most effective to recover, and the recognition that the technologies are not mutually exclusive," Gysin told GWI. "Recovering from the aqueous phase and recovering from ash can go hand in hand."

The most promising market for phosphorus recovery in the near term will continue to be Europe, although China and North America will also be strong markets going forward. The first P recovery project in China came online in 2016, with technology supplied by CNP for recovering struvite from the sludge liquor initially, ▸

before trying the digestate too.

Germany will however be more conducive to technologies recovering phosphorus from the ash or those that can recover chemically bound phosphorus because there are very few WWTPs with BNR for the mainstream. "That's why technologies like Stuttgart are coming out of Germany," Gysin explained. Regulations under discussion in Germany stipulate compulsory recovery of phosphorus from sewage sludge in treatment plants with a capacity greater than 50,000 population equivalent, of which there are around 500. However, recovery from ash will likely dominate, according to Kabbe. "They [German regulators] also want to claim a 50 per cent recovery rate from sludge which means that struvite recovery is not an option anymore because these technologies of first and even combined generation will never have recovery rates above 30 or 40 per cent," he explained.

Gysin is bullish on the phosphorus recovery market in Europe, saying the new EU fertiliser regulations could have an impact on the market. "They are proposing tight cadmium limits and most phosphorus fertiliser in Europe is produced from phosphate rock mined in Morocco and Western Sahara that has high cadmium levels," she told GWI. "That's going to create pressure on existing phosphate sources, which means it will impact availability or drive up costs as producers reduce cadmium levels in those fertilisers." The fact that Western Sahara together with its occupier Morocco holds 72% of the world's phosphate reserves adds another layer of urgency to the drive to recover phosphates from sludge. In North America the driver is more towards meeting stricter phosphorus discharge consents – Ostara has deployed several facilities in order to reduce the phosphorus load returning to the main treatment plant.

Japan began investigating recovering phosphorus from sludge in the late 1990s, but only a handful of projects have been implemented. That said, Hitachi Zosen has recently won an order to construct a new facility in the Tottori Prefecture to recover phosphorus from sludge and use it to enhance the combustion process.

There could be opportunity to recognise synergies between the recovery of phosphorus and nitrogen, the latter also being a problem constituent in mainstream wastewater. A key motivation for recovering nitrogen from the sludge centrate is to reduce the load of this reject water that is returned to the main treatment plant. Nitrogen (in the form of ammonia) can easily be recovered along with phosphorus. "There is a nice synergy once you have recovered struvite as your pH is already above eight," explained Kabbe. "You just need to add a bit more to get above 10 and then ammonia stripping is working quite nicely." (*See GWI December 2016, p.46*).

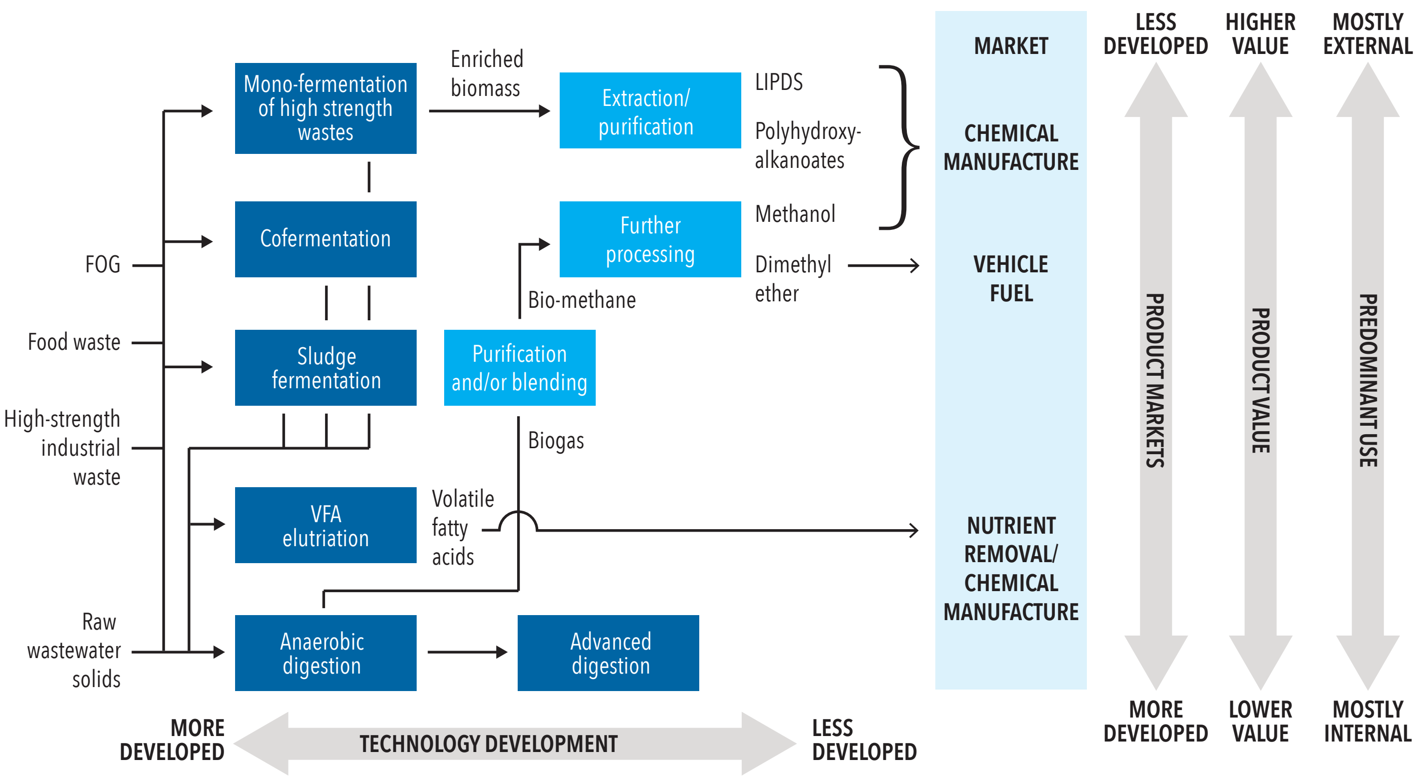
What else can be obtained?

Exploration of other materials that could be recovered from sludge is comprehensively underway.

Plasmids, which are strands of DNA that bacteria use to transmit information, could be used to improve biological or chemical processes, and have strong value for the biotechnology industry. Rare earth elements (REE) are also points of interest, with the WE&RF currently conducting a research project to discover concentrations of such elements in sludge, and review recovery routes. The project's final report is expected in June 2017. ▶

AN EMBARRASSMENT OF RICHES

Sludge can offer up a slew of other valuable products, though the technology to extract maximum value from these is currently very young.



Source: Adapted from Bhatterari

How much headway the recovery of REE makes remains questionable: the concentrations of valuable metals are notoriously low in municipal sludge, unless the plant receives wastewaters from industries that use precious metals in their operations. A WWTP in the town of Suwa in Japan reported collection of nearly two kilograms of gold from every tonne of incinerated sludge ash in 2009, but is located near a high concentration of precision equipment manufacturers.

The recoverability of bio-isoprene from sludge is also being examined by the University of Nebraska-Lincoln as part of a WE&RF project. Isoprene is the principal polymer in rubber, and is usually obtained from the thermal cracking of naphtha.

Though many products are recoverable (*see diagram, opposite page*), "unfortunately many of the technologies are still very young," admitted Samuel Jeyanayagam, Senior Principal Technologist at CH2M. The economic case is yet to present itself, but Jeyanayagam believes the efforts of scouring sewage sludge for such commodities are not fruitless. "Right now it's probably not economical, but we need to think about these things now so that if and when it becomes economical we have a way of doing it," he said.

Cracking the market

Prospects for the uptake of thermal reduction technologies like pyrolysis and gasification are not as yet wholly defined but encouraging. The combination they offer of volume reduction and the potential to recover energy-related products mean "the thermal treatment of sludge has very positive prospects," according to Kevin Bolin, CEO of Orège North America. Though volume reduction still reigns supreme, the concept of resource recovery is coming firmly into focus. "Many municipalities are wedded to the concept of renewable energy or energy efficiency out of their sludge," added Bolin.

Though many of the emerging thermal reduction technologies have been more designed towards wet carbonaceous waste (such as sludge), the processes still require significant amounts of heat because of the liquid still present, and innovation surrounding that would be useful for the industry, according to Zuback. "Anything you can do to reduce the water content of the sludge [before a thermal process] is a good thing," he said. "There are some emerging technologies such as electro-dewatering and better centrifuges. But it's all about mass-energy balance so you can maximise energy left over at the end that you can turn into a product." Hydrothermal carbonisation and hydrothermal processing are naturally suited to wet wastes (in contrast to pyrolysis and gasification), and don't require a drying step beforehand. Progress of facilities employing the technology will be keenly watched.

Although commercial-scale thermal sludge treatment facilities are emerging, the pitfalls of the commercialisation process should be borne in mind. In 2014 thermal gasification company MaxWest Environmental, valued at almost $40 million at the end of 2013, filed for bankruptcy. The cause was mainly a lack of quick financial returns for its venture capital investors, rather than flaws in the technology. In January 2015 PHG Energy acquired the intellectual property assets of MaxWest and its municipal gasification plant at Sanford in Florida, which was designed for treating sludge. PHG is currently looking to re-deploy the plant – when it does, the road for thermal reduction technologies will be opened up further. ■

Terminology

Anaerobic digestion: stabilisation of sludge through the use of anaerobic microorganisms to digest the sludge stream. Takes place with the absence of oxygen in a sealed tank, and a key by-product is biogas.

Biochar: a kind of charcoal produced when sludge is subjected to pyrolysis. Can be used for nutrient removal from wastewater and to improve soil qualities.

Biocoal: fuel made from heating biomass in an inert atmosphere.

Centrate: the reject water from the anaerobic digestion process that is typically high in phosphorus and ammonia. Can also be referred to as filtrate or sludge liquor.

Digestate: the material remaining after the anaerobic digestion of sewage sludge.

Gasification: involves the conversion of organic material into smaller gaseous molecules using high temperatures and a controlled amount of oxygen and/or steam. As well as reducing the sludge mass, the main products are syngas and a residue similar to ash.

Hydrothermal carbonisation: thermo-chemical process converting an aqueous solution of biomass (such as sludge) into powdered biocoal through relatively low temperature and pressure.

Hydrothermal processing: process whereby sludge (around 20% solids) is subjected to heat and pressure to create biocrude oil and natural gas. Hydrothermal liquefaction is employed to form oil, and then effluent water with remaining organics is gasified to produce methane and carbon dioxide.

Incineration: process of combusting sludge in the presence of oxygen, destroying harmful chemicals and reducing the volume of the sludge. Produces ash and flue gas.

Pyrolysis: decomposes sludge by heating above 400°C in the absence of oxygen. Converts sludge into a high carbon solid called biochar as well as syngas and biocrude.

Struvite: magnesium ammonium phosphate product that is crystallised from technologies applied to wet sludge or sludge centrate.

Syngas: gas by-product of pyrolysis and gasification processes which is a mix of carbon monoxide, carbon dioxide and hydrogen.

Thermal hydrolysis: pretreatment method performed prior to AD that uses heat and pressure to disintegrate the constituents of the sludge, increasing the quantity of organic matter accessible to the microbes during AD.

"Many municipalities are wedded to the concept of renewable energy or energy efficiency out of their sludge.

Kevin Bolin, Orège North America