MARKET MAP

Going boldly forward to meet the energy neutral proposition

Anaerobic wastewater treatment is taking on new configurations as the technology matures. GWI investigates the anticipation of conquering new frontiers.

The advantages of anaerobic wastewater treatment versus its aerobic counterpart – no energy required for aeration, less sludge production, and the generation of biogas – seem very attractive on paper, but their application has generally been limited to industrial wastewater treatment applications (this article concerns the anaerobic treatment of mainstream wastewaters, and not primary or waste activated sludge from the wastewater treatment process). Anaerobic treatment works best on wastewaters of high organic strength, which have high levels (usually over 1,000 mg/L) of chemical oxygen demand (COD) (the main parameter used, *see diagram, facing page*) and usually temperatures of 25 degrees Celsius or over.

However, developments in the technology over time have enabled the expansion of their potential application. Food & beverage producers are replacing their aerobic systems – or installing an anaerobic system upstream of an aerobic system – as their concentrations of COD in wastewater become higher. Lower volumes of wastewater are being generated as industrial users look to cut their freshwater consumption. The promise of biogas to decrease reliance on external energy is also enticing, neatly fitting into corporate sustainability agendas.

The municipal market, where lower temperature and lower concentration wastewaters have hindered the uptake of anaerobic solutions, is the next to be conquered, and numerous developments could see that frontier breached in coming years. One of the market leaders, Veolia subsidiary Biothane, has reportedly enjoyed one of its best years in the anaerobic business, a strong indication of a market continuing to offer opportunities.

Technology landscape

The anaerobic degradation of organic matter in the wastewater is carried out in four stages (*see diagram, p.54*) by different microbial consortia such as hydrolytic bacteria, acetogenic bacteria and methanogenic bacteria, which convert the matter into methane (which is the main constituent of biogas), carbon dioxide, ammonium, hydrogen sulphide and water. Systems use either suspended or granular sludge. Sludge granulation is recognised as giving high solids retention time and strong tolerance to fluctuations, however granulation cannot be guaranteed in all applications, meaning some technologies use suspended sludge.

Anaerobic technology is mature. The traditional configurations of anaerobic contact reactors, anaerobic filters, upflow anaerobic sludge blanket (UASB) reactors or expanded granular sludge bed (EGSB) reactors have been optimised over the years, particularly to counter a common problem of losing biomass from the wastewater.

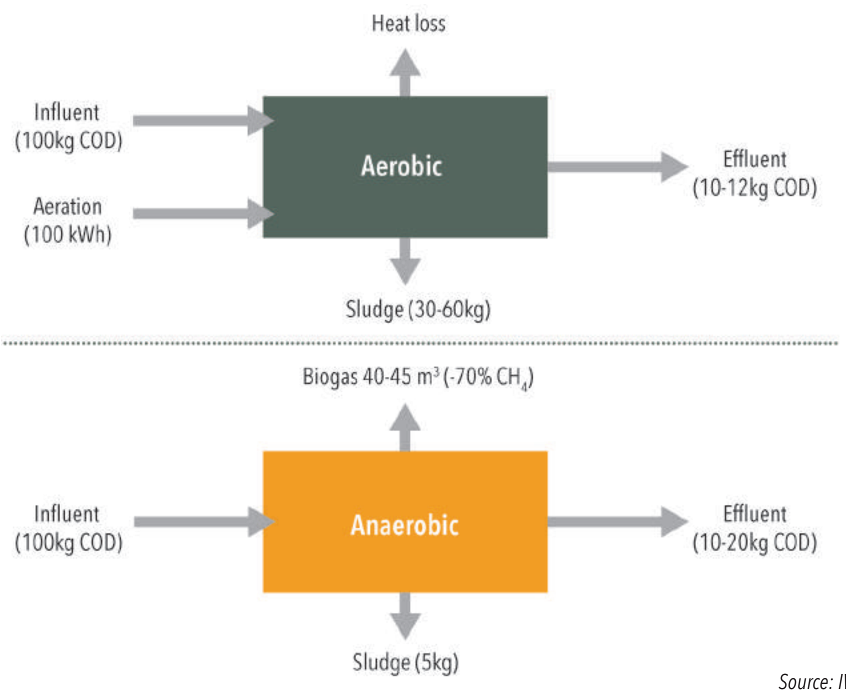
"Most technology suppliers nowadays deliver high rate reactors that depend on a two-stage biomass separation process to retain the granular biomass effectively, to enable higher organic loading rates," explained Jaap Vogelaar, Head of Core Technologies at Paques, the market leader in anaerobic wastewater solutions.

New reactor developments have overcome the previously limiting factor of the quality of the wastewater, which needed to have low levels of solids and of fat, oil & grease (FOG), in addition to high levels (e.g. over 2,000 mg/L) of COD.

Traditionally, the level of pretreatment required was high, with the need for effective screening or filtering, or the implementation of a dissolved gas flotation (DGF) unit to remove FOGs. To avoid the need for pretreatment, many companies have combined pre-, main- and post- treatment into one process. To treat high levels of FOGs, Paques developed the anaerobic flotation reactor, obviating the need ▶

DIFFERING FATES FOR CARBON

Far more benefits result from the conversion of carbon in an anaerobic process compared to aerobic treatment, including lower sludge production and biogas generation.



Source: IWA

for DGF units upfront. The flotation unit floats solids and fats using biogas, before the flotation layer drops back into the reactor to be digested further.

"We are interested in more digestion of fats because they produce more energy," said Paula Gonzalez, head of Paques' industry specialist team. "It is better to produce biogas from fats rather than having to transport them away."

Fellow Dutch company Nijhuis Industries has adopted similar configurations with some of its AECOMIX product range.

To go beyond the UASB and EGSB technologies, Dutch company Hydrothane, started by employees from Biothane who defected following Veolia's takeover of the company in 2008, has developed the external circulation sludge bed (ECSB), which is similar to an EGSB but separates the treated wastewater and biogas in a separate column from the main reactor. Hydrothane CEO Daniel Piet suggests that by recycling the biomass outside of the reactor as well as having a two-level settling system for separating the biogas, the system offers significant advantages in biomass retention. The company has sold around 80 projects since its founding.

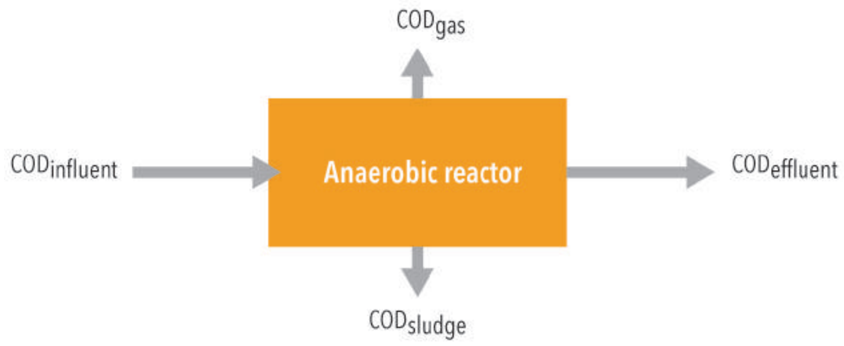
Further optimisation has been especially apparent in the industrial wastewater space, where the technology has developed away from UASB reactors to a more compact, lower footprint, column type technologies. This is evident in products such as Biothane's Biobed DUO system and Paques' Internal Circulation (IC) technology, which are both two stage separator designs.

Paques has recently developed its IC technology further into the ICX technology, which offers more flexibility, particularly in light of rising COD concentrations in industrial wastewaters. According to Gonzalez, the company has secured 30 references with the technology in just two years since its launch, with the Chinese paper industry being a prolific customer. It is targeting new applications with its ICX technology.

"We are looking into a promising new method, together with the energy research centre of Netherlands [ECN], to solubilise organic material from waste sludge into a liquid stream that can be treated with high rate anaerobic systems, such as the newly developed ICX reactor," said Vogelaar.

IT'S ALL ABOUT THE COD

The parameter of COD is widely used as a tool to control the operation of anaerobic treatment. Biochemical oxygen demand (BOD) is also an indicator of biodegradability, but is applied as a test far more commonly to aerobic systems. Unlike in aerobic, COD is not actually destroyed but reformed into different compounds.



$$COD_{influent} = COD_{effluent} + COD_{gas} + COD_{sludge}$$

Source: IWA

Fixed film alternatives

In contrast to upflow systems, some companies, such as aqana and Headworks have developed downflow anaerobic carrier systems, which use carriers usually made from plastic (as used in a moving bed bioreactor) to capture the biomass and improve retention (known as fixed film systems as opposed to biomass being freely suspended in a reactor). Because the influent is fed to the top rather than the bottom of a reactor, it can use gravity flow, lowering the parasitic energy requirement. aqana has eight full scale installations, principally in the pulp & paper and chemicals industries.

"This technology is best suited for applications where granular sludge doesn't work," aqana project manager Redmer Bootsma told GWI. Typical wastewaters where granular sludge struggles to work are those with low molecular organic acid. The company is working with Nijhuis Industries and Envirogen to expand its market reach.

Headworks is currently at the piloting stage, developing the technology on the back of client dissatisfaction with UASB systems.

"The driver behind it was that we've seen people having challenges keeping UASBs operable, because maintaining a sludge blanket is very difficult. We get the advantages of media-based growth so you don't have to worry about maintaining that sludge blanket," explained Imran Jaferey, VP of global sales at Headworks. Though aiming initially at the food & beverage sector, the company has identified any industrial waste streams with high COD levels as an opportunity, including petrochemicals.

The leading biological treatment company in Japan, Kurita, commercialised its Biosaver TK carrier-type technology in 2011, aiming to be able to treat wastewaters with lower concentrations of organics.

> "Most technology suppliers nowadays deliver high rate reactors that depend on a two-stage biomass separation process to retain granular biomass effectively
>
> Jaap Vogelaar, Paques

However, the technology has only achieved nine installations since then. The company examined the ability to apply its Biosaver TK product to wastewater from Japan's large semiconductor industry, but found that the technology is unlikely to be accepted.

"A certain benefit in operational cost should be expected by anaerobic treatment, but it seems like simplicity of single-step aerobic treatment is preferred," explained Sousuke Nishimura, general manager in Kurita's technical department. "Semiconductor factories yield only [a] small mass of organic wastewater."

What of the anaerobic MBR?

One of the most interesting emerging technologies is the anaerobic membrane bioreactor (AnMBR), where an ultrafiltration membrane is placed either inside or outside an anaerobic digestion tank to filter suspended solids down to a level where the effluent is suitable to go into a reverse ▶

osmosis process. MBRs are commonly used in aerobic form (*see GWI Market Map, March 2017*), but transposing them to anaerobic configurations has been the subject of intense R&D over the last decade or more.

"With anaerobic MBRs you can very positively retain biomass in the system to give you good anaerobic treatment," said Glen Daigger, president of consultancy One Water Solutions. "The issue is that it takes a lot of energy for the membranes. It has an inherent process advantage but from an engineering perspective we haven't figured out how to turn that into a real advantage because parasitic energy is too high."

The problem is that although process energy requirements are nil (because it's anaerobic), the parasitic energy required is quite high, particularly because membrane flux rates of anaerobic MBRs are normally around three to four times lower than their aerobic counterparts.

Work to overcome these issues in anaerobic MBRs is extensive. Numerous papers at the recent WEFTEC conference tackled methods to improve energy efficiency of the system. One, from the University of Guelph, Ontario, compared a suspended sludge system with a granular sludge system, using GE (now Suez) ZeeWeed membranes. Though the suspended sludge system performed marginally better on COD removal, the membrane permeability was much higher in the granular sludge system, operating at a higher flux. Another method to lower the parasitic energy is the use of fluidised granular activated carbon (GAC) media to clean the membranes, rather than gas sparging, although GAC has the potential to abrade the membranes.

Moving away from the traditional hollow fibre or flat sheet polymeric membranes could also present a solution. Another paper examined the use of rotating ceramic discs as a fouling mitigation technique, concluding that at small scale (e.g. 500m³/d) these were much less energy intensive than sparging polymeric membranes, while at larger scale, using ceramic discs is potentially also less energy intensive, but the results were less profound.

Carriers of AnMBR technology see it as being able to extend the applications for anaerobic technologies, particularly where effluent quality is becoming more critical. Veolia has deployed reverse osmosis membranes directly downstream of its Memthane AnMBR technology in two applications for dairies, though levels of nitrogen in dairy wastewater are lower than the norm.

"RO suits being bundled with Memthane as the anaerobic conditions minimise the risk of fouling [of the Ro membrane]," said Biothane business development manager Dennis Korthout.

Suez Water Technologies meanwhile has an AnMBR technology, which could complement the legacy Suez UASB and contact reactor systems.

"The AnMBR is complementary to the existing installed base of Analift reactors. If customers are looking to improve effluent quality, or get a little bit more out of existing digester, then we can retrofit with the AnMBR," said Jeff Cumin, Global Product Manager for AnMBR, at Suez Water Technologies.

Other emerging solutions

Some emerging players are coming to the market with new solutions, and aiming to crack the municipal market. Israeli firm AgRobics has carried on the traditional advance of trying to prevent the washing out of biomass from the reactor.

Its technology utilises a form of polyurethane foam that is polymerised together with bacteria, which are then protected from washout. The foam is hydrophilic with a high ratio of open pores.

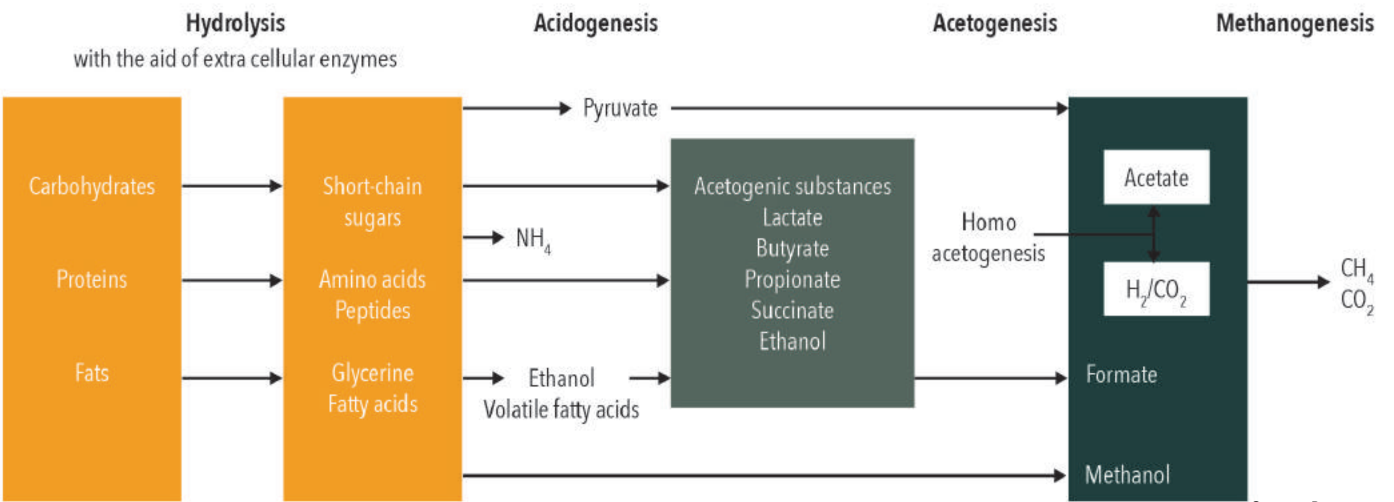
"A promising thing is we're able to put lots more active bacteria in the reactor, which gives us a much faster reaction time," said AgRobics CEO Gilad Horn. "We have reached organic loading rates of up to 40kg COD/m³/d when treating 70,000 milligrams per litre of COD." Horn went on to say that with one system on warm effluent AgRobics had achieved a hydraulic retention of time of 2 hours, which he claimed was "unheard of in municipal anaerobic applications."

It should be said that municipal wastewater in Israel often carries much higher levels of COD compared to Europe, due to a lot of effluent from industrial sources such as abattoir effluent and olive mills, making anaerobic treatment more conducive to municipal streams.

"During peak season, effluents can go up to between 1,500 and 2,000 milligrams per litre of COD, along with high levels ▶

THE FOUR STEPS OF ANAEROBIC WASTEWATER TREATMENT

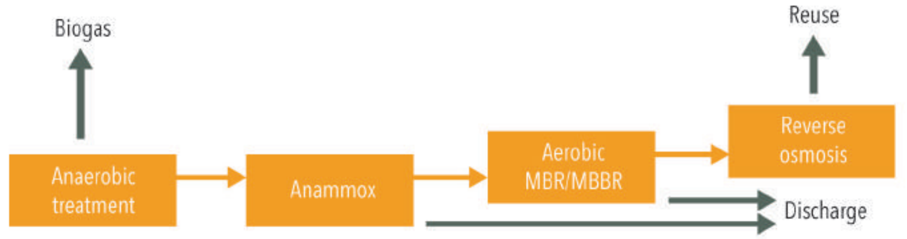
The anaerobic degradation process is a complex series of stages, where organic matter in the wastewater is broken down by a variety of consortia of anaerobic microbes. Ultimately the organic matter is converted into methane, carbon dioxide, hydrogen sulphide, ammonium and water.



Source: Powerstep

TREATMENT TRAIN OF THE FUTURE

With the advent of mainstream anammox expected within five years, it could follow anaerobic treatment as a step to remove nutrients. More conventional aeration may also be needed.



Source: GWI

of fats, oil and toxins," explained Horn.

Although it has a couple of municipal projects (at Karmiel and Kfar WWTPs), AgRobics has recently won its first contract with a food-processing company, whose existing aerobic reactor will be replaced by AgRobics' system. Horn told GWI that it sees the most promising short-term prospects in the industrial sector to build up its reference base, before moving onto more municipal projects.

"We are working on projects to make the technology further suitable for municipal, but we currently don't have a [utility] partner advanced enough," Horn said. AgRobics has worked with Israeli national water company Mekorot, but it is a utility more focused on water distribution than wastewater treatment.

Approaching the market with a black box solution is Irish company NVP Energy, which has a low temperature anaerobic treatment system. The technology was incepted at the National University of Ireland in Galway, and has been about ten years in development.

"It's a lot different to other anaerobic systems," explained business development manager Joe Shinkwin. NVP Energy has a patented unique microbiological and physical design that employs a microbiological consortia formed of granular seed sludge. It claims the system can treat wastewaters at temperatures in the psychrophilic range, as low as four degrees Celsius.

"This is achieved through microbiology and efficient design of the system," said Shinkwin. The system also contains a pumice filter bed, the mechanism for retaining the biomass in the system while producing high quality biogas.

"The two areas that we are focusing on are the food & drink industry, and the municipal opportunity in temperate climates that anaerobic is not usually suited for," Shinkwin said. The company currently has two full scale plants, one with ABP Food Group, one of Europe's largest meat processors, which has been running for 18 months, and a second plant commissioned in April 2017 at a large dairy processor. Shinkwin also told GWI that NVP Energy recently secured a contract for a UK site of "one of the largest brewing companies in the world."

The company is also in the final stages of developing a large-scale demonstration unit with a major water utility understood to be in the west of England, expected to go live within six to twelve months.

Attempting to crack the municipal sector

Anaerobic technologies on main municipal wastewater streams have been limited to countries in warm climates, where the wastewater is warm enough for anaerobic bacteria to operate efficiently. India has the vast majority (about 75%) of installed anaerobic systems, which are usually UASBs. The decision behind the uptake of the technology after its introduction in the 1980s essentially revolved around its low energy and maintenance requirements, key factors in a country with unreliable power supplies and lack of trained personnel. However, the decision backfired.

"UASB was pushed into India on a good vendor marketing strategy and was successfully adopted without knowing how it would work and what would be its results," Uday Kelkar at NJS Engineers India told GWI. Oxidation ponds had to be installed downstream to reduce ammonia levels before discharge, but these failed because ammonia levels were so high from the effluent of the UASB. "Over the past 10 years UASB has been discontinued in India based on past experience," said Kelkar.

Brazil and Mexico also have a number of UASB plants installed, but on the whole the uptake of anaerobic technologies in municipal has been limited. One recent high-profile contract award for a UASB system on municipal wastewater was in the emirate of Ras Al Khaimah in UAE, where Veolia will double the capacity of the WWTP at Al Fileyah using its Upthane technology.

The potential to create energy out of wastewater is increasingly attractive for municipalities, but it remains a case of economics. "New, simplified reactors with at the same time remarkably higher performance have the potential to generate economical business cases even there [in municipal] where anaerobic treatment is not feasible or attractive today," suggested veteran process engineer Ulrich Knoerle from German system integrator Eliquo Stulz.

What might increase the uptake of anaerobic technologies to the municipal sector is the advent of the anammox solution, an alternative deammonification process that removes nitrogen without the need for an external carbon source (*see GWI Market Map, December 2016*). Anaerobic technologies only eliminate carbon from the wastewater, not nitrogen and phosphorus, meaning that subsequent aerobic steps need to be employed to remove those nutrients to meet discharge limits. These would often then need an external carbon source because much of the carbon in the wastewater has been turned into biogas. However, with the development of alternative methods of biological nutrient removal that reduce the reliance on carbon (such as anammox), anaerobic treatment could come back into the picture as part of certain treatment trains (*see diagram, above*).

"There are things being investigated that potentially reduce the amount of carbon for nutrient removal, and the focus is to capture more carbon and divert it to other purposes," explained Daigger. "The question then becomes what's the better ►

> "New, simplified reactors with remarkably higher performance have the potential to generate economical business cases in municipal
>
> Ulrich Knoerle, Eliquo Stulz

way to [use carbon]? Use a high rate biological process like A-B Stage and send material to anaerobic digesters, or mainstream anaerobic treatment."

Anammox has been employed on sludge liquors, but, similar to anaerobic on municipal mainstreams, it is facing challenges such as limited efficiency on low concentrations and low temperatures. The anaerobic solutions providers tend to carry anammox solutions, including Paques and Veolia who continue to test anammox on mainstream wastewaters: the former is testing it on warmer streams in China, while Veolia has been piloting in France and in the USA. Veolia claims it is confident the process works efficiently at temperatures down to 12 degrees Celsius with stable anammox activity.

Trials on municipal wastewater with an anaerobic MBR by Suez Water Technologies have yielded an interesting conclusion. "What we find with membranes is that it allows you to select or retain the biomass that tend to be more productive at lower temperatures," said Cumin.

Cumin also believes that the use of anaerobic MBRs has positive implications for nutrient recovery. "Now that you have these nitrogen and phosphorus compounds in a cleaner effluent, there's new opportunities to recover those as a product of value. Prior to anaerobic MBRs, the TSS made it difficult to create a fertiliser product that was a saleable product in an industrial space," he said.

Low concentrations of COD also pose a problem when trying to produce as much biogas as possible. Methane has a solubility level in water, and it is lower at higher temperatures and higher strength. The higher the concentration of organic matter, the lower the fraction of methane that remains dissolved in the water. In municipal wastewater it has been shown that around a third of the methane produced during the anaerobic treatment process cannot be caught, and remains soluble in the effluent leaving the anaerobic reactor.

Industrial opportunities

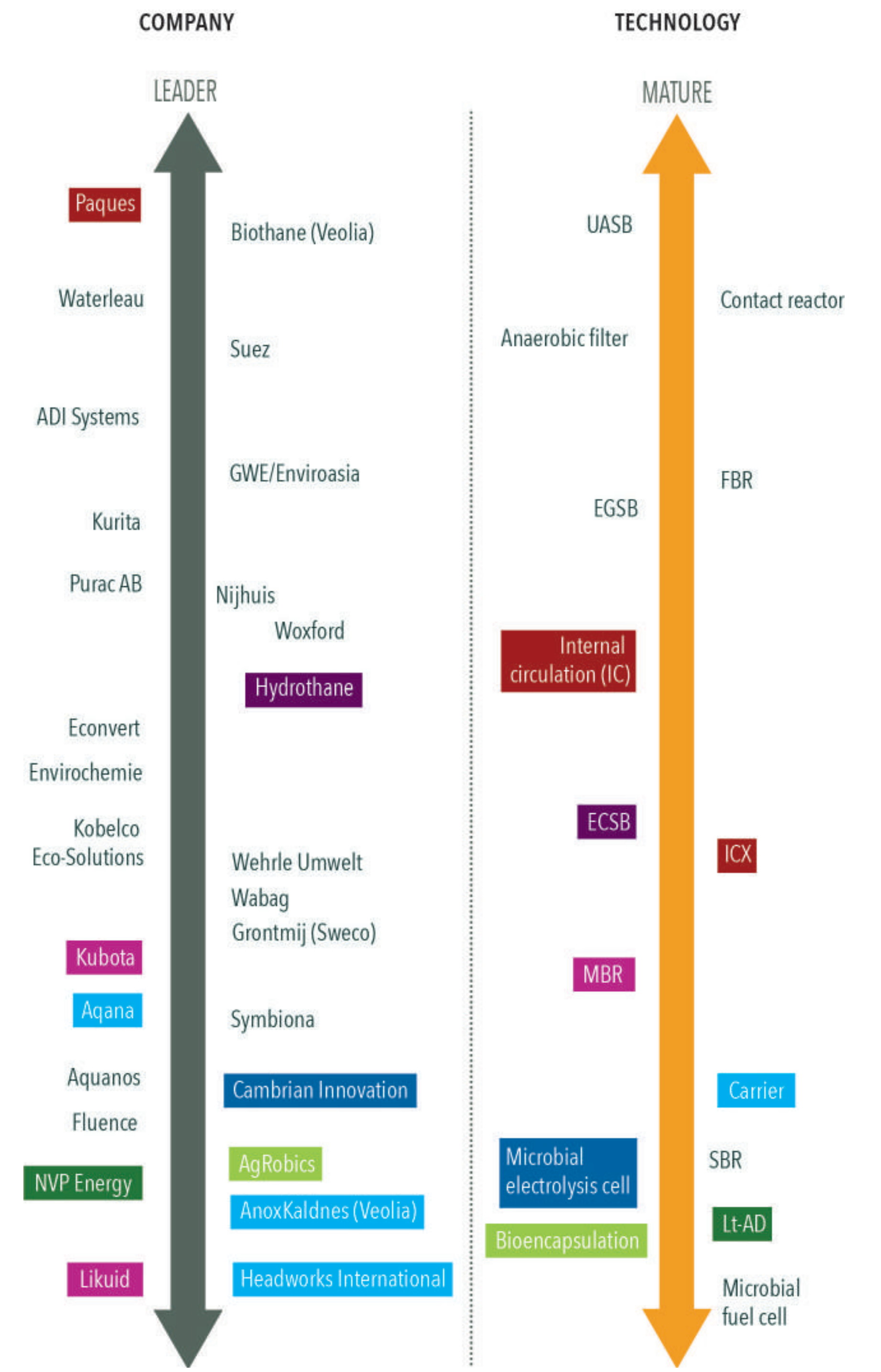
As sustainability agendas help drive the uptake of anaerobic treatment (generating energy, reducing carbon emissions etc.), prospects in the food & beverage sector remains strong for vendors. However, in terms of an emerging market, the craft brewing space is offering opportunity. Because they have tended to be very small operations, craft brewers are usually able to discharge wastewater into a municipal sewer system with very minimal treatment. As the industry explodes – and microbrewers' operations expand in size – the situation is expected to change.

"One microbrewery, when it becomes quite substantial, can produce the wastewater, from an organics perspective, of a few thousand people. The wastewater utility then becomes overloaded, turns around and says no [to discharge into its system]," said Daigger.

Many craft brewers struggle with high solids in their effluent, which is due to the greater volume of hops used in the brewing process, meaning they need meticulous pretreatment steps to keep solids out of ▶

JOSTLING FOR POSITION

Over the years players have tried to differentiate themselves with unique takes on more established technologies. New market entrants are preying on the weaknesses of old UASBs.



*Colours indicate a company's specialism in a particular technology

Source: GWI

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> Jeff Cumin, Suez Water Technologies

their existing anaerobic treatment systems. Failing that, they need high rate anaerobic treatment that can handle higher solids. New Belgium Brewing Company, one of the largest craft brewers in the US, in 2017 is understood to have installed an anaerobic MBR at its Asheville brewery.

Boston-based Cambrian Innovation, which employs a microbial electrolysis cell technology to undertake anaerobic treatment in a fixed film reactor, has had promising initial successes in the brewery sector – as well as wineries – with a modular-type unit.

Some see potential beyond the traditional food & beverage and pulp & paper industries. "Textiles is a potential market as long as there is biodegradable COD in the water – then anaerobic could be applied," said Hydrothane's Piet.

Looking into the future

As the trend towards industries saving water grows, two key things are happening. Firstly, with less freshwater consumption by industry, it means lower hydraulic loads of wastewater. However, absolute values of COD in the wastewater will remain the same, meaning the wastewaters are becoming more concentrated. This is driving the need for systems to tolerate higher organic loading rates, which in turn leads to continued development of systems with better biomass retention.

Secondly, an increasing amount of water is kept in the internal circuits of a facility. Agents that are dosed to minimise biological activity in the water contain toxic substances, which can have a detrimental effect on anaerobic biomass.

"Detoxification of such wastewaters can be an important point, since due to its much lower reproduction rate anaerobic biomass is much more sensitive [than aerobic sludge] to toxic substances, like disinfection agents," said Knoerle.

Knoerle earmarks bio-encapsulation technologies as potential future solutions. "It can be expected that toxic shocks will not have the same impact as on suspended or granular biomass."

Although the production of biogas offers the ability for municipal and industrial clients to offset some (or all) of their energy costs, some see more opportunity in the production of bioplastics from excess sludge. Polyhydroxyalkanoates (PHAs) are fully biodegradable plastics that are made by bacterial fermentation of sugars and lipids. The key to retrieving them from anaerobic treatment is to stop the process before the methanogenesis step, which is the stage that biogas is produced. Companies such as Paques are working towards implementing this at commercial scale.

"Bioplastics will have five to ten times higher value than biogas," said Gonzalez, adding that if less than 2,000 tons of plastics are being produced per year, the economics are not so attractive.

The timeline for commercialisation of microbial electrochemical technologies meanwhile (the success of Cambrian Innovation so far being an anomaly), has been repeatedly overestimated, especially for microbial fuel cells. Well tested in the laboratory, they have failed to reach commercialisation due to scaling and cost issues. Several start-ups continue to work on the technology, but a full scale application is not anticipated any time soon. ■

Terminology

Anaerobic wastewater treatment: mainstream wastewater is treated in the absence of oxygen using anaerobic bacteria, which do not require aeration to grow. Anaerobic treatment is best applied to streams with high COD loads. Technologies that undertake this are also known as 'high-rate anaerobic reactors to differentiate from anaerobic digestion of sludge.

Anaerobic contact reactor: free biomass is mixed with wastewater in a closed tank, usually followed by a decantation phase to separate treated water from the biomass.

Anaerobic filter: a closed tank houses a filter medium which the anaerobic microbes populate.

Biogas: the mixture of different gases produced by the anaerobic treatment process, predominantly methane and carbon dioxide. It can be used to as a fuel to generate electricity, or compressed to create a renewable form of natural gas.

Chemical oxygen demand (COD): a measurement of biodegradable and nonbiodegradable organic matter, widely used as a means of measuring the strength of wastewaters.

Expanded granular sludge blanket (EGSB): similar to a UASB but the biomass within the reactor is fluidised into granules, which freely mix with the wastewater. An EGSB also contains more stages of settlers to prevent biomass being discharged along with the treated wastewater.

Fluidised bed reactor (FBR): similar to UASBs and EGSBs in terms of process but in a fluidised bed, the biomass is fixed on carriers such as sand or plastic.

Hydraulic retention time (HRT): measure of the average length of time wastewater remains in a bioreactor. Calculated by dividing the vessel volume by the amount of liquid removed per day.

Mesophiles: bacteria that grow best at temperatures between 25 and 40 degrees Celsius - these tend to be used in anaerobic wastewater treatment.

Organic loading rate: measure of the amount of COD per cubic metre being loaded into a bioreactor.

Solids retention time (SRT): how long sludge solids remain in the system. The term is interchangeable with sludge retention time, and is calculated by dividing the mass of solids in the vessel by the solids removed (litres per day).

Upflow anaerobic sludge blanket (UASB): technology where wastewater flows upwards in a biological reactor through a sludge blanket, with treated wastewater discharged and biogas recovered at the top.