Singapore International Water Week

WATER TECHNOLOGY FUTURES:

A GLOBAL BLUEPRINT FOR INNOVATION

Acknowledgements: This report has been prepared by staff from PUB Singapore and Global Water Intelligence (GWI). It includes market research by GWI and case studies which expand on the Summit's main discussions. We wish to thank all who have contributed to this document, including by sharing information for the case studies.

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MESSAGE FROM PETER JOO HEE NG, CHIEF EXECUTIVE, PUB, SINGAPORE'S NATIONAL WATER AGENCY

Six months have passed since we gathered in Singapore for the SIWW Technology and Innovation Summit (STIS).

Our motivation for organising the meeting was straightforward: we wanted to know the lasting thinking on how innovative technology can allow us to increase our water resources, to lower our cost of production, to increase the quality of our product, and to improve water security for our countries and communities.

And so we gathered more than 300 international experts and practice leaders, from across the water sector, and engaged them in a guided conversation over two intensive days on the future of technological innovation in the water business. In the process, we were able to tease out from the group, and then to consolidate, what is a set of collective insights that will help to point the way forward for the next wave of innovation in water and wastewater management.

You now hold the final version of the outcome document for the June 2015 STIS Singapore Summit. After months of review and study, the authors have attempted to present in this document, in a lively and concise fashion, the essence of the Summit's proceedings. After making the case for change, they have identified the key technological areas for urgent focus and go on to suggest the best ways to bring innovative solutions to operation.

This document provides clarity on where the promise lies for water innovation, and in what areas we should be investing our limited resources and attention. It also offers useful pointers on how best to encourage technological innovation, to finance it and to bring it to market.

As you peruse this outcome document, my hope is that you will become even more convinced that it will be high technology and clever innovation that will allow us to provide the water and services that our customers demand. And that it will be technology and innovation again that will let us collect and clean our wastewater, and therefore continue to keep our soil, rivers, lakes and seas clean and hospitable.

Our plan is for the contents of this document to further inform the agenda of Singapore International Water Week 2016 (10-14 July; www.siww.com.sg), when many of the participants at STIS will convene again.

My best wishes to all for a happy and successful 2016. I hope to see you soon in Singapore at SIWW 2016.

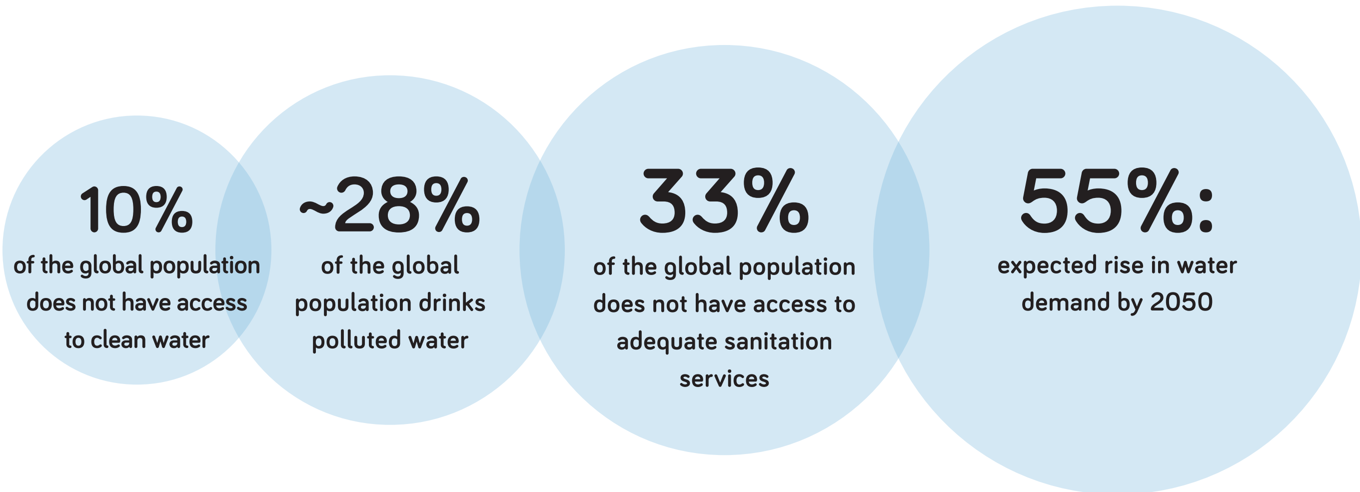
CHAPTER 1

THE TOP DRIVERS FOR INNOVATION TODAY

OVERVIEW OF THE GLOBAL WATER SECTOR: CHALLENGES AND OPPORTUNITIES

Managing water resources has become one of the biggest challenges of our time. 10% of the world's population does not have access to clean water and 33% does not have access to adequate sanitation services. 2 billion out of 7.2 billion people drink polluted water. In 2015, the World Economic Forum ranked the risk of water crises as having the highest likelihood of happening and with the greatest impact on humanity.

Behind the mounting risk are factors associated with current major global challenges such as population growth, industrialisation and increasing urbanisation. The world's population is expected to burgeon by a further 3 billion by around 2030, with 60% in urban areas and water needs expected to exceed viable production by 40%. As a result, a global middle class is emerging which will double to 4.9 billion people in 2030, according to the Brookings Institution. Most of these people (about 3 billion) will reside in Asia.



Per capita consumption generally increases with higher standards of living and greater aspirations, as do expectations towards public services. Such phenomena are driving global demand for water, expected to rise by 55% by 2050. All of these challenges are compounded by the effects of climate change: more and more regions are being affected by long periods of drought, which further increases the competition for water.

The forecasts for growth in the water sector, especially in Asia, therefore suggest huge business opportunities. Global Water Intelligence (GWI) expects a compound annual growth rate of 7% for capital expenditure in municipal and industrial water supply between 2015 and 2019. By 2019, capital expenditure on water for household and industrial use would be in the region of US $137.5 billion. In China alone, capital expenditure on water infrastructure will grow at a CAGR of 8% to US $57.7 billion by 2019. With the Ganga River Management plan recommending reusing 100% of municipal wastewater, the Indian market is expected to grow at a CAGR of 13% from US $8.6 billion to US $ 14.2 billion over the same period, with the wastewater sector seeing the fastest growth.

Other major changes are also occurring in the global industrial water market. Despite falling oil prices, the global industrial water market will grow by a CAGR of 8% from US $19.9 billion in 2015 to US $26.2 billion in 2019. Investment in unconventional oil and gas (shale gas, oil sands) will decrease dramatically, but will be compensated by investment in conventional resources. Opportunities are expected in China where the government has issued the Water Pollution Prevention and Control Action Plan, obliging industries to treat their effluent. A potential direct investment is evaluated at about US $230 billion. There is also a growing awareness within the pharmaceutical sector of the necessity to tackle trace pharmaceutical products in the environment, by applying stricter treatment standards to effluent streams. Consequently, investment in the sector will rise at an annual rate of 7% from US $770.8 million to US $993.3 million.

Governments and those in the business of producing water and treating wastewater can thus expect rising demand for innovative solutions and technologies. Meeting the growing needs of citizens and industry will be a test of human ingenuity for the water sector, as innovation is not a straightforward process. The Summit highlighted that innovation involves deliberate application of information, imagination and

By 2019, capital expenditure on water for household and industrial use would be around

US $137.5 billion

From 2015 to 2019, the global industrial water market will grow by a CAGR of 8% from US $19.9 billion to

US $26.2 billion

initiative in deriving greater or different values from resources. It includes all processes by which new ideas are generated and converted into useful products, which must be replicable at an economical cost and satisfy a specific need. Innovation should also be a responsible process, through which new ways of thinking are explored and habits are changed.

As a first step towards developing innovative technology, the Summit identified the following 8 key drivers for innovation based on the aforementioned challenges.

8 KEY DRIVERS FOR INNOVATION

1. PROTECTION OF WATER QUALITY
2. CLIMATE CHANGE / EXTREME WEATHER EVENTS
3. DEMAND MANAGEMENT
4. NEED FOR NON-CONVENTIONAL WATER SOURCES
5. WATER-FOOD-ENERGY NEXUS
6. ENVIRONMENTAL SUSTAINABILITY, E.G. WASTE MINIMISATION / RESOURCE RECOVERY
7. FIT FOR LOCAL CONTEXT
8. GOVERNANCE / LEADERSHIP

KEY DRIVER 1 PROTECTION OF WATER QUALITY

Water utilities are facing the challenge of producing more water while maintaining the quality of the water produced. A reliable, safe, fit-for-purpose, and affordable water supply is not only fundamental for the protection of public health, it is also a prerequisite for economic development. The challenge is that water sources are increasingly limited and polluted, so we now need to go beyond the traditional water treatment process. Depending on the quality of the water source, treatment levels must also be higher.

Water quality can be protected by treating wastewater before discharge to mitigate pollution. There is thus growing interest in advanced treatments such as membranes for water production. The detection and treatment of emerging contaminants in urban water sources, including micropollutants such as drug residuals and endocrine disruptors, is also a major challenge for water utilities.

Ageing infrastructure in cities is another concern to take into account here. Water distributed through an ageing network could be contaminated, obliging the operator to add more chlorine to the water stream, raising operating costs. As replacing old assets is usually expensive, more effective and affordable solutions and alternatives are required.

KEY DRIVER 2 CLIMATE CHANGE / EXTREME WEATHER EVENTS

Water quality is also increasingly affected by extreme weather events brought about by climate change, such as severe droughts or flooding, which also have a direct impact on the availability of water resources and the organisation of water infrastructure.

Furthermore, long periods of drought may oblige water utilities to use water resources of lower quality, such as surface water with a much higher level of suspended solids than groundwater. There is thus a growing need to look into technologies which can help in key areas such as flood forecasting, hydraulic modelling, urban-drainage masterplanning, and environmental impact assessments.

KEY DRIVERS 3 & 4 DEMAND MANAGEMENT / NEED FOR NON-CONVENTIONAL WATER SOURCES

Managing water demand and using non-conventional water sources can be described as an adaptive response to the increasing shortage of water. If there isn't enough to go around, the rational option is to not consume more than what is needed. In principle, water demand management involves devising ways to optimise the production and use of water so that less water and the right quality of water is used to satisfy various needs. It also involves implementing intelligent ways to reduce leakages in the process of distribution, and developing a distribution system that has the flexibility to adjust to seasonal or other changes in water demand. Hence, besides controlling water demand with stricter regulation on water withdrawal or incentives to decrease water consumption, there is also growing interest in technological advances in demand prediction, leak-detection to minimise non-revenue water (NRW), and forecasting asset failure.

Technological improvements have also made recourse to non-conventional and weather-resilient water sources possible, which are becoming more important due to climate change. For example, thermal and membrane technologies remove salt from brackish water and seawater, while wastewater treated to a certain level of purity can be reused. Treated wastewater can be used for irrigation, cooling in industry or even in drinking water production – Singapore, for instance, has four NEWater[1] factories that combine reverse osmosis (RO) membranes and ultraviolet (UV) disinfection.

KEY DRIVER 5 WATER-FOOD-ENERGY NEXUS

Advanced treatments and non-conventional water resources require technologies that are more energy-intensive than conventional processes. In his Welcome Address to Summit participants, Dr. Vivian Balakrishnan, then Singapore's Minister for the Environment and Water Resources, highlighted that there is therefore the risk of replacing a water issue with an energy issue (refer to the box on the right for more details). Priority should be given to innovative solutions that can achieve smaller energy footprints, either through lower energy consumption or through energy recovery or production. For instance, pressure exchangers reduce the energy consumption of desalination. Anaerobic treatment processes, applied to sludge or wastewater with a high level of carbon, can produce biogas that can be used to generate electricity. We should also look into technologies that enable energy recovery from biosolids, including food waste.

[1] High-grade reclaimed water

7 STEPS TOWARDS WATER-AND-ENERGY INDEPENDENCE

Dr. Vivian Balakrishnan, then Singapore's Minister for the Environment and Water Resources, delivering his Welcome Address to STIS participants

In his Welcome Address to STIS participants, Dr. Vivian Balakrishnan, then Singapore's Minister for the Environment and Water Resources, recalled that water had always been an existential issue for Singapore but underlined the fact that innovative technologies, such as RO membranes, have played a crucial role in overcoming this vulnerability. Such technologies have enabled Singapore to develop a more resilient water supply using non-conventional water sources such as desalination and large-scale water reuse, which can currently meet over half of the country's water needs. However, given the energy-intensive nature of RO membranes, Singapore has increased its reliance on energy.

Dr. Balakrishnan thus outlined seven practical measures that Singapore could take to become water-and-energy-independent by 2060:

1. Improve the energy efficiency of RO through research and development (R&D)
2. Decrease the energy consumed by pumps by reducing the distances over which water is conveyed and rectifying leaks with smart technologies
3. Recover energy from used water via anaerobic treatments
4. Generate energy from solar power by installing floating solar panels over water
5. Harvest the potential energy of falling water, using hydraulic micro-turbines
6. Reduce per capita water consumption
7. Prevent water leakage through pipe maintenance

KEY DRIVER 6 **ENVIRONMENTAL SUSTAINABILITY**

Besides reducing energy consumption, industries and water utilities will have to minimise the volume of waste they produce, which includes the sludge resulting from wastewater treatment or the brine produced by RO membranes. While the constituents in sludge and brine can be hazardous to the environment, they can also be of great value if recovered effectively. For example, energy recovered from waste can lower the overall costs of sludge treatment and desalination. Thus, technologies of interest in this area would include sludge anaerobic digestion which not only produces biogas, but also dramatically reduces the volume of biosolids which must be disposed of. Ways to extract valuable minerals from RO brine are also being actively researched, though no method has been effectively commercialised as yet.

KEY DRIVER 7 **FIT FOR LOCAL CONTEXT**

In any case, innovative solutions need to be adapted to the local context. Summit attendees put particular emphasis on the necessity of a better appreciation of consumer needs, be they clearly expressed or latent. Three questions should always be answered:

- What are the needs?
- Where are the needs located?
- What are the difficulties associated with these needs?

A distinction was made between organised mature water markets and developing, less organised markets. In the former, the focus tends to be on achieving optimum performance with existing technologies, including applying them to areas such as energy recovery, smart water grids and asset management. Developing markets are more likely to prioritise low-cost innovation, and require more engagement with entrepreneurs with in-depth understanding of local needs. Low-cost innovation can be developed in various ways, including improving "old" technologies, and exploring the development of unconventional technologies that are inexpensive and effective. This could be done by observing and learning from the natural processes that surround us, and looking into biological processes that use less energy and have lower capital and operating costs.

KEY DRIVER 8 **GOVERNANCE / LEADERSHIP**

The above changes will not take place, however, without clear leadership and good governance in the water sector. This does not just imply the importance of political will. It is equally essential to engage other key stakeholders like entrepreneurs, innovators and thought leaders to create a more viable financial and economic landscape for developing innovative technologies, and ensure that goals, targets and incentives are clearly set. Governments, public utilities and private companies should therefore work hand-in-hand, and profit-driven innovation and social responsibility should move forward together.

Good governance also means holding all stakeholders accountable. At a broader societal level, every stakeholder needs to be educated and informed about the realities of decreasing water resources, chiefly so that clean potable water is not taken for granted. For instance, attitudes of citizen consumers toward water need to change to support government efforts to prioritise water conservation, while service providers and industrial users must meet environmental standards regarding wastewater treatment and discharge.

Moreover, there needs to be greater investment in education to match the need for innovative solutions. For example, we should explore how teaching and research can build on fundamental knowledge and first principles to develop and responsibly apply disruptive innovation. Engineering schools should look into expanding their typical range of disciplines, and offer students more opportunities to help affect change, such as in societies which are less developed. This can guide them in developing appropriate technologies to tackle water issues. A generation that is acutely aware of the resource challenges of the 21st century is more likely to be inspired to find solutions to the world's water problems.

CHAPTER 2

TOWARDS MORE FOCUSED INNOVATION: PRIORITISING TECHNOLOGY FOCUS AREAS

In order to address the top innovation drivers identified in Chapter 1, Summit participants agreed on the need to prioritise different Technology Focus Areas (TFAs) for clean water and wastewater, according to where best to invest resources to further develop key TFAs. The TFAs were ranked by the four following categories:

- High Priority (Low-Hanging Fruit)
- High Priority (Disruptive)
- Medium Priority
- Low Priority

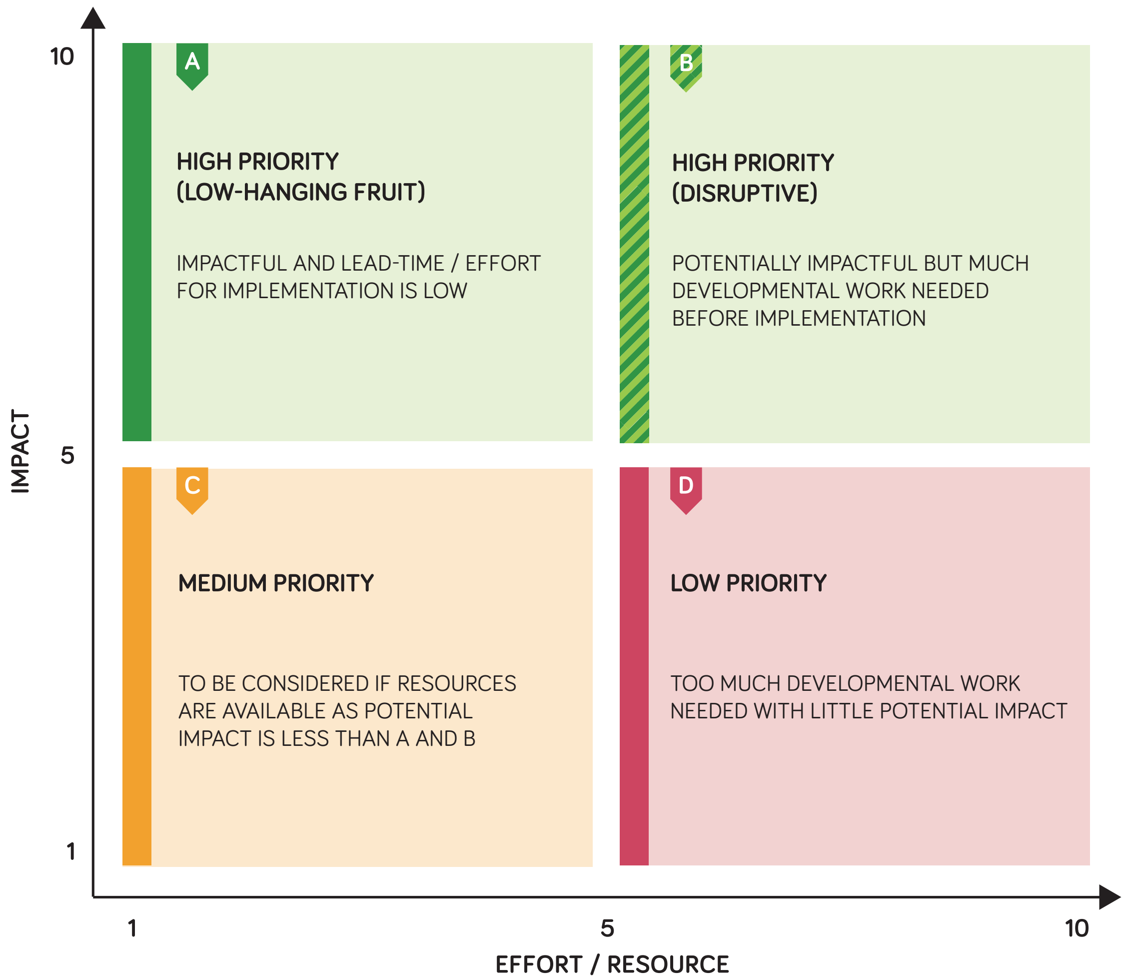
The broad criteria used to classify the TFAs were the **impact** of each TFA on the water sector and the **effort / resource** needed to bring the TFA to reality, as indicated by the diagram below.

IMPACT

Impact, that is the extent to which a problem can be solved, is understood as the capability of the TFA to address one or many of the innovation drivers identified. Several criteria were considered: is it possible to standardise the new technology, realising potential economies of scale and making it more affordable? Is it possible to replicate it for different applications and geographical markets, making it adaptable to local context and specific needs? Can the product be rapidly produced to meet demand?

As innovation does not mean replacing all available technologies with completely new solutions, the potential of established technologies and how they could be updated or adapted should therefore also be considered.

CLASSIFICATION OF TECHNOLOGY FOCUS AREAS



Indeed, the adaptability of a technology determines its applicability in various contexts. The scalability of a technology is important because its efficiency and efficacy should not be compromised as its adoption widens. It was emphasised at the Summit that we need technology that actually works, pinpointing the fact that many technologies have eventually proved to be ineffective when applied at a large scale. It was agreed that the "high priority" label should be accorded to technologies that have the highest potential future benefits and are adaptable to varying circumstances.

Participants therefore considered performance to be one of the main criteria for evaluating a technology, which includes robustness, safety of operation, and capacity to meet standards for drinking water quality or wastewater discharge. Performance, however, should not only be assessed according to the result, but also with regard to other considerations such as energy consumption and the working environment: for instance, technologies more suitable for dense urban environments would be those which are compact, energy-efficient, and have minimal disturbance (such as noise or odour).

Another criterion which was highlighted is the return on investment, which should be significant enough to motivate key stakeholders such as utilities and private companies to invest in the technology. Factors such as the environmental and social impact of the technology should also not be ignored. The goal is to avoid solving a problem by creating a new one: for instance, while RO membrane processes are particularly efficient at removing pollutants, they generate brine which has to be treated before disposal.

EFFORT / RESOURCE

Effort / resource covers the cost-effectiveness, financial backing and time required to develop a technology – from lab scale to pilot trial and first reference to full-scale commercialisation – and also its complexity.

A key point raised was how challenging it is to have the technology accepted by end users and consumers. Does the operation, maintenance and further development of the technology require very specific skills or resources (such as energy and chemicals) – and are those resources locally available, now and in the future? For instance, a technology which is highly dependent on foreign imports for its operation should be avoided, unless the operator is controlling part of the supply chain. Similarly, using advanced technology implies training the staff responsible for its operation. For example, there is a stronger need for properly trained operators where technologies are more advanced, such as when applying membranes, modern microbial processes, molecular biology, or involving advanced communications or automation of control systems. In line with this, appropriate technology and knowledge transfer is necessary for sustainable usage: for instance, smart network sensors require a radio network for communication.

Furthermore, a technology should be evaluated by taking into consideration its whole life cycle, not only the capital and operating costs. As the implications may be both financial and social, a comparison should be made between the cost and the benefits in the long term. A solution may appear inexpensive at the onset but impose environmental damage in the long run, for which the economy and society would have to pay for ultimately.

Secondly, it is important for countries to be aware of the need for innovative technology, as well as to create an environment that encourages the development of such technologies. For example, policies and government programmes (including grants, funding, and facilities) can help mitigate financial risks associated with investing effort and resources in the development and testing of new ideas. This is particularly important for companies to put greater effort in R&D with less hesitation about how their bottom lines would be affected.

OVERVIEW OF PRIORITY LEVELS OF TFAS IDENTIFIED

The Global Technology Roadmap on the next page provides an overview of the priority levels of all 28 TFAs discussed at the Summit. These TFAs will be elaborated in the following 3 chapters on: (i) Joint TFAs that apply to both clean water and wastewater treatment such as biological processes, and technology for water recovery (ii) Clean Water TFAs that involve energy-efficient and environmentally-sustainable desalination, real-time data collection and data mining for management of water demand and assets, including for flood control (iii) Wastewater TFAs that develop better sludge management techniques, more resilient membranes for RO, and optimise wastewater collection systems. Additionally, box-outs within the TFA chapters also feature some frontier or emerging technologies for consideration, such as those related to separation / membrane technologies, biological processes, resource recovery, oxidation and disinfection.

GLOBAL TECHNOLOGY ROADMAP

8 KEY DRIVERS FOR INNOVATION:

1. PROTECTION OF WATER QUALITY
2. CLIMATE CHANGE / EXTREME WEATHER EVENTS
3. DEMAND MANAGEMENT
4. NEED FOR NON-CONVENTIONAL WATER SOURCES
5. WATER-FOOD-ENERGY NEXUS
6. ENVIRONMENTAL SUSTAINABILITY, E.G. WASTE MINIMISATION / RESOURCE RECOVERY
7. FIT FOR LOCAL CONTEXT
8. GOVERNANCE / LEADERSHIP

	JOINT TECHNOLOGY FOCUS AREAS	CLEAN WATER TECHNOLOGY FOCUS AREAS	WASTEWATER TECHNOLOGY FOCUS AREAS
A HIGH PRIORITY (LOW-HANGING FRUIT)	• Industrial Water Technologies • Separation / Membrane Technologies (Wastewater) • Biological Processes (Wastewater)	• Low-Energy Seawater Desalination • Water Demand Management • Network Asset Management • Storm Water Management for Flood Control and Water Supply	• Optimisation of Wastewater Collection Systems • Improving Energy Efficiency and Generating Energy from Wastewater Treatment • Sludge Management
B HIGH PRIORITY (DISRUPTIVE)	• Low Energy and High Water Recovery for Reuse • Decentralised Treatment Technologies • Biological Processes (Clean Water)	• Low-Temperature / Energy-Efficient Thermal Desalination • Brine Management	• Source Separation for Wastewater Management • Point of Use Reuse
C MEDIUM PRIORITY	• Separation / Membrane Technologies (Clean Water) • Advanced Oxidation Processes • Water Quality Analytics • Man-less Systems / Automation		• Nutrient Recovery • Fit-for-Purpose Reuse • Disinfection • Low-Tech Solutions • Natural Systems
D LOW PRIORITY			• Electrochemical Processes • Smaller-Footprint Treatment Technologies

CHAPTER 3

SOURCE-TO-USER AND USER-TO-SOURCE: JOINT TFAS (FOR BOTH CLEAN WATER AND WASTEWATER)

The following 10 TFAs were identified for both clean water and wastewater:

JOINT TECHNOLOGY FOCUS AREAS

A — HIGH PRIORITY (LOW-HANGING FRUIT)

- Industrial Water Technologies
- Separation / Membrane Technologies (Wastewater)
- Biological Processes (Wastewater)

B — HIGH PRIORITY (DISRUPTIVE)

- Low Energy and High Water Recovery for Reuse
- Decentralised Treatment Technologies
- Biological Processes (Clean Water)

C — MEDIUM PRIORITY

- Separation / Membrane Technologies (Clean Water)
- Advanced Oxidation Processes
- Water Quality Analytics
- Man-less Systems / Automation

INDUSTRIAL WATER TECHNOLOGIES

There is a growing need to look into industrial water technologies which can address issues of increasing water scarcity and stricter regulations for wastewater discharge. Industrial water end-users are facing growing challenges both in trying to dramatically increase the volume of industrial wastewater which is treated before discharge, and limiting their water footprint by recycling more water. For example, the pulp and paper industry generates up to 3.4 m^3 of wastewater per day in the US. Large international water companies, such as Suez Environnement and Veolia in France, are thus working on delivering integrated solutions to the industrial market. In Asia in particular, the trend is towards industrial water utilities supplying services to industrial parks: companies such as Beijing Enterprises Water Group Limited (BEWG, China) or Evides Industriewater (the Netherlands) deal with the whole water cycle, from supplying process water to treating wastewater.

In Singapore, water consumption in the non-domestic water sector currently accounts for 55% of total water use and is expected to increase to 70% in 2060. Managing non-domestic demand is crucial to secure Singapore's water future. Since 2014, Singapore has held an annual Jurong Island Industrial Water Solutions Forum to boost networking among government agencies, industrial water end-users, utilities, water service and technology providers, schools and consultants. PUB, Singapore's national water agency, also hosted an Industrial Water Solutions Forum at the Singapore International Water Week 2014. More targeted platforms, such as the Industrial Water Solutions Seminar Series, were also created in 2014, to help companies learn how to use existing, new and emerging technologies. Two seminars were held in October 2014 and April 2015 on low-temperature thermal desalination, as well as industrial wastewater treatment and recycling technologies.

There is also a demand for technologies that can treat different types of non-biodegradable and highly polluted, industrial wastewater, such as that from pharmaceutical plants with a high chemical oxygen demand (COD); from electroplating; or from electronic semi-conductors with organic chemical COD. For instance, Mitsubishi Electric (Japan) has devised ways of using micro-filtration and RO to recycle 100% of their wastewater generated from metal plating activities (see **Case Study 1** on page 22). Similarly, with the rising costs of producing clean water, recycling wastewater in the production process is beginning to make much more economic sense. Solutions such as these may help alleviate the pressure on clean water supply.

According to GWI, total global spending on water and wastewater treatment by the industrial market will increase to US $29 billion in 2019. Of this US $29 billion, US $4 billion will be spent on oil-water separation, US $3.2 billion on suspended solids removal, US $1.6 billion on dissolved solids removal, US $1.1 billion on biological treatment, US $626 million on disinfection and oxidation, and a further US $18.4 billion on other equipment and non-equipment costs.

SEPARATION / MEMBRANE TECHNOLOGIES

Separation / membrane technologies also represent a major market in water and wastewater, for both municipal and industrial sectors, worth US $3.9 billion in 2015 and expected to reach US $5.0 billion in 2019, according to GWI. The Summit agreed that membranes are going to play an increasingly important role in water and wastewater treatment. It is possible to make incremental improvements to RO, such as potentially reducing the energy consumption of RO membranes by about 25% with new materials. For example, membranes incorporating nanoparticles have been commercialised for some time by US-based company LG NanoH2O (part of Korean group LG Chem since 2014), while membranes with carbon nanotubes are currently being developed by American start-up company nanOasis. Graphene membranes are currently gaining a lot of interest, with research led by the US Department of Energy's Oak Ridge National Laboratory.

While RO and nano-filtration (NF) work well, they are energy-intensive, though NF has higher recovery and selectivity. The future for MF, ultra-filtration (UF), and NF membranes thus lies in new kinds of membranes made of more robust materials, requiring less cleaning and with a higher porosity, and reactive membranes with catalytic or even biocidal properties. The Singapore Membrane Technology Centre (SMTC) has developed hollow fibre NF membranes for low-pressure water softening, together with Evoqua Water Technologies Pte Ltd. A research team at the National University of Singapore (NUS) is also working on such membranes with Mann+Hummel Ultra-Flo Pte Ltd, for applications in NEWater and seawater desalination.

Ceramic membranes are currently the most promising technology which deserve more attention, as they are energy-efficient and have a much smaller footprint, with a life-cycle cost which is expected to be lower compared with existing membrane systems. In 2014, PWN Technologies refurbished the 120,000 m^3/d Andijk III drinking water plant in the Netherlands with ceramic membranes supplied by Japanese company Metawater. Meiden Singapore, a subsidiary of Japanese Meidensha, is working with PUB Singapore on a demonstration plant combining a ceramic membrane bioreactor (MBR) with an upflow anaerobic sludge blanket (UASB) at Jurong Water Reclamation Plant to treat and recycle industrial wastewater more effectively (see **Case Study 2** on page 24).

German company akvola Technologies has also developed a process which enhances the separation of suspended solids and oily residuals, by combining ceramic membranes and flotation using microbubbles. More interest in NF membranes, currently confined to spiral wound modules, should also be encouraged. Creating hollow fibre NF membranes would open some potential niche applications, such as membrane distillation with waste heat or combining forward osmosis (FO) with the low pressure of RO. FO, which relies on the natural diffusion of water between solutions of different concentrations, is gaining momentum, especially in industrial applications. There is also room to improve more conventional types of separation: for example, Dow Water & Process Solutions (US) has recently launched a new self-cleaning filter, Tequatic Plus, which uses a combination of centrifugal force and cross-flow filtration.

FRONTIER TECHNOLOGIES: SEPARATION / MEMBRANE TECHNOLOGIES

Technology: Tequatic Plus fine particle filter
Company: Dow Water & Process Solutions

The filter unit is housed in a vortex chamber. Centrifugal force pushes heavy particles outward, while lighter solids are removed by cross-flow filtration. Solids are then collected into a chamber below the vortex and are purged as concentrate, while other particles flow into a recirculation pipe for reuse. During the process, the filter media is being continuously cleaned. Filter cut-offs are from 10–55 microns.

Strengths:
- Can tolerate high levels of total suspended solids, up to 10,000 mg/L
- Minimal backwashing required, increasing uptime
- No need for changing filter cartridges and reduced risk of fouling

Weaknesses:
- Small or light particles could build up in filtration chamber due to lack of particle settling

Technology: Ceramic membranes
Companies[1]**:** CeraMem (Veolia), Liqtech (Denmark), Likuid Nanotek (Spain), Kubota (Japan), MetaWater (Japan), atech innovations (Germany), Hyflux (Singapore), Meiden (Japan)

Strengths:
- Can tolerate high temperature water or very oily wastewater
- High mechanical strength can withstand high temperature, highly acidic cleaning processes to remove cake layer from the membrane surface
- High flux: membranes can be operated at flux rates consistently over 100 lmh, whereas polymers typically operate in the range of 40–60 lmh

Weaknesses:
- High capital costs
- Unknown membrane life (difficult for companies to guarantee the membrane)

[1] Companies which manufacture ceramic membranes

LOW ENERGY AND HIGH WATER RECOVERY FOR REUSE

Technologies which involve low energy and high water recovery for reuse are also in particular demand in both municipal and industrial markets. Capital investment by industries in brine concentration technologies is expected to more than double between 2015 and 2019, reaching US $444.2 million, with a majority of these investments coming from the oil and gas and power sectors. The technologies normally involved are RO membranes and thermal concentrators, with the main issue for both being energy consumption (especially for the latter). Hence, one of the most promising developments in this field is FO. The chief advantages of FO systems are their lower consumption of energy, as well as use of a low temperature heat source, which means they can be powered by renewable energy and electricity. This also eliminates the need for materials that can withstand high temperatures. American companies such as Oasys Water, Porifera and Trevi Systems are currently developing FO to concentrate effluent generated in unconventional oil and gas extraction. Scientists at the KWR Watercycle Research Institute in the Netherlands are also testing FO methods for application in industries that do not require high quality drinking water for production (see **Case Study 3** on page 26).

BIOLOGICAL PROCESSES

Biological processes should also be considered for both industrial and municipal applications. Biology has enabled considerable advancements in wastewater treatment, and with increasingly better understanding of this TFA, further significant developments and opportunities could be expected in the next 5 to 10 years. Capital expenditure is forecasted by GWI to reach US $1,247.7 million by 2019, with 76% of this being accounted for by utilities.

The global trend, in both municipal and industrial markets, is also towards solutions with a smaller footprint, especially in dense urban areas. Activated sludge is still the most popular technology, but technologies using a fixed biofilm, such as Moving Bed BioReactors (MBBR), are gaining ground. GWI expects that fixed film technologies will represent up to 46% of the industrial market in 2019. Other companies specialising in such technologies include Veolia and smaller companies such as HeadworksBio (USA) or Aqwise (Israel).

Technical innovations in anaerobic treatment technologies are also leading to their more widespread adoption. Such technologies can treat effluent with a high level of carbon (which is very common in the food and beverage and pulp and paper industries), and have a lower energy footprint than aerobic treatment. Moreover, no aeration is required (thereby consuming less energy) and biogas is produced, which can be used to generate electricity or heat. Anaerobic treatments are thus gaining momentum and are expected to be increasingly explored by companies, such as Black & Veatch in the USA (see **Case Study 4** on page 28), Suez and Veolia.

Smaller, specialised companies such as Paques and Hydrothane in the Netherlands are also exploring niche applications, such as external circulation sludge beds and Annamox, to treat specific contaminants in effluent produced by the mining industry or flue gas desulphurisation in power generation. Another trend, highlighted during the Summit, is to maximise the removal of contaminants by combining biological treatments with membranes, such as in anaerobic membrane bioreactors, activated carbon or oxidation processes. Dutch company Royal HaskoningDHV has also developed an aerobic granular sludge process that dramatically reduces energy consumption. (The box on Frontier Technologies in Biological Processes provides more details on technologies mentioned in this paragraph).

Though biological processes have been traditionally employed for wastewater treatment, they also have applications for clean water. For example, Xylem Services GmbH (Herford, Germany) is collaborating with PUB to test-bed a biological activated carbon (BAC) filter at a PUB waterworks, with the focus on efficient removal of specific target compounds[2] from source water in Singapore.

Moreover, MBR technology, coupled with RO, produces better quality NEWater. In addition, it can potentially reduce the production cost of NEWater by about 20%. Through PUB's pilot and demonstration studies, the design and operation of MBR systems were optimised with specified energy consumption of less than 0.5 kWh/m^3 and stable operation at 25 lmh flux. MBR technology is now being incorporated in any upgrading or new water reclamation plants.

[2] Such as methyl-isoborneol, geosmin, assimilable organic carbon, total organic carbon, natural organic matter, iron and manganese

FRONTIER TECHNOLOGIES: LOW ENERGY AND HIGH WATER RECOVERY FOR REUSE

Technology: Membrane brine concentrator (MBC)
Company: Oasys

Oasys' MBC employs FO and uses a proprietary membrane and draw solution to treat high-total dissolved solids (TDS) waters, including RO concentrate and industrial wastewater streams with increased scaling or fouling potential. The thermolytic draw solution exploits the properties of volatile solutes that vaporise with small amounts of externally applied heat, helping reduce the overall energy requirements.

Strengths:

- Treats both high-TDS and contaminated waters
- Energy-efficient draw solution recovery
- Removes need for thermal brine concentrator

Weaknesses:

- Draw solution recovery requires additional energy input

Technology: Porifera forward osmosis (PFO)
Company: Porifera

Porifera provides FO solutions using its proprietary carbon nanotube membranes, which are designed to increase flux levels by a factor of 2–3. Small-footprint units can be created using individual PFO elements, which can be arranged either in series or in parallel. Porifera's hybrid solution uses FO as a pretreatment to RO, helping to reduce energy requirements and providing the ability to handle difficult streams with changing quality.

Strengths:

- Reduced energy consumption
- Reduced footprint

Company: Trevi Systems
Technology: Trevi FO

An FO process that uses a proprietary draw solution that has a low-temperature phase separation when low-grade heat is applied. This abrupt change enables the removal of the draw chemicals from the product water with less energy. Trevi Systems was one of four companies selected by Abu Dhabi's Masdar in May 2014 to construct a demonstration plant in the UAE using renewable energy sources.

Strengths:

- Low-temperature operation

Weaknesses:

- Requires low-grade heat source

FRONTIER TECHNOLOGIES: BIOLOGICAL PROCESSES

Technology: External circulation sludge bed (ECSB)
Company: Hydrothane

The ECSB is an improvement of the extended granular sludge bed (EGSB). Like in an EGSB, the biofilm (in granular form) is mixed with the wastewater to be treated and the flow moves through the biofilm at a high velocity, ensuring that the time spent in the reactor is limited. Unlike the EGSB, the separation between the treated wastewater and the biogas in the ECSB is carried out in a column separated from the main reactor. The biofilm is then sent back to the bottom of the reactor through a closed loop.

Strengths:
- Better mixing conditions between the biofilm and the wastewater, which maximises biogas production
- Improved biomass retention and recycling
- No odour emission

Weaknesses:
- Bigger footprint because of the external column

Technology: Anaerobic ammonium oxidation
Companies: Paques, Veolia Water Technologies, Degrémont Industry (subsidiary of Suez)

The anaerobic ammonium oxidation (Anammox) process was first commercialised by the Dutch company Paques, but has since been mastered by French companies Veolia and Suez. The selection of bacteria takes place in a sequencing batch reactor (SBR), in anaerobic conditions. It replaces traditional aerobic nitrogen treatment in two steps (that is, nitrification followed by denitrification). Annamox is usually used to treat effluent from an anaerobic wastewater treatment process or an anaerobic sludge digester.

Strengths:
- Allows the treatment of wastewater with a high nitrogen load without any external source of carbon
- Requires no free oxygen, so no aeration through blowers is needed
- Decreases the footprint of the wastewater treatment plant, as the nitrogen load going through the aerobic step is reduced

Weaknesses:
- Maintaining the bacteria is more complex than traditional biological treatments (involving activated sludge)
- Wastewater must have a significant concentration of nitrogen and be kept at a warm temperature, which is currently limiting applications of the Anammox process

Technology: Anaerobic MBR
Companies: Veolia Water Technologies, GE Water (US), ADI Systems (Canada), Hydrothane, Pentair (US / the Netherlands), Kubota

Until recently, combining a biological treatment with UF membranes was limited to the aerobic treatment process. In fact, biogas production during biological treatment creates specific conditions which reduce membrane lifespan. Improvements in membrane structures have made it possible to combine them with anaerobic treatment. Veolia Water Technologies, in collaboration with membrane manufacturer Pentair, was the first company to commercialise the anaerobic MBR, followed by ADI Systems in partnership with Hydrothane (membranes from Kubota) and GE Water (which integrates the group's own membranes).

Strengths:

- Allows the treatment of wastewater streams with a high concentration of suspended solids without increasing the footprint of the reactor
- Increased separation between the sludge and the treated wastewater, making water reuse easier

Weaknesses:

- Energy consumption is higher than other anaerobic processes (such as UASB and EGSB)
- Complex operation and maintenance for backwash and membrane cleaning, because biogas is mixed with the wastewater

Technology: Granular aerobic sludge
Company: Royal HaskoningDHV, Valbio (France)

The process involves creating the conditions for bacteria to freely agglomerate in granules. Aerobic/anoxic bacteria are fixed on the surface of the granule, while anaerobic bacteria grow inside the granule. Such a combination allows the treatment of all three pollutants – carbon, nitrogen and organic phosphorus – almost simultaneously in the same reactor, which is a simple SBR. DHV (later merged with RoyalHaskoning) was the first company to launch a treatment process based on granular aerobic sludge (Nereda) in 2007. French company Valbio has also proposed a similar process, although this has not yet been widely commercialised.

Strengths:

- Reduces reactor footprint and energy consumption
- Easier separation between the biofilm and treated wastewater

Weaknesses:

- Selecting and maintaining the bacteria for granule formation is a complex operation

DECENTRALISED TREATMENT TECHNOLOGIES

Decisions about water infrastructure are often based exclusively on economies of scale, which favours centralised systems. However, the economics of the entire network should be taken into account, including the distance between the sources, pumping needs, geological and geographical environments such as mountainous areas, and large water bodies which make a shortcut difficult. A very recent paper[3] proposes a planning tool which considers all these factors, allowing us for the first time to make informed decisions on the optimal degree of centralisation (ODC).

In most European countries and elsewhere, drinking water pipelines must have the capacity to also quickly deliver considerable amounts of water to extinguish fires. Due to capacity limitations, decentralised systems cannot do this. Thus, decentralisation in water supply can only be initiated when paralleled by alternative water delivery systems for putting out fires. In highly populated areas, the economics also rule for centralised delivery infrastructure. However, in low-density areas, like the western USA or Canada's Prairie States, the sheer length of the necessary pipes make a centralised system almost impossible.

Nonetheless, decentralisation is becoming particularly important in countries where rapid urbanisation is making the construction of centralised water and wastewater systems difficult, with cities growing faster than the rate at which utilities are able to expand their networks. Rising land prices are also making extensive plants impractical, and the cost of transferring water and wastewater over long distances is becoming prohibitive. Advances in alternative treatment technologies, like modern low-maintenance membrane technologies and sensors for control, now allow for a fully decentralised water treatment, down to a single family home or very small industrial operation.

Companies involved in the market for decentralised treatment technologies include Singaporean company Ecosoft and Indian company Ecosan Services. Denmark-based pump supplier Grundfos has also combined its proprietary pumps with membranes to launch packaged units for both water and wastewater treatment. Known as the BioBooster, the modular system can treat wastewater locally either for reuse or safe discharge to the environment. At the BioBooster's core is a biological reactor that breaks down pollutants, and a membrane reactor which carries out filtration. Compact systems like these are changing the landscape for wastewater processing in Europe. Decentralised systems also provide an economical solution for developing countries by cutting through long and capital-intensive work of laying long pipe networks.

ADVANCED OXIDATION PROCESSES

Advanced oxidation (AO) processes, understood as a combination of UV or ozone with a reactive or a catalyst, are a very efficient way of helping municipal utilities deal with trace organic compounds, emerging contaminants and hard-to-treat pollutants, including micropollutants and endocrinian disruptors. AO is also used in process water production for microelectronics and pharmaceutical industries where the highest levels of purity are required, and in tertiary treatment before reusing or discharging water into an aquatic body. According to GWI, the market is expected to grow from US $8.5 million in 2015 to US $625.5 million in 2019, driven largely by industrialisation in Asia. Companies active in this market include Ozonia (a subsidiary of Suez), British company Atg UV and American company Trojan. Again, the need for hybrid systems has been underlined, illustrated by the example of micro-pollutants: some are resistant to oxidation, such as chlorinated flame retardants. The future lies in a combination of AO with biological treatment and activated carbon, in order to maximise the synergies of the different technologies and lower operating costs. There is also a need to look into further developing proven AO technologies using UV / peroxide and the ozone BAC / granular activated carbon (GAC) system.

[3] Eggimann S, Truffer B, Maurer M. 2015. To connect or not to connect? Modelling the optimal degree of centralisation for wastewater infrastructures. Water Research 84:218-231.

WATER QUALITY ANALYTICS

The topic of micropollutants led the Summit to address the question of which contaminants in our water supply and wastewater need to be removed, since it may not always be possible to do so without losing more water. Increasing improvements in water quality analytics are key in detecting emerging contaminants in urban water sources and industrial effluent, such as trace organics, pesticides, and pharmaceutical products. However, it is also necessary to consider thresholds below which the levels of a particular contaminant have no adverse impact on human health or water operations. This would enable sound decisions on whether further resources are needed to enhance the accuracy of related technologies. Procedures such as bioassays can help to clearly determine which contaminants are really relevant and the extent to which it is possible to treat them.

Smart water technologies that enable real-time water quality monitoring, with the use of intelligent sensing and sampling devices connected wirelessly to the Cloud, have emerged over the last decade. Their development has been driven by national security concerns (particularly in the US) and operational objectives. For example, apart from security issues, utilities in the EU are motivated to modernise and raise quality standards. The EU's objectives have resulted in private companies and utilities collaborating with universities to compete for grants under the EU Framework Programme. This spawned two research programmes in the form of SecurEau and SmartWater4Europe.

SecurEau's main objective was to find the best ways to rapidly restore a drinking water network that may have been deliberately contaminated. Under this project which ended in 2013, the solutions studied by the consortium of utilities, universities, and water companies included the integration of sensors in a surveillance system.

SmartWater4Europe, a four-year project that began in December 2013, aims to identify the business case for adopting smart water networks across Europe. It involves 12 participants across the supply chain. The consortium includes Vitens (the Netherlands), Acciona Agua (Spain), Thames Water (UK), and the University of Lille (France). Vitens led the project involving the installation of water quality sensors over 2,300 km of pipes. The sensors monitor free chlorine, mono-chloramine, dissolved oxygen, pH/ORP, conductivity, pressure, temperature, turbidity and flow. Data is then transmitted in real time to a data hub. Partners in this area include Optiqua, Quasset, and KWR Watercycle Research Institute from the Netherlands, Intellitect Water and Syrinix from the UK, Mycometer (Denmark) and S::CAN (Austria).

MAN-LESS SYSTEMS / AUTOMATION

Man-less systems / automation can help bolster the development of other TFAs, especially where there is a need to manage operational costs or lack of manpower. For instance, sensors can sharpen water-quality monitoring in decentralised distribution systems and ensure safety of the water supply. Related systems could also be installed in desalination plants to enhance monitoring and provide early warning of any faults that may occur. With real-time sensors and autonomous water-control systems, advanced treatments would be monitored more closely, chemical doses would be more exact and energy consumption would be better managed. In the US, this could support efforts to encourage greater public acceptance of potable reuse. Companies offering such monitoring solutions include Kurita from Japan and US companies Nalco Ecolab, Solenis, ChemTreat, and ChemAqua. To reduce the operating costs of its many wastewater treatment plants and minimise the number of site operators, BEWG is considering establishing regional control centres across China, able to remotely optimise the working state of the energy-consumption equipment and facilities. Instrumentation and automation have also deepened DC Water's understanding of how resilient its assets are, so as to manage and maintain them in a prognostic way.

Therefore, technologies related to data analytics, integrated system modelling, the 'internet of things', or better instrumentation offer great potential to improve the performance and resilience of water-related operations. The water industry needs to accordingly improve its sharing of good and sufficient data which is needed to populate, calibrate and validate models involved in such technologies. As is the case for water quality analytics, we should also consider what levels of detail or accuracy are worth striving for with such technologies, and whether these may compromise their robustness or performance.

CASE STUDY 1

REDUCING WATER USE AND ENVIRONMENTAL IMPACT IN THE INDUSTRIAL WATER SECTOR[4]

Mitsubishi Electric

Water conservation and management is increasingly taking high priority in the corporate agenda of industrial users. Being large volume users, corporations are becoming more aware of issues such as water scarcity, stricter standards for wastewater discharge, and the reputational risk when citizen activism points to the role they might have in causing wells to run dry. "As an industrial water user, Mitsubishi Electric Group is continuously looking for solutions to reduce its environmental impact and conserve water. Its goal is to achieve 100% recycling of water to eliminate unnecessary wastewater, encourage water conservation and promote cost-savings. Mitsubishi Electric has looked into various technologies to do so," says Dr. Nozomu Yasunaga, Group Manager, Advanced Water Treatment Technology Group, Environmental Technology and Systems Department, Advanced Technology R&D Center, Mitsubishi Electric.

One such technology is Mitsubishi Electric's High-density Microbubble Cleaning Process, which applies high-density, microscopic bubbles 1/100th the size of normal bubbles. These microbubbles have adsorption properties that attract impurities like microscopic oil in the water. Microbubbles permeate water, reach grease even on various-sized and complex-shaped instruments, scour them uniformly, and eventually rise to the water surface. As they float, they transport the impurities that adhere to them as they are drained into an overflow bath.

Mitsubishi Electric has been applying the microbubble cleaning system to its own operations since 2006, for production processes as well as the cleaning of greasy machine parts. The process has reduced the environmental burden caused by wastewater due to reduction in the use of chemical agents; and has also helped reduce water

Mitsubishi Electric Transmission and Distribution Systems Center

Water recycling equipment for the new metal plating process

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[4] References:
http://www.mitsubishielectric.com/company/environment/ecotopics/water/microbubbles/index.html
http://www.mitsubishielectric.com/company/environment/ecotopics/water/recycling/index.html

consumption as water can be used for cleaning many times after the microbubble process brings oil and other impurities to the water's surface.

Mitsubishi Electric also uses membrane separation methods to recycle water. One of its biggest achievements can be seen in the application of membrane technology at the Mitsubishi Electric Transmission and Distribution Systems Center. The center produces devices for high voltage power supply and electrical current. In 2010, after a-year-and-a-half of planning and implementation, Mitsubishi Electric rolled out a membrane separation system for the treatment of wastewater generated at the plant's metal plating facility.

Water from metal plating activities contains hazardous amounts of heavy metals that require detoxification before disposal. Previously, 30% of the treated wastewater was reused for toilet flushing, with the remainder being discharged to a sewerage system. The new system was constructed to be adjacent to the facility and made use of micro-filtration to remove substances measuring over 0.5 microns. The reverse osmosis (RO) process, meanwhile, filters the water of soluble particles that are detrimental to the plating process. The treatment system design was economical with space, reducing the drainage pipe from 600 metres to 70 metres. As a result, the plant was able to recycle 70% of the treated water into the production process which it would have otherwise expelled into the environment. The remaining 30%, which contains soluble acids and alkalis, is detoxified and reused in the plant's toilet system. This meant that the plant was able to recycle 100% of its wastewater generated from the metal plating facility.

More recently in January 2015, Mitsubishi Electric announced that it had developed its version of an advanced oxidation process (AOP) to recycle industrial water and sewage at low cost. The technology uses hydroxyl radicals (OH) generated through an electric discharge created at a gas-liquid interface which can efficiently remove organic substances in wastewater. AOP can greatly reduce the volume of contaminants in wastewater, but inefficiently generating OH through, for example, the reaction of ozone with ultraviolet, prevents AOP from being a substitute to other methods of wastewater treatment. Mitsubishi Electric believes it has found a method to generate OH reliably, thus making its system "twice as efficient" as conventional AOP methods. In a schematic representation of its AOP system, wastewater from a plant is first pretreated and then channelled through plates of electrodes in humid oxygen positioned at an incline. A pulsed corona discharge generated at the interface of humid oxygen and wastewater produces OH with an oxidation potential of 2.85 V, compared to 2.07 V in ozone treatment.

In collaboration with Yasushi Minamitani, an associate professor at the Graduate School of Science and Engineering of Yamagata University, Mitsubishi Electric is working to develop this method for practical use in industrial wastewater treatment.

"As an industrial water user, Mitsubishi Electric Group is continuously looking for solutions to reduce its environmental impact and conserve water. Its goal is to achieve 100% recycling of water to eliminate unnecessary wastewater, encourage water conservation and promote cost-savings. Mitsubishi Electric has looked into various technologies to do so."

CASE STUDY 2

CUTTING ENERGY COSTS THROUGH MATERIAL AND PROCESS INNOVATION IN MEMBRANE TECHNOLOGY

Meiden Singapore

In resource-scarce Singapore, reintegrating treated used water into the water cycle is a priority for sustainable water supply. Reclaiming industrial used water is particularly challenging due to the high organic loading in such water, and the high energy cost involved.

The collaboration between PUB, Singapore's national water agency and Meiden Singapore (a subsidiary of Japanese electrical components and ceramic membrane manufacturer, Meidensha Corporation) on Singapore's first Upflow Anaerobic Sludge Blanket (UASB)-Ceramic Membrane Bioreactor (MBR) demo plant thus marks an important development in the search for ways to treat and recycle industrial used water effectively. While UASB is an established process, the innovative aspect of this venture was the combination of UASB with ceramic membranes, which can achieve a consistent, high-quality output of recycled water.

Supported by a co-funding grant from the TechPioneer Scheme administered by the Environment and Water Industry Programme Office (EWI) in Singapore, the pilot plant has a capacity to treat 4,550 m^3 of industrial used water per day. This UASB-Ceramic MBR installation will provide a reference for industrial used water treatment facilities at the future Tuas Water Reclamation Plant.

Constituting the pre-treatment component of the system, the UASB can remove organic contaminants efficiently prior to filtration by the ceramic MBR. Such pre-treatment reduces biofouling (that is, build-up of microorganisms over time) of the membrane surface. Furthermore, the treatment process reduces the volume of excess sludge by 30% compared to typical aerobic treatment. The biogas derived from the UASB can also be utilised for in-house power generation.

Meiden's flat sheet ceramic membranes were found to be superior to other alternatives such as polymer membranes. Ceramic membranes are robust and able to withstand the stress from heat and chemicals and therefore ideal for treating industrial used water containing solvents, oils, and chemical substances.

"One of the project's greatest achievements was significant reduction in energy consumption for reclamation of industrial used water. It requires much less energy than conventional processes using polymer membranes," says Dr. Hiroshi Noguchi, Head of the Ceramic Membrane and

Opening Ceremony of the UASB-Ceramic MBR plant

“ One of the project’s greatest achievements was significant reduction in energy consumption for reclamation of industrial used water. It requires much less energy than conventional processes using polymer membranes. ”

Water Technology Centre of Meiden Singapore. This was made possible by an innovative configuration which has reduced the overall membrane surface area, meaning that less energy is needed for the aeration cleaning process. Moreover, the downstream Ceramic MBR can produce consistent water quality.

Industry analysts have described the innovation as a potential “game-changer”, and Meiden estimates that this could be in growing demand in the USA, Australia and the Middle East. While the initial capital outlay of S$10.3 million for this infrastructure may seem high, its increased adoption and the consideration of whole-of-life costing for the asset is expected to bring down costs to be on par with that of polymeric membrane solutions.

Ceramic membrane unit

The UASB-Ceramic MBR plant

Site tour of the UASB-Ceramic MBR plant

CASE STUDY 3

CLOSING THE WATER LOOP: TECHNOLOGICAL AND PRACTICAL CHALLENGES TO WASTEWATER RECLAMATION

KWR Watercycle Research Institute

KWR Watercycle Research Institute is privately owned by all 10 of the Dutch publicly listed water utilities. Its focus is on research to find practical solutions for urban water problems. One area that the institute is actively pursuing is to find ways to reintegrate wastewater into the water supply and consumption loop (or to achieve what is termed as "closing the loop" in industry lingo). The main drivers for industrial wastewater reuse are local water shortages and a desire to save costs, according to Emile Cornelissen, Senior Scientific Researcher at KWR and Visiting Researcher of the Singapore Membrane Technology Center (SMTC).

In September 2010, KWR undertook a study of opportunities for reuse of sewage treatment plant effluent, or wastewater. Wastewater reclamation is already typically practised in countries that experience water shortages, but the study had a broader objective of outlining current standards and practices, and of determining the conditions under which wastewater reclamation presents a feasible solution. This research project was followed by a cross-sector study of loop-closure feasibility which included participants from heavy industries, drinking water companies, and wastewater authorities. The cross-sectorial research was necessary because these industries would collectively determine the critical factors required for successful closure of the water loop.

Writing in the Dutch Journal, 'Utilities', Frank Oesterholt, Manager and Senior Scientific Researcher for wastewater at KWR; and Hans Huiting, Scientific Researcher for wastewater at KWR, note that loop closure can bring cost savings in the form of lower water intake, reduced water discharge, and reduced energy consumption. An indirect – but no less important – return is the improvement in a company's corporate image which comes with its use of sustainable practices. However, there are also drawbacks. These are: limited cost advantages, very long payback times on investments, and fears of damage to product quality, and hence risks of damage to reputation if public perception and expectations are not managed carefully. Still, the authors take a sanguine outlook and suggest that closing the loop can be both technically and economically feasible for most companies. One of the factors critical for success is the need for a public partner for co-financing and to help facilitate legal procedures.

> "Ultimately, an engineering solution that makes wastewater reclamation cost-effective frees up the pressure on drinking water supply since industries no longer have to tap high quality water from the drinking water supply for use in production. This optimises the entire process of water resource management within an ecosystem."

On the technological side, current challenges largely relate to the membrane technology and technical processes employed in wastewater reclamation. Some processes such as reverse osmosis (RO) are high energy consumers. In looking for more viable solutions, KWR has developed new processes involving forward osmosis (FO) with a re-concentration step to produce high-grade water from wastewater. Such processes offer cheaper alternatives to extracting water from wastewater suitable for industrial use.

Unlike pressure-driven membrane processes, the osmotic solution is the driving force in FO processes. KWR's Sewer Mining Concept implements FO in a closed system to recycle the osmotic solution and to recover high-quality water. This separation occurs in a recovery process (e.g., RO), which is the energy-consuming step in closed FO applications. Wastewater contains organics, which can be converted into biogas with anaerobic digestion. The biogas can then be used in the recovery process, thus reducing the total energy consumption of the process. In addition, the concentrated nutrients from the digested sludge can be recovered and recycled, for example, as a fertiliser.

Cornelissen, the lead researcher in this project, explains that FO is economically feasible when applied to niche applications where FO can be used as a stand-alone process, such as for concentration of certain water streams or for controlled dilution purposes. New membranes available in the market can also help to make FO economically feasible. "Ultimately, an engineering solution that makes wastewater reclamation cost-effective frees up the pressure on drinking water supply since industries no longer have to tap high-quality water from the drinking water supply for use in production. This optimises the entire process of water resource management within an ecosystem," says Cornelissen.

FO at KWR test facility. Researchers Danny Harmsen and Dirk Vries.

A final obstacle to wastewater reuse comes in the form of negative public perception. In 2008, KWR conducted a study which found that public disgust levels were high in relation to wastewater reclamation for drinking purposes. Yet, campaigns for the addition of wastewater into the general drinking supply have been successful in places like Singapore and Namibia. Oesterholt and Huiting note that the critical success factor lies in public communication. Industries like the food and beverage sector could do well by learning from the experiences of municipalities that have integrated wastewater into their supply. A sensible strategy is to be proactive in their communication to allay any inherent fears that food or drink products might be contaminated with wastewater, and to build confidence. In conclusion, Oesterholt and Huiting note that closing the water loop should not be considered an end-target in itself, but instead should be taken as an integral part of the overall energy conservation effort.

CASE STUDY 4

GENERATING ENERGY WITH BIOLOGICAL PROCESSES

Black & Veatch

"There is no one technology or 'one-size-fits-all' that addresses all the issues facing the water sector. There are numerous technologies emerging that show significant promise depending on the particular drivers and constraints for individual sites. Taking a broader view, the most promising technologies are those that redirect carbon away from traditional secondary treatment towards digestion, coupled with low energy and low carbon nutrient recovery or removal," says Cindy Wallis-Lage, President, Black & Veatch's Water Business.

Constructing the Thermal Hydrolysis Process (THP) at Davyhulme, Manchester, UK

Black & Veatch is a global leader in the consulting, engineering, construction and operation of facilities in the energy, water, and telecommunications sectors. The company – which is headquartered in Kansas – has been active in the business of water treatment and supply since landing its first industrial contract in 1915.

According to Wallis-Lage, an exciting area in this field is in enhancements to anaerobic digestion to maximise energy production whilst minimising reactor size. Energy and nutrient recovery programmes are vital to delivering strong returns on investment while satisfying rising calls for sustainability. Energy represents universally one of the highest operational costs in water treatment and the opportunity for advanced digestion processes exists in any market where energy neutrality is a major driver.

One of Black & Veatch's most prominent projects is in energy-neutral wastewater treatment. The company was appointed principal contractor from 2010 to 2014, for the upgrading of United Utilities' wastewater treatment facility in Davyhulme, Manchester in the UK. A new energy self-sufficient plant was constructed in this facility to increase treatment capacity.

Increased Capacity

The upgrade increased the facility's biosolids processing capability from 39,000 tonnes of dry solids (tDS) per year to an annual maximum capacity of 121,000 tDS (with an average of 91,000 tDS per year), allowing the facility to treat the dewatered biosolids cake previously handled at seven satellite sites. The increase in capacity means that Davyhulme is now capable of processing biosolids equivalent to a population of approximately 4.4 million people.

Energy Self-sufficiency

Biosolids at Davyhulme go through a multi-stage process of thermal hydrolysis (THP), anaerobic digestion, and incineration. Four thermal hydrolysis streams feed eight digesters. Biosolids displaced from the digesters flow by gravity into a degassing tank where air is injected to inhibit methanogenesis. From the degassing tank, sludge is transferred to digested sludge storage tanks. Biogas from the digesters is balanced using two 9,000 m^3 double membrane gas holders. The gas is pumped via a gas clean up system to feed five combined heat and power (CHP) engines and three combination boilers. The combination boilers are capable of raising steam for the thermal hydrolysis process using a combination of exhaust waste heat (from the CHP engines) and biogas burned in the fired section of each boiler. Heat is recovered from the CHP engine jacket cooling systems to pre-heat the final effluent dilution water used to dilute sludge cake being fed to the THP and boiler feed water. Electricity is generated from the CHP engines, making the site energy self-sufficient.

Wallis-Lage added, "We are continuing to look at a range of energy and nutrient recovery technologies. These are without doubt exciting and evolving areas of research and are at varying stages improving themselves at different scales and utility conditions."

"When it comes to nutrient recovery, the world's supply of minable phosphorus is finite. As more than ninety percent of this supply is linked to one country, Morocco, it renders the resource risky in terms of supply security on a global scale. At the Stickney Water Reclamation Plant in Cicero, Illinois, which is the largest used water treatment facility in the world, we're designing and building a new nutrient recovery system.

"It's an area of research that my long-standing colleague, friend and Lee Kuan Yew Water Prize Laureate 2011, Dr. James Bernard has championed for decades and we are beginning to see major movements in this area."

"We are continuing to look at a range of energy and nutrient recovery technologies. These are without doubt exciting and evolving areas of research and are at varying stages improving themselves at different scales and utility conditions."

CHAPTER 4

SOURCE-TO-USER: CLEAN WATER TFAS

The following 6 TFAs were identified for clean water:

CLEAN WATER TECHNOLOGY FOCUS AREAS

A — HIGH PRIORITY (LOW-HANGING FRUIT)

- Low-Energy Seawater Desalination
- Water Demand Management
- Network Asset Management
- Storm Water Management for Flood Control and Water Supply

B — HIGH PRIORITY (DISRUPTIVE)

- Low-Temperature / Energy-Efficient Thermal Desalination
- Brine Management

It is noteworthy that three TFAs (low-energy seawater desalination, low-temperature thermal desalination, and brine management) are linked with one driver for innovation in particular – the "need for non-conventional water sources". Growing pressure on groundwater and surface water resources is leading to the increased use of unconventional water sources, such as desalinated water. Gulf countries already rely almost entirely on seawater desalination for potable water production. The Summit's attention was drawn to the fact that an increase of seawater desalination is inevitable, given that almost half of the world's population lives within 100 km of a coastline. GWI's latest Desalination report forecasts that capital expenditure on desalination, for both municipal and industrial applications, will grow from US $3.7 billion in 2015 to US $6 billion in 2019. Seawater desalination technologies such as RO membranes and thermal desalination technologies, including Multi Stage Flash (MSF) and Multi Effect Distillation (MED), are mature and well accepted. However, these are both energy-intensive. It has been thus been underlined that we should look into developing desalination technologies that require less energy, less work and have a lower impact on the environment. Over the next five years, we need to redouble our efforts to reduce energy usage in desalination.

LOW-ENERGY SEAWATER DESALINATION

A crucial challenge is therefore developing low-energy seawater desalination technologies that can help lower greenhouse gas emissions as opposed to when fossil fuels are used. There are different ways to reduce energy consumption in desalination: pressure exchangers and turbines recover part of the energy required in the RO process, while varieties of membranes that are more efficient at salt rejection and less energy-intensive are already available on the market (for example, with carbon nanotubes) or under development (including those with graphene material or biomimetic membranes).

A few examples of new desalination membrane processes that are currently being explored were given during the Summit:

- **Closed-circuit desalination:** Pioneered by American start-up Desalitech, this is a batch process where one gradually pressurises a batch of seawater to above osmotic pressure and drives the water through the membrane[1]. While this would be an efficient way of purifying water using membranes, it would require pumps which can simultaneously deliver high pressure and high efficiency.
- **Biomimicry:** This consists of observing naturally occurring phenomena to try to replicate them in technical processes. Biomimetic membranes are the most advanced examples of such nature-inspired solutions for water and wastewater treatment. Two Danish companies, Aquaporin and Applied Biomimetic, are currently working on biomimetic membranes. Danish company Aquaporin gets its name from a type of natural protein that transports water through a non-permeable surface, such as the kidney. The goal is to create a membrane with capabilities close to the aquaporin's: rapid and selective water transport through the membrane, along with a high salt rejection (see **Case Study 5** on page 34). Applied Biomimetic uses special coatings to embed aquaporins in polymer membranes.

The Summit also agreed that we should explore how to integrate renewable energy into desalination. Desalination plants powered by renewable energy (solar power in particular) are currently taking off. Spanish company Abengoa is building a 60,000 m³/d solar-powered plant in Saudi Arabia, while development company Masdar, owned by the Abu Dhabi government, is working with four companies (Veolia, Suez, Abengoa and Trevi Systems) to study the best possible combinations.

Another way of enhancing the energy efficiency of desalination could entail redesigning the cascade or aspects of the desalination plant, which may involve changes to plumbing, or additional pumping. This would save energy on delivering of water from desalination plants.

LOW-TEMPERATURE OR ENERGY-EFFICIENT THERMAL DESALINATION

Another solution is to lower the temperature or increase the efficiency of energy required in thermal desalination processes. Although MED requires less energy than the older MSF technology, GWI is expecting capital expenditure on large thermal desalination plants for drinking water production to steadily decrease between 2015 and 2019, in favour of less energy-intensive membrane processes. However, new processes combining thermal and membrane desalination are being explored. Membrane distillation, for instance, is a process that utilises a vapour pressure gradient to draw water vapour through a hydrophobic membrane which is permeable to vapours but not liquids. Several versions of the process have been developed by German company Memsys and Singaporean company Keppel-Seghers. The main advantage is that it requires a lower temperature than conventional thermal desalination and works with waste heat from industrial processes or renewable energy sources.

In spite of developments in membrane technologies, reliable MED systems are not yet on the road to decommissioning. The Doosan Group from South Korea, one of the leaders in thermal desalination processes, is still pushing the limits of efficiency with its MED plants. By increasing top brine temperatures with new anti-scalants, Doosan has been able to achieve higher performance ratios from its plant designs (see **Case Study 6** on page 36).

BRINE MANAGEMENT

Another key area of opportunity for thermal desalination processes is in brine management. Membrane processes produce brine. For large desalination plants this can usually be discharged back to the sea, but brine from industrial wastewater or produced water treatment contains a high concentration of contaminants. Stricter regulation is increasingly obliging plant operators to minimise the volume of brine. Hence, we should also explore more environmentally-friendly technologies and processes (see **Case Study 7** on page 38, on the Saline Water Conversion Corporation in Saudi Arabia). This includes those which can achieve higher recovery of water from brine. New types of membranes and FO allow for concentration of brine, but thermal processes such as evaporators are necessary to achieve the highest step of concentration. The byproducts of the brine concentration process are clean water which can be reused, and solid waste which can be more safely and easily disposed of.

[1] The brine is continuously recirculated through a shorter membrane train until the maximum concentration is achieved, while energy consumption is minimised.

Pressure retarded osmosis (PRO) is another key process for brine management. Pioneered by Norwegian company Statkraft and Israeli company IDE Technologies, this uses an FO membrane that takes freshwater across from low salinity to high-pressure and high-salinity seawater to generate power[2]. In Singapore, this could involve combining high osmotic pressure seawater brine with NEWater brine (which has very low osmotic pressure) across an FO membrane to generate energy (see **Case Study 8** on page 40). The Environment and Water Industry Programme Office (EWI) is supporting research teams in the National University of Singapore (NUS) and Nanyang Technological University (NTU), to demonstrate that PRO technology is viable for tapping seawater RO (SWRO) and NEWater brine streams for energy production, or to offset desalination cost.

There is also considerable work being carried out, such as in the Netherlands, on reverse electro-dialysis (RED), a PRO competing technology. This aims to recover water from the brine generated by RO membranes. EWI has an on-going programme (of 4 sub-projects) with GE Water and Process Technologies, to study RED-based seawater desalination technology for higher recoveries and reduced capital costs.

The future also lies in technologies that can recover valuable elements such as lithium or magnesium from brine at a viable cost. The possibility of using brine to remineralise desalinated water to potability levels has also been raised, since water that comes out of membranes may not be suitable for drinking or irrigation. One suggestion was to reclaim the magnesium from the brine and introduce it back into the system. The Summit also noted that brines can provide energy even beyond PRO. There have been some estimates that combining salinity gradient energy production with SWRO could reduce the energy consumption by up to 25%.

WATER DEMAND MANAGEMENT

Beside desalination, other solutions to ensure a sufficient water supply include water demand management, which is a general term covering the different ways of reducing the volume of water consumed. This can be achieved through policies and incentives that lead people and industries to reduce water consumption through water-saving devices. For instance, the Public Utilities Act regulating the water sector in Singapore stipulates that water fittings and certain products (such as taps, mixers, and washing machines) must bear a label indicating their water efficiency rating. One step forward would be greater efforts to make water-saving devices compulsory, but it is a whole change in behaviour that is necessary – a change that could be accelerated by new technologies. Smart meters allow consumers to be more aware of their water consumption and ultimately change their habits. More and more utilities, especially in Asia, Western Europe and the USA, are launching initiatives to replace traditional meters with smart ones. Consequently, the market size for smart meters is expected to grow from US $1,124.6 million in 2015 to US $1,537.7 million in 2018. Consumption profiling using meter data has been studied by Suez, which recommends that data from smart meters be combined with socioeconomic data and seasonal demand patterns to develop new ways to influence water consumption (see **Case Study 9** on page 42).

Other ideas for managing water demand put forward at the Summit mostly involved alternative models for potable water distribution, such as using different distribution networks for different water uses. For instance, the point was raised that if just 0.6% of treated potable water is actually used for drinking, the majority of other water uses (such as cleaning and fire extinguishing) could be fulfilled with water of a lower quality through a separate system. This would radically reduce the need to treat large amounts of water to potable standards, and reduce NRW, since a significant proportion

[2] I.e. producing energy using the difference of osmotic pressure between two fluids (for instance, seawater and the brine)

of water is often wasted in distribution systems. Similarly, given that 70% of the energy in the urban water system is used for heating the water, utilities should consider separate systems for supplying hot and cold water. However, dual-distribution systems may mean increased costs, since often only 10% of the cost is in treating water while 90% stems from distribution.

NETWORK ASSET MANAGEMENT

Efficient management of water demand cannot be dissociated from active network asset management. Asset management refers to coordinated policies and actions aimed at optimising performance, risk and expenditure over the whole network lifecycle. The first step of such a policy is a comprehensive diagnosis of the water and wastewater infrastructure, usually with a particular emphasis on the water distribution network. Data modelling and sensors allow utilities to gain a clear overview of the strengths and weaknesses of their network and to make the best possible investment decisions. Examples of this include Singapore company Visenti Pte Ltd's smart sensor networks (see **Case Study 10** on page 44), Canadian company Echologics' acoustic sensors, and the Demand Driven Distribution system supplied by Danish company Grundfos. Based on smart pumps, this system enables operators to adapt pressure in the pipe to water demand, enhancing pipe lifespans and reducing investment in pipe replacement. We should also focus on developing predictive tools that can strengthen leakage-control capacities. Israel-based company Miya has built its business model on offering complete asset management solutions to water utilities, from leak detection and network modelling to pressure modulation, leak repair and pipe replacement.

STORM WATER MANAGEMENT FOR FLOOD CONTROL AND WATER SUPPLY

In order to respond to the extreme weather events brought about by climate change, water utilities must also take storm water management for flood control and water supply into account. During a storm, large quantities of rainwater can overflow the wastewater collection and treatment system, and lead to raw sewage spilling into the environment. The objective of storm water management is not only to protect people and goods from flooding, but also to protect water sources from pollution – and ultimately to use storm water as a complementary water source. The most straightforward solution to avoid sewage overflow is to separate wastewater collection and storm water collection networks. As a result, the pollution load received by the treatment plant is not diluted, while storm water is treated separately. Storm water is not usually heavily polluted, with the main issue being fragments and suspended solids picked up by the storm water running off the ground. Settling tanks are the easiest treatment solution, sometimes combined with lamella clarifiers. In dense urban areas, where it is not possible to build separate collection networks, a solution is to store and treat storm water (perhaps through natural systems) and gradually release it or use it for further applications (such as reservoir replenishment). When well-managed, storm water can therefore be used by water utilities as a supplementary water source, rather than being seen entirely as a risk.

In addition to building infrastructure, storm water management also involves gathering and analysing data, from weather forecasts to the volumes of storm water that the network has to absorb. Again, sensors monitoring volumes and the pollution levels of storm water will play a central role in the development of solutions for storm water management, along with computational solutions such as climate modelling and intelligent watershed management, like the one developed by Singapore R&D centre DHI-NTU (see **Case Study 11** on page 46).

CASE STUDY 5

DEVELOPING NEXT-GENERATION MEMBRANES WITH BIOMIMICRY

Aquaporin

The development of water purification technology with the use of synthetic membranes has helped solve many problems related to the demand and disposal of water. Since the successful demonstration of seawater desalination in the mid-20th century by UCLA scientists, membranes have enabled the commercialisation of techniques such as reverse osmosis (RO). But it's not only in desalination where membrane-based technology is applied. Wastewater reclamation; water purification for food manufacturing; and increasingly, energy generation also require highly efficient and durable membranes.

One of the biggest challenges in membrane filtration is its high electricity consumption, and high operations and maintenance costs brought about by biofouling – the accumulation of microbes on the membrane surface. Over time, biofouling affects membrane permeability, increases energy consumption, and at worse, causes irreversible damage. The inevitability of biofouling raises the operational cost of maintaining a membrane filtration system. As such, membrane systems require pretreatment to minimise the damage that feed water can cause to the membrane. These pretreatments usually involve applications such as sedimentation, dissolved air flotation, screening with micro-filtration (MF) or ultra-filtration (UF), anti-scalants, and biocides. These options come with their respective operational and environmental costs. With MF and UF systems, exopolymer particles may still pass through and cause membrane damage; meanwhile biocides and antiscalants are harmful to the ecosystem.

The solution to these problems may lie in biomimetic membranes, specifically in the synthesis and mimicry based on the use of aquaporins. Found in all organisms, aquaporins are membrane proteins that selectively channel water through cell membranes. Aquaporins exhibit two of the most desirable features of membrane technology, that is, high water permeability and a high salt rejection rate. This makes it particularly ideal for the pharmaceuticals, and the food and beverage sectors which demand a very high product water quality; as well as in meeting the performance demands of pressure retarded osmosis (PRO) where high permeability is paramount.

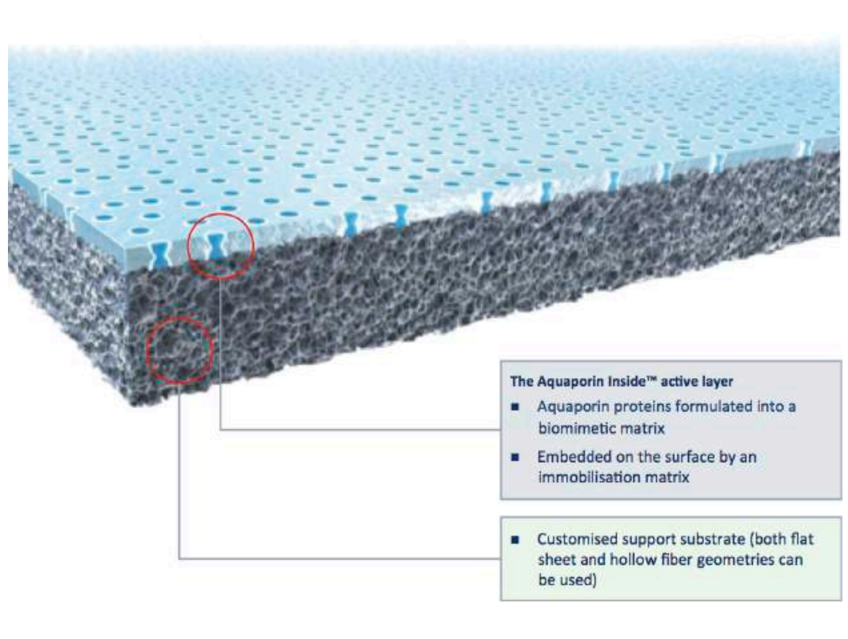
Aquaporin Asia Pte Ltd, a Singapore-based joint venture between Aquaporin A/S, DHI Singapore, and the Nanyang Technological University Ventures, has developed an aquaporin-coated membrane that meets the requirements of high water flux and high solute rejection, at low energy-consumption rates. Scientists at Aquaporin are confident of being able to achieve a full-scale design of its application in the near future. According to Claus Helix-Nielsen, chairman of Aquaporin Asia's Scientific Advisory Board, the use of biomimetic membranes in forward osmosis (FO) could potentially cut costs significantly if applying FO membranes as a pretreatment to existing technologies such as RO or membrane distillation (MD).

"By using a biomimetic FO membrane with an inherently high water flux and high solute rejection coupled with low fouling propensity, the RO or MD operational expenditure will be reduced as the need for cleaning the RO or MD membranes will be less compared to current state-of-the-art pretreatments such as ultra-filtration," he says.

The scientific field of biomimetic membranes has witnessed significant progress over the last decade, particularly within the area of water treatment. Aquaporin development has also received much attention and investment in recent years. However, Helix-Nielsen notes that making the transition from science to commercialised technology is a challenge of scale, with a key issue being the availability of membrane proteins, which is currently unavailable as a bulk commodity. Its production in a cost-effective manner will thus be an important determinant for the economic feasibility of future applications based on biomimetic membranes.

Nonetheless, there is still keenness from those interested in new water treatment technologies, to explore aquaporin's potential. Success in the lab has courted the Chinese, with Heilongjiang Interchina Water Treatment and Poten Environment forming a joint-venture company AquaPoten with Aquaporin A/S. The payoff for all the risk is the potential to break the cost barrier to reclaiming water from earth's most abundant water resources – the sea, and human-generated wastewater.

Aquaporin has further observed that where low-energy seawater desalination is concerned, there seems to be a tendency these days for researchers and technology providers to focus primarily on achieving ever increasing membrane performance. However, in many applications, increased membrane performance and economic benefits for end users do not go hand-in-hand, especially because advances in engineering aspects, such as module and system design, are lagging behind. The development of future water treatment technologies should thus look into ensuring that membrane development and membrane engineering go hand in hand.



> "By using a biomimetic FO membrane with an inherently high water flux and high solute rejection coupled with low fouling propensity, the RO or MD operational expenditure will be reduced as the need for cleaning the RO or MD membranes will be less compared to current state-of-the-art pretreatments such as ultra-filtration."

CASE STUDY 6

KEEPING MED RELEVANT IN DESALINATION THROUGH GREATER EFFICIENCY

Doosan Group

As far as the future is concerned for seawater desalination, membrane technologies such as reverse osmosis (RO) will continue to undermine the growth of thermal processes. The economics simply work out in favour of RO in the long run because of its lower total energy consumption. In the last 15 years, RO growth has outpaced that of multi-effect distillation (MED). In the Gulf Cooperation Countries (GCC), where thermal desalination typically has a stronghold, 121 contracts for RO plants were awarded in 2014 while no thermal contracts were awarded that same year, according to the 2016 Global Desalination Markets (GDM) report.

Yanbu Phase 2 Expansion MED, Saudi Arabia

Nevertheless, the world's geography and climate is diverse and with that comes specific needs for different solutions. For the Doosan Group, the market leader in thermal technology, the world's desalination market may not yet rule out thermal systems as an option entirely. As long as oil prices remain tolerable, thermal desalination plants like MED systems will stay economically viable as they have several advantageous features. Among them are their capacity to produce large volumes of high-quality water, their ability to handle feed water salinity, and a very long asset life cycle – some MED plants can operate for 30 years.

MED plant efficiency can be measured by using the performance ratio (PR) metric. The PR measures the ratio of the mass of water product to the energy input. Informed by its past experience with the development of MSF systems, Doosan had long intended to develop MED systems with greater evaporator capacities and higher top brine temperature (TBT), hence higher PR. TBTs in MED systems are usually capped at 65°C to inhibit scaling and fouling of the system, but higher TBTs can increase MED efficiency because of the greater number of effects it can generate. An effect refers to the process of feed water turning into vapour when it comes into contact with heat exchange tubes in one chamber, which is then channelled to a lower pressure chamber for the next condensation cycle to begin.

> "In this century, energy efficiency and sustainability are some of the key drivers in many industries... Regarding thermal desalination, higher PR solutions could be an answer with their reliability and proven experience for long-term operation."

To counteract the residual effects of higher TBTs, collaboration with the chemical company BASF SE was essential. "The physical removal of tube-outside-scale in MED is very difficult so we needed to rely on chemical solutions and optimal operating conditions to control the scale deposit risk at higher temperatures," says Avtar Jirh, CEO of Doosan Enpure Ltd.

In 2008, Doosan signed a joint development agreement with BASF SE for the development of new advanced anti-scalant for higher TBT MED and completed its design for a 15 MIGD (68,190 m^3/d) capacity MED plant. In 2012, the world's largest MED-TVC evaporator of 15 MIGD was commissioned in collaboration with the Saline Water Conversion Corporation of Saudi Arabia. Regarding higher PR, a full year of testing and experimentation in 2009 found that the optimal TBT it could achieve was 85°C at the point of first effect, which was demonstrated in Doosan's industrial size (410 m^3/d) pilot through 2011 to 2012 operation. TBT 85°C MED-TVC could potentially produce an efficiency measure of 15.8 PR, while typical PR in the market is usually around 10 with the same low pressure steam of 3~4 bara.

"In this century, energy efficiency and sustainability are some of the key drivers in many industries. We know very well that MENA clients want better energy-efficient solutions for desalination. Regarding thermal desalination, higher PR solutions could be an answer with their reliability and proven experience for long-term operation," says Jirh.

Without denying that investors have shifted their focus on RO technology, Jirh keeps a pragmatic outlook, noting that a country's mix of energy sources are partly determined by the policy of its government, which is in turn influenced by considerations of economics, security, reliability, and environmental factors.

"In a similar way, desalination – especially in MENA – could be such a mix of technologies. For thermal desalination, increasing PR is essential to be one of such mix options. By introducing the developed high PR MED technology to the market, we are looking forward to MED taking some share in the future market."

CASE STUDY 7

MAKING BRINE MANAGEMENT MORE ENVIRONMENTALLY-FRIENDLY

Saline Water Conversion Corporation

The desalination plants operated by the Saline Water Conversion Corporation (SWCC) in Saudi Arabia, of which a vast majority are dual thermal plants producing water and generating electricity, have a combined capacity to produce 3.3 million m^3 of water per day. SWCC draws about 30 million m^3 of seawater daily as feed water for the plants, as well as cooling purposes, and discharges 26 million m^3 of brine reject (mixed with huge quantities of cooling water from the plants' electric circuits) back into the coastal waters.

His Excellency Dr. Abdulrahman M. Al-Ibrahim, Governor of the Saline Water Conversion Corporation

With such high volumes of desalination activity, it is no surprise that environmental impact and conforming to regulatory standards has been of great concern for SWCC. Brine typically carries twice the salinity of seawater, though in SWCC's case, the salinity increment in the discharged brine is only 6% above normal seawater salinity at most. Given its greater density, brine will sink to the ocean floor when it is discharged back to the sea. Dilution in the sea occurs much more slowly than at the surface because there is no wave energy mixing the brine into the seawater.

To optimise its brine management, SWCC takes several measures, including co-locating thermal plants with its seawater reverse osmosis (SWRO) membrane plants to share common intakes and reject structures, where brine rejects from each process can be mixed and discharged at one outfall. The two brine streams benefit each other: brine from membrane plants decreases the temperature of the brine from thermal plants, while thermal plant brine dilutes that of the membrane plant. In open discharge lines, the mixing is vigorous enough to allow for the replenishment of oxygen and getting rid of residual chlorine. The co-location of plants also means minimal disturbance to coastlines.

In RO membrane plants, which have only recently gained serious traction in Saudi Arabia in recent years as heavily subsidised fuel has accommodated thermal plants, the main issue for SWCC has been residuals from membrane cleaning agents in the brine. SWCC has developed treatment processes to capture chemicals from cleaning processes as well as corrosive metals, so these will not be mixed and discharged with brine. Employing dissolved air flotation (DAF) has also enhanced the removal of suspended solids and emulsified oil from brine. Furthermore, research conducted by SWCC's Saline Water Desalination Research Institute has culminated in the drastic reduction of chemical additives such as antifoams or antiscalants in brine discharges.

SWCC is confident that its brine discharges have limited environmental impact. "We are satisfied with our research findings that clearly indicate the effect of brine discharges from SWCC plants is benign, or at worse minimal, to coastal environments," says Dr. Abdulrahman M. Al-Ibrahim, Governor of SWCC. A research project conducted with PUB, Singapore's national water agency, and integrated water solutions company Hyflux on microbial species in SWRO plants proved that brine reject from plants at Jubail supports microbes growing as biofilm on solid surfaces.

SWCC also extols the virtues of careful design of discharge structure and picking the optimal site location for establishing a desalination facility to make brine management easier. A sloping outfall, a breakerwall in front of the discharge point and a protected intake lagoon have all contributed to mitigating environmental impact at Jubail. Outfall structures are also designed to alleviate temperature effect, provide more dissolved oxygen and eliminate residual chlorine in the brine. More recently developed methods of salt concentration and mineral recovery are generally unsuitable for SWCC's mega-sized plants.

"We are satisfied with our research findings that clearly indicate the effect of brine discharges from SWCC plants is benign, or at worse minimal, to coastal environments."

The corporation has a string of new desalination projects lined up for the foreseeable future. Meeting environmental responsibilities will accelerate the shift towards RO plants for SWCC and make dependence on thermal plants a thing of the past. "Our environmental concerns are limitless as our ultimate goal in SWCC is to attain sustainability. We went further, as we have even abandoned some of our thermal plants when we felt it could become environmentally unsustainable", says Dr. Al-Ibrahim.

"SWCC uses huge quantities of crude oil to fuel its plants. We are accelerating our research effort in the area of exploring alternative energy sources that are friendlier to the environment", he added.

CASE STUDY 8

HIGH STRENGTH AND POWER DENSITY MEMBRANES FOR MAXIMISING ENERGY GENERATION FROM THE PRO PROCESS

National University of Singapore

Reverse osmosis (RO) is the premier seawater desalination process used across the globe, gaining strong market share over thermal methods over the years because of lower energy use. However, energy consumption in seawater reverse osmosis (SWRO) can still be a pain point – it can comprise over 50% of a desalination plant's total operational costs. Alternatives are being widely sought among the industry. Concerns over high energy prices and a drive towards using renewable energy sources has brought pressure retarded osmosis (PRO) into the picture.

PRO is a novel membrane-based technology that harvests energy from the mixing of solutions with different salinities. In a typical process, water is osmotically drawn from a low-salinity feed to a pressurised high-salinity solution across a semi-permeable membrane due to the difference in water chemical potential. Osmotic power can then be generated through a continuous water influx into the high-pressure compartment, driving an energy-recovery device.

The NUS PRO research team

Researchers at the National University of Singapore (NUS) have been exploring methods to use the power generated from PRO to reduce the energy consumption for the SWRO desalination process, reduce the production cost for clean water and develop a greener RO process. Much of PRO research has looked at mixing seawater and river water, but such a system has a low extractable energy due to a low osmotic pressure difference. NUS has developed a PRO-RO hybrid process using wastewater RO retentate as a feed solution, which has salinity close to that of river water, with SWRO retentate (a waste brine from seawater desalination plants) being used as the draw solution. Singapore has a strong recycling agenda through its NEWater programme which aims to reclaim all the used water. However, wastewater retentate from the NEWater plants must still be dealt with. Using wastewater retentate helps power RO systems, reduces discharge and contributes to the water-energy nexus.

The problem NUS found was that when using wastewater retentate, the levels of power produced in the process can be significantly affected by fouling on the membrane, because of microorganisms, organic and inorganic matters present in the wastewater feed. Research found that ultra-filtration and nano-filtration (NF) pretreatment helped ameliorate fouling. However, adding such treatment steps entails significant extra cost to a system. Therefore, the properties of the membrane being employed are key to the process, impacting power output, operating conditions, process efficiency and cost. As a result, much resource has gone into developing membranes with high power density, good mechanical strength and anti-fouling properties. NUS has developed hollow fibre membranes with 27W/m^2 power density at an operation pressure of 20 bar, as well as flat-sheet membranes with 18W/m^2 power density, at an operation pressure of 22 bar. These values comfortably surpass the power density of 5W/m^2 that had previously been considered for PRO processes to be economically viable.

“As well as augmenting the prospects for PRO to generate enough energy to help power RO systems, NUS also hopes that the high-strength anti-fouling membrane could have potential across other applications, such as next-generation low pressure RO (operating between 10-20 bar), or NF for water treatment, and to filter liquids other than water.”

The hollow fibre membranes also boast effective anti-fouling properties and high recovery rate after cleaning, and the outer selective hollow fiber thin-film composite (TFC) membranes offer an ultra-low salt permeability. NUS has found a way to develop TFC hollow fibre membranes with an outer-selective layer for the PRO process. Previously, TFC membranes have been fabricated in either flat sheet or inner-selective hollow fibre configuration. Outer-selective membranes are less inclined to blockages and pressure drops than their inner-selective counterparts, as well as offering a much larger surface area per module for commercial uses. Continuing work on different membrane configurations will widen the feasibility of the PRO process.

“As well as augmenting the prospects for PRO to generate enough energy to help power RO systems, NUS also hopes that the high-strength anti-fouling membrane could have potential across other applications, such as next-generation low pressure RO (operating between 10-20 bar), or NF for water treatment, and to filter liquids other than water,” says Professor Chung Neal Tai-Shung, Department of Chemical and Biomolecular Engineering, NUS. To continue towards the commercialisation stage, mainstays of research into PRO should include membrane module development, process optimisation, better anti-fouling membrane development, membrane / module cleaning strategies and economical analysis.

CASE STUDY 9

AMR FOR CUSTOMER PROFILING AND WATER RESOURCE MANAGEMENT

Suez Environnement

Smart meters which capture energy and water usage data at a granular level are changing the way utilities manage their customer databases. With advanced communications technologies, such high frequency data can be mapped onto graphs to represent each household's unique consumption patterns in a given season or year.

For water utilities, automated meter reading (AMR) infrastructure or smart meters integrated with analytics software are a necessary development in order to optimise network management, manage operational costs, and conserve precious water resources. The benefits of having AMR infrastructure are primarily witnessed in resource conservation.

In countries such as Malta where operators find themselves caught in "utility-hell" – water shortages coupled with high non-revenue water rates – AMR infrastructure has been an effective way to manage consumption of water which is especially costly to produce because of a dependence on groundwater and seawater sources. An AMR system provides both utilities and customers with information that lets them monitor their consumption, ultimately to help customers reduce wastage. In 2010, Suez deployed 250,000 smart meters in Malta integrated with IT solutions, while housing organisations in France have implemented Suez's "IsiHabitat" in more than 300,000 apartments. In Singapore, Suez Environnement is working with PUB on a research project to implement AMR infrastructure to collect detailed data on household water consumption, which will then be analysed and provided to customers. The impact of the provided information on customers' water consumption and conservation patterns will be investigated.

A website designed and operated by the "Smart Building" Division of Suez, to help customers monitor their water consumption

"An increasing number of cities are looking for solutions to preserve and better manage their water resources. AMR allows water companies to have access to their customers' real-time water consumption and to adapt their pricing and invoicing policy accordingly. Direct applications of such benefits can be seen in holidays cities where population can double during the summer and where seasonal water management is critical. AMR can also be used to define social tariffs and/or to invoice customers more frequently, such as on a monthly basis rather than annually. The AMR solution can also be combined with incentives and rewards schemes to encourage citizens and industrials to reduce their consumption for the benefit of the environment," says Jean de Montal, Operations Director Singapore at Suez Environnement.

In a paper entitled 'Smart Water Customers Profiling and Engagement', Julien Batisse and Karim Claudio of Le LyRE (the research centre of Suez, Bordeaux) and Benjamin Evain, Project Manager at Suez Environnement report that data from AMRs which are typically used for billing processes can be combined with socio-economic data to build rich customer profiles that inform utilities of what drives the consumption choices of their customers. This form of 'consumption determinant' analysis was first practised by energy companies alongside the deployment of smart grids. According to the report, Suez Environnement's approach brings a "better understanding of water users based on the analysis of water consumption enriched by socioeconomic data".

Between 2012 and 2014, Suez Environnement carried out a project with three water utilities in France – Carbon Blanc, Creteil, and Chalon sur Saône – which gathered data from almost 25,000 households. Customer profiles were built based on level of consumption, variation of consumption, and their geographical environment. From its analyses, Suez Environnement was able to group consumption behaviours into four categories of domestic profile. These were the 'sparing consumers' (low level and variation), 'seasonal consumers' (low level, high variation), 'mass consumers' (high level, low variation), and 'shifting consumers' (high level and variation). For each profile, Suez Environnement was able to develop customer engagement scenarios to advise respective customers on how to change their consumption behaviours. These may take the form of education through awareness messages, or incentives through 'gamification' methods where consumers are rewarded as they act to conserve water.

As such, the modern AMR system is not just a passive system that measures units of consumption for any given period. With the help of analytics software, much richer information can be extracted for developing better methods to improve resource management and reduce overall water consumption.

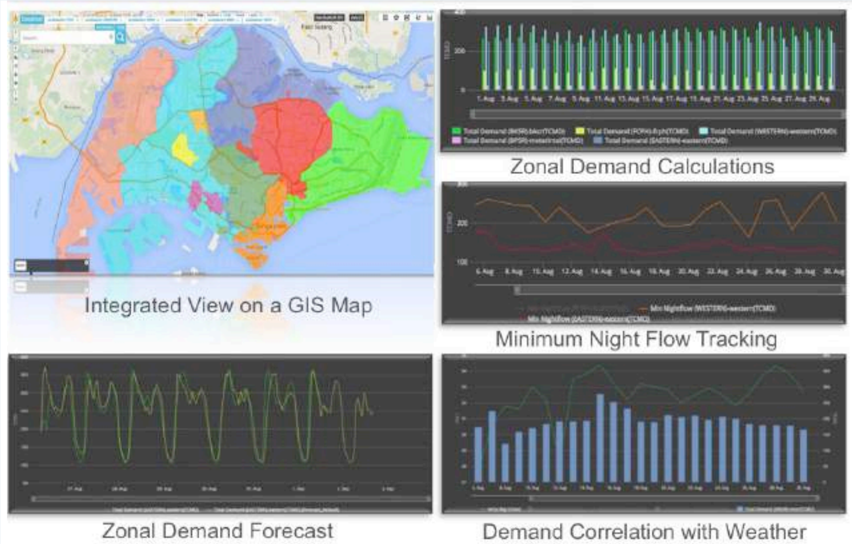
"An increasing number of cities are looking for solutions to preserve and better manage their water resources. AMR allows water companies to have access to their customers' real-time water consumption and to adapt their pricing and invoicing policy accordingly... The AMR solution can also be combined with incentives and rewards schemes to encourage citizens and industrials to reduce their consumption for the benefit of the environment."

CASE STUDY 10

REAL-TIME ANALYTICS FOR BETTER NETWORK ASSET MANAGEMENT

Visenti Pte Ltd

The future city may not yet be a place for swerving hoverboards or flying vehicles but it is likely to be kitted out with thousands of sensors monitoring the moment-to-moment functioning of city infrastructure. When it comes to water supply in such "smart" cities, utilities now have the capability to deploy sensors onto their vast pipe networks. These sensors detect pressure changes within the network and are able to provide valuable data on asset wear and tear.



Demand zones analysis

Visenti Pte Ltd is a developer of such smart systems that make use of secure cloud computing to transmit real-time information of pipe conditions. Monitoring systems like these help cities reduce their non-revenue water (NRW) rates. Whether it is a small leak or a critical pipe burst, reliable information allows utilities to trouble-shoot problems swiftly. Crucially, data collection and powerful analytics software enable them to take pre-emptive measures and to deal with problems before they turn critical and difficult to manage. Advance simulation software, when run in conjunction with network sensors, also allows utilities to generate scenarios of the impact of planned maintenance work or supply diversions.

The predictive power of smart sensor networks was tested by Visenti during a pilot project in early 2015 with a utility in Australia. The objective of the pilot was to identify assets within the network that were under stress and likely to fail. Pressure sensors were deployed at critical locations along a section of the network that was roughly 70km in pipeline distance, to monitor abnormal pressure changes. The test pilot generated a pipeline 'health report' for the utility. Visenti identified pipes that were under stress and were going to fail in the near future. In the months that followed, pipe bursts were reported in areas that were identified as hot-spots by Visenti.

"We believe that this predictive pipe failure information was taken as an important input into their

> With new methodologies for asset management being made possible due to advancements in the technologies, some of those well practised procedures need reviews. We believe that it is a common responsibility shared between the technology providers and the water utilities in helping each other with technology trials and validations, and a commitment to help the water industry.

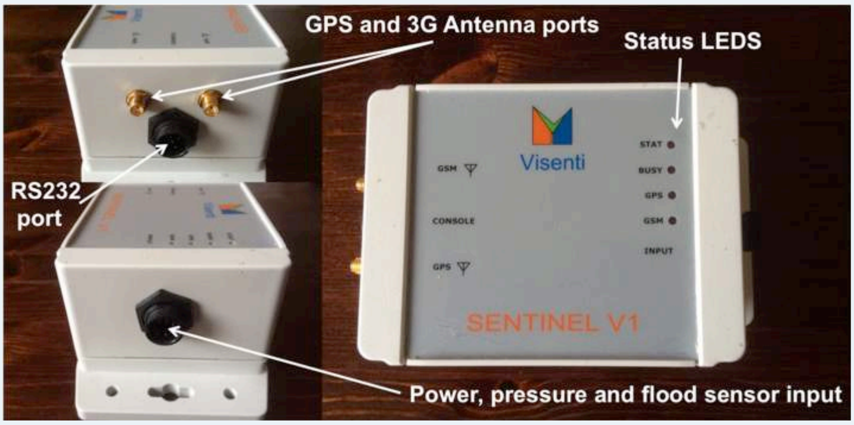
asset rehabilitation programs," says Mudasser Iqbal, Executive Director of Software Systems and Product Development at Visenti.

Information at this level of detail and accuracy gives utilities a lot more control and flexibility in the management of assets, potentially saving them millions in capital expenditure. According to Iqbal, the demand for technological solutions that provide an online closer picture of asset health is growing the world over with utilities keen to invest in technological trials.

As more utilities begin to implement and make use of monitoring systems, one challenge that could emerge is the inaccuracy of asset information records kept by the utility. When pipes and pumps are replaced over time, information may not be updated to accurately reflect changes in their assets' profiles. This poses a challenge for technology providers like Visenti which rely on the accuracy of underlying data in order for their system to provide reliable information.

Current advances in geoinformatics and their adoption in city management are also forcing changes in the way public utilities are organised. Iqbal points out that utilities may have their established standards and protocols for asset management, asset maintenance, and capital expenditure but these need to be reconsidered.

"With new methodologies for asset management being made possible due to advancements in the technologies, some of those well practised procedures need reviews. We believe that it is a common responsibility shared between the technology providers and the water utilities in helping each other with technology trials and validations, and a commitment to help the water industry," Iqbal says.



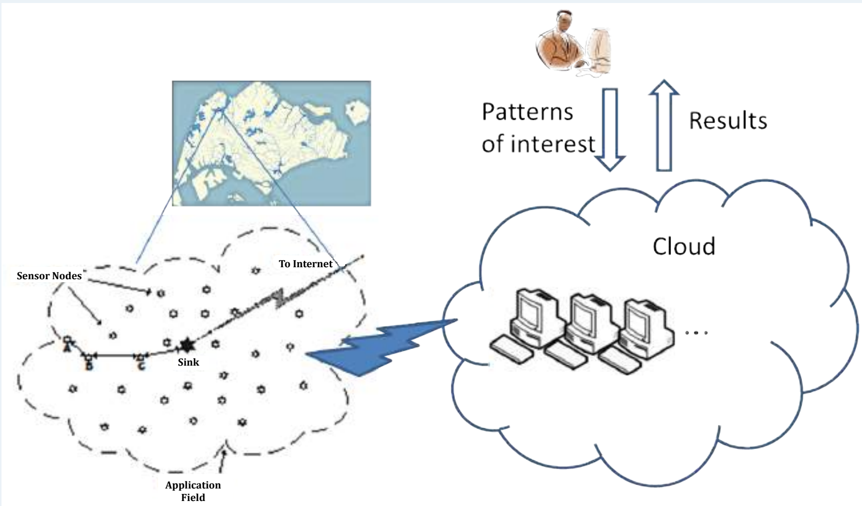
Transient pressure transmitter

CASE STUDY 11

CLOUD COMPUTING AND BIG DATA FOR STORM WATER MANAGEMENT

DHI-NTU

It is a consequence of circumstance and history that the collection and channelling of storm water and wastewater in most urban centres like London are not segregated. As cities expand, so do their impervious surfaces. This encourages greater surface runoff during periods of heavy rainfall which can cause catchment systems to overflow, increasing the risk of sewage spilling into the environment. Adequate storm water management has become a priority for urban planners; after all, storm water is much less polluted than wastewater, thus making it another valuable supplementary water source.



DHI-NTU storm water system

An obvious solution is to build separate catchment systems for wastewater and storm water, even though space constraints in some cities may limit this option. Planned cities like Singapore have constructed separate networks of drains, canals and reservoirs to harvest rainwater which is treated and added to the supply of potable water.

However, even with the segregation of sewage and storm water, constant monitoring and management of the latter is necessary to mitigate localised flooding in a city with high annual rainfall.

In recent years, Singapore has been turning some of its water catchment areas into attraction sites for urban recreation to bring Singaporeans closer to water, so that they can better appreciate and cherish this precious resource. The Marina Reservoir is the city's largest catchment site which also serves as a site for recreational activities and a tidal barrier that prevents flooding in the low-lying areas of the city. The water conditions need to be monitored for public health reasons and to prevent the spread of waterborne diseases. One of the challenges faced is that the site of the Marina Reservoir is surrounded by tall buildings in the Central Business District which cause the wind distribution over the area to be erratic. This impacts the hydrodynamics and quality of the water body, creating a need for accurate predictions of the spatial and temporal dynamics of the surface wind field. Conventional monitoring methods involve interpolation and assumptions of uniform distributions which greatly constrain the accuracy of predictions. Modern computing, however, has turned this effort into a more exact science.

Together with Danish water and environmental research organisation, DHI, researchers at the Nanyang Technological University (NTU), Singapore, are piloting a real-time water quality monitoring project at the Marina Reservoir with the aid of sensors and cloud computing. Locations for the sensors were determined through statistical modelling. These installed sensors then feed wind measurements over the entire reservoir to the Cloud via the Internet.

For water quality analysis, DHI and NTU have adapted the ELCOM-CAEDYM computer simulation model for measuring lakes and ocean water quality to focus on tropical, shallow urban reservoirs. By combining this with Computational Fluid Dynamics (CFD) modelling, the researchers are able to investigate and quantify the wind shielding effects of the surrounding landscape on hydrodynamics and water quality. This model is integrated with other models like rainfall-runoff catchment model and spatial wind prediction scheme, and implemented onto the Cloud system to mine the datasets from the sensors to perform comprehensive analyses which can guide PUB engineers and technicians to make better decisions.

"This project will hence provide the information for PUB engineers to decide on alternative reservoir management options such as the operation of aeration pumps, barrage gates, barrage pumps and pumping to storage reservoirs during periods of intense rainfall," says Dr. He Bing Sheng, Assistant Professor at the School of Computer Engineering at NTU, and lead researcher of the project.

According to Dr. He, the findings from the pilot project, which is scheduled to end in April 2016, can be applied to other inland water bodies in Singapore, or shallow tropical lakes and reservoirs in locations of similar climate and population density.

“ This project will hence provide the information for PUB engineers to decide on alternative reservoir management options such as the operation of aeration pumps, barrage gates, barrage pumps and pumping to storage reservoirs during periods of intense rainfall. ”

USER-TO-SOURCE: WASTEWATER TFAS

The following 12 TFAs were identified for wastewater:

WASTEWATER TECHNOLOGY FOCUS AREAS

A — HIGH PRIORITY (LOW-HANGING FRUIT)

- Optimisation of Wastewater Collection Systems
- Improving Energy Efficiency and Generating Energy from Wastewater Treatment
- Sludge Management

B — HIGH PRIORITY (DISRUPTIVE)

- Source Separation for Wastewater Management
- Point of Use Reuse

C — MEDIUM PRIORITY

- Nutrient Recovery
- Fit-for-Purpose Reuse
- Disinfection
- Low-Tech Solutions
- Natural Systems

D — LOW PRIORITY

- Electrochemical Processes
- Smaller-Footprint Treatment Technologies

The relatively high number of wastewater TFAs identified emphasises the challenges that the sector is offering, especially with increasingly tighter quality standards for wastewater to reduce environmental impacts. The water industry needs to look into the complexities of treating wastewater before discharge, as well as combining physical, chemical and biological processes to deal with the specificity of the wastewater. However, this also presents opportunities to generate energy, extract resources and eventually reuse as much water as possible, including direct potable reuse.

OPTIMISATION OF WASTEWATER COLLECTION SYSTEMS

Wastewater collection is the first stage of the downstream part of the water cycle. Connecting every household to a wastewater network is the first step towards a sustainable wastewater management scheme, as it avoids environmental pollution. In developed countries, the wastewater collection system tends to be ageing and require upgrading, while in developing countries, such networks are often not only in poor shape, but also need expansion to keep up with rapid urbanisation. Hence, optimisation of wastewater collection systems is crucial. GWI anticipates that capital expenditure on utility wastewater networks will steadily grow to reach US $92.4 billion in 2019, compared with the US $71.6 billion invested in 2015.

Optimisation of such networks could involve Integrated System Modelling, which can include data analysis, better sensors, and the development of algorithms to help design better future water recycling treatment trains. The issue of system resilience must also be addressed, especially in a context of extreme weather events such as flooding, which may cause issues such as overflowing of wastewater treatment plants (WWTPs). Integrated treatment processes can also offer potential economic benefits, as illustrated by a pilot plant developed by the Australian Water Recycling Centre for Excellence (see **Case Study 12** on page 54). Other possible ideas are:

- Designing the network so the wastewater flows efficiently, to avoid clogging and the production of hydrogen sulphide in the pipe.
- Ensuring that the distance between the wastewater source and the wastewater treatment plant is optimised, thereby minimising the cost of transferring the wastewater.
- Using materials which will give the pipes a long lifespan, and reduce wastewater leakage and costly pipe replacement.

IMPROVING ENERGY EFFICIENCY AND GENERATING ENERGY FROM WASTEWATER TREATMENT

Another key challenge in wastewater management is its energy-intensive nature. We need technologies which can improve energy efficiency and generate energy from wastewater treatment, such as from the sludge produced by biological treatment. Besides anaerobic treatment processes as discussed in Chapter 3, including Anammox which can greatly reduce overall energy consumption, other solutions available for operators to improve energy efficiency include blowers which enhance oxygen transfer into the wastewater, or adding sensors which closely monitor degradation of the pollutants. In both cases, the goal is to minimise the duration in which pumps and compressors are running.

When it comes to efficiency in wastewater treatment, Israel is undoubtedly a world leader. The national water company, Mekorot, boasts a water reuse rate of 80% which it aims to raise to 90% by creating a national treated wastewater distribution grid. An advance wastewater treatment method it employs is the Attached Growth Airlift Reactor (AGAR) technology developed by Aqwise. AGAR involves the deployment of recyclable plastic biomass carriers into biological reactors. These carriers increase the surface area for more efficient utilisation of reactor capacity.

Other ways of striving towards the kind of energy neutrality exemplified by some WWTPs in Europe would be to install solar panels at such sites for additional power generation. For instance, to reduce plant operating costs, BEWG is using solar panels installed on its facilities and heat pumps to recover energy from wastewater.

Microbial fuel cells (MFCs) was another option raised during the Summit, as these could potentially help recover energy and enable industrial production sites in remote areas to be less dependent on an external energy supplier. There are different kinds of microbial fuel cells currently being developed. Some of them turn methane from biogas into hydrogen, which is then used to generate electricity. Other types of fuel cells are fed with raw wastewater directly. The technology has been proven at a lab scale, but the main challenge is to increase the amount of electricity produced.

The National University of Singapore (NUS) had completed a project on "Microbial Fuel Cell Technology for Wastewater Treatment and Alternative Clean Energy Production" from 2008 to 2011. However, results then showed that MFC for energy generation was not viable due to electrode inefficiency. It is noted that while there have been significant improvements in MFC technology[1], more are needed for commercial and municipal applications. Interestingly, PUB, Singapore's national water agency, found a new application in water toxicity detection. Therefore, PUB has funded the NUS research team to further develop the MFC technology for toxicity detection in sewage. Currently, the technology has completed the field trial and validation of the performance under actual field conditions. The development and further optimisation of a compact system, with an SMS alert system to be installed at 5 industrial trade effluent sites for monitoring illegal discharge, is ongoing. This technology, if

[1] Microbial fuel cell as new technology for bioelectricity generation: A review. Mostafa Rahimnejad et al., Alexandria Engineering Journal, Volume 54, Issue 3, September 2015, Pages 745–756

successfully developed, will be very useful for PUB, as it can be used as an early warning system to identify illegal discharge at source, to ensure sufficient time for the PUB operators to react.

SLUDGE MANAGEMENT

Treating wastewater without proper sludge management would be replacing one problem with another. Traditional options of using raw sludge as fertilisers or disposal in landfills may no longer be feasible, especially in increasingly densely populated urban areas. This issue is even more challenging in countries like China and India, where growing populations mean higher volumes of wastewater to be treated, resulting in higher volumes of sludge. For instance, in 2013, China produced 9.8 million dry tonnes of sludge, while the USA and Europe generated about 7 million each.

Anaerobic digestion (AD) is currently one of the established and well-accepted technologies for reducing the volume of sludge (or biosolids) produced by aerobic wastewater treatments. One key area for research interests includes looking into dramatically enhancing the efficiency and cost-efficiency of AD systems without affecting their resilience, such as increasing the volume of biogas generated from sludge. This could be achieved through combining pretreatment technologies with a two-stage enhanced AD process developed by the Nanyang Environment and Water Research Institute (NEWRI) in Singapore (see **Case Study 13** on page 56). Canadian company Anaergia Pte Ltd is also collaborating with PUB on Singapore's first project aimed at producing more biogas for energy generation. This is done by co-digesting used water sludge from the Ulu Pandan Water Reclamation Plant with food waste from the Clementi district. This treatment of used water has the potential to produce more biogas due to the higher calorific value in food waste (see **Case Study 15** on page 64 for more details).

Other efforts include Dutch company Paques' standardardisation of anaerobic units, making them easier and safer to operate. Norwegian company Cambi is also continually looking for ways to improve the performance of its sludge thermal hydrolysis process (THP), which reduces the digestion capacity required, thus lowering capital costs (see **Case Study 14** on page 58, on US utility DC Water).

There is also strong interest in technologies related to Granular Activated Sludge (GAS), which offers immense opportunities in wastewater treatment. This can vastly extend the capacities of WWTPs by greatly intensifying the conventional activated processes by factors of 2 or 3, because the sludge settles at 4 or 5 times the settling velocities of a regular activated sludge. Granular sludge can also accommodate the growth of different organisms within the same granule, such as biological phosphorus-removal organisms and aerobic organisms such as nitrifiers. Other significant benefits include the ability to meet stringent water quality guidelines, use of less resources, and different Solids Retention Time. Some key future directions for granulated sludge would involve the use of hybrid systems, with both flocs (to enhance treatment quality) and granules (to improve intensification) in the same system. These could be potentially built into existing infrastructure to extend its life.

NUTRIENT RECOVERY AND ELECTROCHEMICAL PROCESSES

It is not only energy that can be recovered from wastewater and sludge, but also valuable elements such as carbon, nitrogen and phosphorus. As a result, nutrient recovery is one of the most promising trends in the wastewater sector. It was stressed that phosphorus recovery should receive further attention, especially as it is a non-renewable resource. Technical solutions, such as the proprietary Ostara Pearl process for recovery from dewatered sludge liquid, and the Outotec Ash Dec process for recovery from incinerated sludge ash, already exist. (The box on Frontier Technologies on Nutrient Recovery provides more details). Furthermore, there is a regulatory driver for phosphorus removal from wastewater streams, such as the EU's Urban Wastewater Directive 1991. Still, recovering phosphorus from wastewater remains less economically viable than phosphorus mined from conventional sources.

The question of nitrogen recovery also arose during the Summit. Currently, nitrogen removal is typically carried out by oxidation in a biological reactor (aerobic or anaerobic, depending on the concentration of nitrogen.) New processes which not only remove nitrogen or ammonia from the wastewater stream, but also recover it as a fertiliser, would be a leap forward. In Belgium, there has also been interest in exploring the recovery of metals from wastewater using electrochemical processes, especially in the mining and metal processing industries. Other possibilities being explored include fibre recovery.

FRONTIER TECHNOLOGIES: NUTRIENT RECOVERY

Resources such as nutrients or metals can be recovered from the wastewater stream using physico-chemical treatments, sometimes combined with biological ones. Phosphorus is the most commonly recovered nutrient. Canada-based company Ostara has developed the Ostara Pearl nutrient recovery process. This technology involves controlled chemical precipitation in a fluidised bed reactor to recover magnesium ammonium phosphate in the form of crystalline pellets. Ostara's Outotec Ash Dec process uses high temperatures to replace heavy metals in mono-incinerated sludge ash with lighter metals. The process detoxifies the sludge ash while producing phosphorus, potassium, and calcium.

Traces of metal are also present in effluent streams from the mining and metal processing industries. Canada-based company BioteQ and Dutch company Paques have developed processes which involve adding sulphide to the wastewater to precipitate metals. Future trends in nutrient recovery involve recovering other valuable substances. American company Nutrinsic has developed a biological process to recover proteins in effluents from the food and beverage industry in order to produce animal feed. Another innovative process, currently being developed by Veolia, employs naturally occurring bacteria to turn nutrients into bioplastics.

SOURCE SEPARATION FOR WASTEWATER MANAGEMENT

Centralised or decentralised treatment of wastewater from various sources in the municipal and industrial sectors is usually driven by the economics of infrastructure. For example, centralised solutions would be more suitable for high volumes of municipal wastewater or combined industrial and municipal wastewater which usually contain very low chemical concentrations. In this case, the choice of treatment procedures and recycling options is also more limited. In cases where mixing all waste streams can make optimised treatment processes very difficult or even impossible, there is a need to explore source separation.

Source separation consists of separating different wastewater streams, depending on their nature and characteristics, rather than applying one single treatment at the end of the wastewater collection pipe. A different treatment process would be applied to each of the different effluent streams, with the most advanced treatment being used for effluent with a high pollution load, while basic processes such as filtration would be used to treat the rest.

For example, wastewater from the vegetable or fruit canning industry contains high carbohydrate concentrations with little nutrients. In addition, it only arises during the fruit or vegetable season. Nitrogen-containing compounds need to be added to prevent bulking, losing the sludge and discharge of untreated wastewater. When the industrial wastewater is co-treated with municipal sources, the nutrient composition of the wastewater must be tightly controlled. Otherwise, severe contamination of the receiving water body can occur, as was the case in the San Francisco Bay Area which brought shrimp fishing to a halt for months. Aromatic compounds in industrial wastewater are already difficult to treat alone. In combination with other streams, the toxicity of the metabolic intermediates excreted during the biological treatment process may have a severe negative effect. Hence, it would be better in this case to consider decentralised treatments close to the source, to allow tailor-made treatments and optimised solutions for specific needs of industrial production.

Source separation can also enhance resource recovery from waste such as urine. For instance, municipal wastewater treatment plants are designed for the morning discharge peak and usually run at less than half their capacities for the rest of the day. Urine is the source of most of the nitrogen and phosphorus in wastewater, and is diluted about 200 times in water closet systems. One way to overcome the inefficiencies of the entire system is to spread the urine release over 24 hours, saving considerably on infrastructure and operating costs. To do so, the original non-diluted urine needs to be separated at the source and a small safe storage will allow it to be discharged at an optimal rate. In combined sewer systems, urine discharge may even be stopped during heavy rain events, preventing it from contaminating the overflow.

Separated undiluted urine opens up interesting options. The urine can be discharged in a separate conduit within the existing sewer system and be treated either centrally or de-centrally, whichever makes economical sense. Treatment can include specific advanced elimination technologies, while for small volumes with relatively high contaminant concentrations, very advanced separation and treatment options exist. Urine also contains most of the pharmaceuticals and their metabolites. Nitrogen and phosphorus can also be recovered for reuse in agriculture.

POINT OF USE REUSE AND FIT-FOR-PURPOSE REUSE

Like source separation, point of use reuse can radically shorten the water cycle through the direct reuse on-site of part of the wastewater generated: for example, water used for hand washing can be used to refill a toilet cistern. The treatment involved for such applications is usually simple, such as cartridge filters. Point of use reuse is strongly linked with fit for purpose reuse, which involves the quality to which water is treated being determined by its end use. Water used for irrigation, for instance, does not need to be purified to potable levels. In an industrial context, tasks such as cooling or cleaning can be carried out with water which has already been used for other purposes, rather than process water. Industrial users like Mitsubishi Electric (see **Case Study 1** on page 22) have applied micro-filtration and RO processes to recycle all the wastewater generated from manufacturing processes. The reclaimed water is either used for flushing or recycled for production purposes.

It was also highlighted that there is a need for more investment in R&D and technology which can help capture and treat human waste at source, for example, through catalytic processes such as pyrolysis and carbonation/carbonisation. Such technologies could minimise our water, energy and spatial footprints by reducing the need for flushing, end-treatment and landfills, and be a more cost-effective solution for sanitation needs in developing countries. This would necessitate rethinking the tendency to centralise wastewater treatment systems.

DISINFECTION

Disinfection is a key part of the treatment process in wastewater reuse, making it safe and reliable. Chlorine injection is the easiest and most common way of removing pathogens, but there are two other solutions: ultraviolet lights and ozone or what is referred to as oxidation processes. For both of these technologies, opportunities for innovation and improvement lie in addressing energy consumption and process efficiency. With advanced oxidation, processes generating reactants like hydrogen peroxide and ozone remain prohibitively costly. Mitsubishi Electric is currently working on a new method to generate ozone at lower cost (see **Case Study 1** on page 22). The box on Frontier Technologies on Disinfection and Oxidation provides more details on other emerging technologies.

LOW-TECH SOLUTIONS, NATURAL SYSTEMS, SMALLER-FOOTPRINT TREATMENT TECHNOLOGIES

The remaining TFAs identified by the participants are all related to the necessity to adapt wastewater solutions to the local context. The choice of treatment should be driven by local needs, resources and capabilities, and low-tech solutions can be an answer for regions and countries which lack resources like skilled staff and reliable sources of energy. Such solutions can include natural systems such as constructed wetlands, lagoons or reed filters, which are applicable to wastewater with high organic content, pH imbalances, and polluted water. These usually require a minimal amount of capital expenditure and a low level of maintenance. More sophisticated natural solutions are currently being developed, involving algae, but most of these are still at the pilot testing stage. Besides lower performance than advanced treatments, the main disadvantage of natural systems is their relatively large footprint, which makes them unsuitable for dense urban areas which demand technologies with a smaller footprint (such as biofiltration, membrane bioreactors).

FRONTIER TECHNOLOGIES: DISINFECTION AND OXIDATION

Developments in disinfection or oxidation relate to improving and combining existing technologies to increase efficiency, and extend their use to more applications in wastewater treatment. Notable ones include:

Technology: Electrochlorination
Company: CeramHyd (France)

This technology involves the production of hypochlorous acid and caustic soda onsite through the electrodialysis of a brine solution. The technology uses a ceramic membrane, which is installed in electrochemical stacks. When the stack is electrically charged, the molecules in the brine are broken up.

Strengths:
- No need to convey and store chemicals

Weaknesses:
- Requires regular operation and maintenance

Technology: Ozone combined with biological treatment
Company: Degrémont Industry

This combines biological treatments with ozone generators to break hard-to-treat contaminants in certain types of industrial wastewater, to enhance their degradability by biological treatments. Degrémont has developed two products: 1) Oxyblue is a solution which combines an ozone reactor before a fixed biofilm biological treatment. The process is suitable for the refining industry where complex organic pollutants have to be treated; 2) Microgreen sets an ozone generator between an aerobic biological treatment reactor and an anoxic one, to treat wastewater from the microelectronics industry, especially tetramethylammonium hydroxide.

Strengths:
- Allow the degradation of hard-to-treat contaminants;
- Reduces the footprint of the biological treatment reactor
- Makes wastewater reuse easier

Weaknesses:
- Ozone generation increases energy consumption of the treatment process

CASE STUDY 12

OPTIMISING TREATMENT SYSTEMS TO SECURE AUSTRALIA'S WATER SUPPLY AND ADDRESS CLIMATE CHANGE

Australian Water Recycling Centre for Excellence

The Australian Water Recycling Centre for Excellence (AWRCE) was established in 2010 and received funding of AUD $20 million from the Federal Government to lead a national research programme in water recycling. Its focus is on the research and development of new technologies which can help to secure the national supply of Australia's water. AWRCE thus invests in research projects across the entire water recycling spectrum.

AWRCE's research focuses are identified in consultation with the Australian water industry, and includes areas like reducing carbon footprint in water recycling and optimal integration of water sources, users and technologies to achieve most suitable outcomes with least impacts.

In the area of optimising treatment systems using new treatment trains, AWRCE has developed a pilot plant to showcase the potential economic and environmental benefits offered by, and the feasibility of, an integrated treatment process. Within this project, two new wastewater treatment trains were designed, and two Anammox reactors to enrich Anammox organisms were also commissioned.

The successful enrichment of Anammox biomass and testing of the Anammox process in this pilot demonstrated how significant savings could be made in terms of overall expenditure on wastewater treatment. Depending on plant capacity, AWRCE estimates that costs could be cut by 10 to 46%.

"All Centre projects directed at system optimisation have, as their core aim, been focused on increasing system resilience in the face of greater climate uncertainty, rising energy costs, market incentives and regulatory compliance requirements for reduced waste discharge with economic and environmental benefit," said AWRCE's CEO Dr. Mark O'Donohue.

To reduce the operating cost of water recycling, AWRCE has also looked into using Free Nitrous Acid (FNA)[2] as a low cost, non-oxidising cleaning agent for preventing and removing biofouling in reverse osmosis (RO) membranes used in water recycling and desalination. In membrane technologies, biofouling of membranes can increase operation and maintenance costs, as large quantities

TWO NEW WASTEWATER TREATMENT TRAINS	TWO ANAMMOX REACTORS
1. An anaerobic membrane bioreactor (AnMBR) for carbon removal + anaerobic ammonium oxidation (Anammox) for nitrogen removal 2. A high rate activated sludge (HRAS) system for carbon removal + sequencing batch reactor (SBR) for nitrogen removal + sidestream Anammox	1. A suspended culture to enrich biomass in granular form 2. A carrier-based culture to enrich biomass in biofilm form

[2] Free nitrous acid (FNA) is the protonated form of nitrite and inevitably produced during biological nitrogen removal and has been demonstrated to strongly inhibit the activity of polyphosphate accumulating organisms (PAOs). (Source: http://www.nature.com/articles/srep08602)

of chemical cleaning agents are required to deal with foulants. The project showed that FNA-based cleaning can both improve the permeability of membranes by up to 29%, and reduce the differential pressure drop by 28% to 38%. This gave FNA, when measured against processes using sodium hydroxide/hydrochloric acid, a cost benefit of US $0.22 to US $0.53/m^3 compared with US $1.73 to US $2.34/m^3. The project's findings have attracted interest from membrane manufacturers who are interested in further comparing and benchmarking the use of FNA against other commercial cleaning solutions.

In addition to working with the industry to identify research areas, AWRCE also takes a strategic business approach when it comes to commercialising any new water recycling technologies which result from its research projects. AWRCE brings in industry experts to assess the prospective marketing potential of any projects and to develop a commercialisation process that is aligned with the Centre's objectives. Factors which must be considered include market trends, competition from existing products or alternative solutions, patent barriers, and the regulatory environment. This enables the AWRCE to make informed decisions regarding whether or not to allocate more funds towards licensing the product, or to assign the intellectual property to a suitable industry partner.

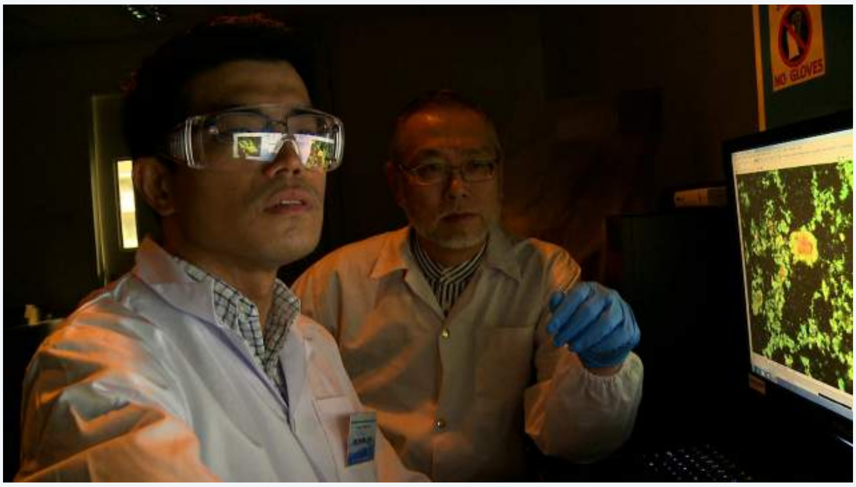
The Anammox pilot plant trial at Queensland Urban Utilities (QUU) wastewater treatment facility at Luggage Point, funded by AWRCE

"All Centre projects directed at system optimisation have, as their core aim, been focused on increasing system resilience in the face of greater climate uncertainty, rising energy costs, market incentives and regulatory compliance requirements for reduced waste discharge with economic and environmental benefit."

CASE STUDY 13

EXTRACTING HIGHER BIOGAS YIELD FROM SLUDGE

Nanyang Environment and Water Research Institute (NEWRI), Nanyang Technological University (NTU)



Professor Ng Wun Jern, Executive Director (right) and Dr. Lim Choon Peng (left) of NEWRI-NTU Singapore assessing the bioprocess technology developed by NEWRI

Population growth, rapid urbanisation, and stricter environmental standards are placing immense pressure on municipalities to solve problems related to mounting wastewater and waste generation. In wastewater treatment, the resulting waste would be sludge which, if managed optimally, can be a valuable source of renewable energy.

It is a challenge for those in the wastewater treatment industry to reduce the volume of sludge requiring disposal in landfills and to instead recover more resources (biogas, nutrients, fertilisers, etc.) from it. Cost of sludge treatment and disposal may be as high as 50% of the total operating cost at a wastewater treatment plant. Wastewater treatment processes produce primary sludge and waste activated sludge which are high in organic content and which need to be stabilised (usually with biological processes) to reduce the risks they may pose to the environment. Anaerobic digestion (AD) – the process wherein organic matter is broken down by micro-organisms in the absence of oxygen – is a renewable energy technology which recovers biogas (essentially methane and carbon dioxide) from sludge while reducing sludge volume before disposal. AD can be enhanced by pre-treatment processes that decompose the large organic molecules found in sludge, and thereby facilitating digestion by the micro-organisms. The end result is a higher yield of biogas and less holding time required for the AD process. Pre-treatment, however, is typically an energy-consuming process which needs to be balanced against the gains from higher biogas yield.

With the objective of enhancing sludge pre-treatment without incurring more energy used than generated, the Nanyang Environmental and Water Research Institute (NEWRI), an internationally reputable research institute in Singapore hosted by the Nanyang Technological University, has developed innovative pre-treatment technologies that are capable of enhancing the AD process.

> “These pre-treatment technologies are based on dispersion and localised heating resulting in modified surface areas open to chemical attack. The net consequence is enhanced rupturing of cellular walls and release of the organic cellular material.”

NEWRI has developed three new pre-treatment processes: (i) an in situ thermal-alkaline process, (ii) ultrasonication combined with enzymatic pre-treatment of waste activated sludge, and (iii) stepwise ultrasound-alkaline pre-treatments (Figure 1). The three options have been developed to ensure better fit when upgrading existing assets which may include different technologies.

Ultrasonic disintegration of sludge is carried out by bombarding sludge with sound waves at very high frequencies, ranging from 20 kHz and 10MHz. Sonotrodes deliver the ultrasonic waves that compress and expand the sludge to form millions of microscopic cavities. As the water vapour and gas-filled cavities are recompressed they burst, sending shock waves through the sludge matrix, breaking down its constituents. Ultrasonic treatment on its own is very fast and effective, with a reported 30% to 45% increase in biogas production and 20% to 30% greater solids reduction. However, ultrasonication has high energy requirement. The NEWRI pre-treatment configuration differs as it does not deploy ultrasound in the typical fashion – instead ultrasound is used to support chemical and biochemical reactions, and hence substantially reducing energy requirements.

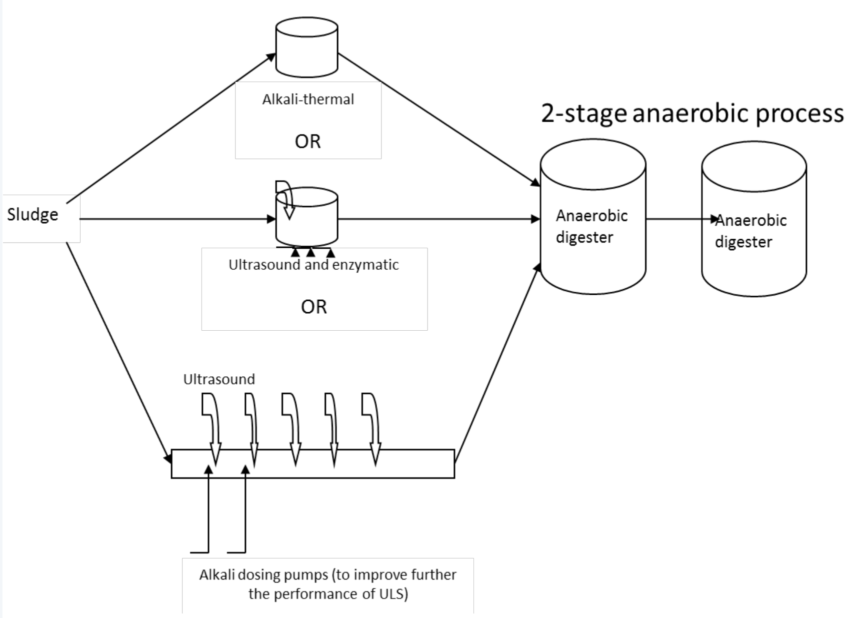


Figure 1

By pairing any one of the pre-treatment processes with its recently developed enhanced staged AD process, NEWRI has been able to produce a 40% increase in biogas yield and a 60% to 75% decrease in particulate solids. This is about a doubling in performance compared with conventional AD processes coupled with conventional ultrasound pre-treatment. NEWRI's pre-treatment process requires typically 10 to 20 minutes only. The key to NEWRI's pre-treatment effectiveness is the enhancement of hydrolysis with the resultant solubilised organic components being more amenable to fermentation. The hydrolysis stage in the AD process can be the most time-consuming of the various reaction steps therein and causes a bottleneck in sludge processing.

"These pre-treatment technologies are based on dispersion and localised heating resulting in modified surface areas open to chemical attack. The net consequence is enhanced rupturing of cellular walls and release of the organic cellular material," says Professor Ng Wun Jern, Executive Director of NEWRI.

An advantage of this NEWRI system is its small footprint and that it can be retrofitted onto existing assets. Innovations such as these reduce the volume of residue requiring landfill capacity.

CASE STUDY 14

DC WATER AND CAMBI, A SUCCESSFUL COLLABORATION FOR GENERATING ENERGY FROM WASTEWATER

DC Water

The District of Columbia Water and Sewer Authority (DC Water) is the utility responsible for water and wastewater services in the District of Columbia, the capital of the US (more commonly known as Washington DC). DC Water operates the Blue Plains Advanced Wastewater Treatment Plant, which serves more than 2 million residents in Washington DC, and in surrounding communities in Maryland and Virginia. The plant has an annual average treatment capacity of 1.45 million m³/d (384 MGD). The wastewater treatment process consists of primary treatment (decantation), followed by biological secondary treatment, nitrification / denitrification and advanced treatment involving filtration, chlorination / dechlorination and post aeration.

In 2011, DC Water selected Norwegian company Cambi to refurbish the sludge treatment process of the plant with its proprietary digestion booster process, making DC Water the first utility to commission a thermal hydrolysis plant (THP) in North America. Cambi's sludge treatment process consists of a high-pressure steam pretreatment of the sludge before feeding the digester. Blue Plains'

DC Water Biosolids plant at the Potomac River refurbished sludge treatment line started operating in 2014: it is now made of four sludge digesters, each with a 15,000 m^3 capacity. The plant treats up to 410 t dry solid sludge/day.

The THP has three main advantages for the plant operator: digester load is increased by about 2 to 3 times; biogas production is enhanced; and the final product obtained is free of pathogens and dewaters to higher cake solids at higher throughput rates. In Blue Plains, biogas generated goes to a cogeneration facility which covers the entire steam needs of the THP process itself and can generate up to 13 MW of power, and corresponding carbon footprint reduction by about 45,000 t CO_2/year. Meanwhile, final dewatered wet biosolids quantity is reduced from approximately 500,000 t/year to 200,000 t/year.

As a result, DC Water has been able to halve the digestion capacity required, thus reducing overall footprint and capital costs. Operating costs are also lowered: savings amount to approximately US $10 to US $15 million/year, deriving from the energy produced, the reduction of the volume of biosolids to be handled and by avoiding the use of lime. Moreover, the THP allows digesters to operate at higher pH than usual, making them more resilient when exposed to loading that may cause souring of the digesters. Consequently, the Blue Plains plant can serve as a regional co-digestion centre, receiving solid waste and other dewatered sludge, hence maximising biogas production. There are only two disadvantages which have been noted by the plant operator: the digester may require a longer commissioning time without seed sludge from another THP facility, and special design provisions are needed for THP filtrate treatment in a deammonification process.

The success of the project has been made possible by a close collaboration between DC Water and Cambi. The DC Water team visited plants which were already using the THP to assess operability of the process and the possibility of replicating it at Blue Plains. The team addressed the issue of inhibition by developing approaches to manage dewatering (inhibition source reduction) and by diluting the filtrate to reduce the concentration of the inhibitor. Sudhir Murthy, Innovations Chief at DC Water shared, "We addressed technology risk by developing pilots of the process using DC Water sludge. We also addressed downstream factors by piloting side-stream filtrate treatment and we evaluated odours in the biosolids produced for beneficial reuse."

There was also collaboration with Thames Water, the utility for London, to assess throughput rates for dewatering in presses. "For example, we were able to double the throughput rate in belt filter presses by including a flocculation step prior to dewatering. This innovation considerably reduced the dewatering equipment needed," said Murthy.

"We addressed technology risk by developing pilots of the process using DC Water sludge. We also addressed downstream factors by piloting side-stream filtrate treatment and we evaluated odours in the biosolids produced for beneficial reuse."

CHAPTER 6
MAKE INNOVATION HAPPEN

The water sector has always been less innovative and more risk-averse than other industrial sectors such as telecommunications or energy, and insufficiently attractive for investors. Of the US $2.1 trillion private investment in infrastructure recorded by the World Bank for the last twenty years, just US $75 billion has been invested in water. Changing this situation will not only require new financing, investment and procurement models, it calls for a full change of perception and behaviour towards innovation from all key stakeholders in the water industry.

CONDITIONS SLOWING DOWN INNOVATION

Firstly, the water market is extremely fragmented, localised and uncompetitive. There are thousands of utilities all over the world with their own characteristics, and they tend to have a monopoly in a particular territory with regard to service provision. Facing no competition, water utilities, especially small local ones, are not incentivised to differentiate themselves by offering customers better or new services. Moreover, regulatory frameworks may be extremely rigid and conservative, and disallow the use of new technologies to improve utility operations. Procurement processes often give little priority to innovative technologies, favouring conventional well-known solutions with a track record of successful references.

More importantly, the risk of failure with a new technology is often considered too high to be undertaken, especially for drinking water production which affects public health and safety. Any malfunction in a drinking water plant could lead to a degradation of drinking water quality and affect consumers. A failure in a wastewater plant may have fewer consequences, but in both cases, plants would be temporarily shut down, with the water utility suffering heavy losses or financial penalties as well as a damaged reputation. High capital expenditure can also discourage utilities or industrial water users from investing in innovative processes. Building a new plant, setting up a new network or refurbishing an existing one, often demand huge investments that utilities do not always have sufficient resources to meet. To compound these issues, there is a lack of communication between utilities, which are often reluctant to exchange information concerning the success or failure of new technologies.

This situation has major consequences for solutions suppliers. A first reference is mandatory in order to see a new technology accepted, yet often nobody is ready to risk being the first. It is thus extremely difficult, especially for smaller companies such as start-ups or Small Medium Enterprises (SMEs), to establish a track record for a new technology, and to realise economies of scale. The challenges are greater for radical, discontinuous innovation which tends to be outside people's comfort zones, necessitating a longer period to be developed and proven. Even solutions suppliers are not exempt from a certain conservatism in their approach to the market. If there is no demand for innovative technologies, solutions suppliers are not incentivised to introduce new processes. Larger companies may also have a monopoly on technology and be less motivated to enhance their products and services. On the side of the industrial water end-user, innovative solutions are not required as long as water is not a crucial issue or posing risks that would interrupt industrial production. Industrial water end-users may also not be aware of the adverse impact such operations can have on water resources, or the damage which this can eventually cause their brand and production processes.

On the investor side, the gap between investors' expectations and the reality of innovation in the water sector is a crucial issue. Investors are not sufficiently motivated by the expected return on investment in the water sector, which is lower than in other sectors such as energy or transport. The main reason for this is that water is often free or not priced at its true value. Moreover, raising water tariffs is often a politically sensitive issue. Hence, water pricing does not reflect the cost and the risk inherent in the business; and also leads to utilities with inadequate finances to invest in innovation for improving water services. Investors have found it difficult to find the right innovation to invest in, since it may not be easy for water technologies to be substantially cheaper than what is currently on the market, proven by various references, or able to prove itself relatively fast in solving a problem that people are willing to pay for.

Moreover, there is a mismatch between the investors' time frame and the relatively longer period required to establish a new technology in the market. A majority of the Summit attendees estimated that it can take between 7 and 10 years for a water start-up to reach its breakeven point, and more than 15 years to reach a US $50 million turnover. This is in comparison to an investors' time frame which is typically a 5-year investment period and a 5-year divestment period. Furthermore, the funds available for innovation are highly dependent on the economic situation. In a context of economic crisis and austerity, public authorities are often reluctant to invest in the development of technologies that may take a long time to enter the market, while private investors specialised in venture capital are more cautious about their choices, especially if the investment involves a start-up with untried technology. Riskier investments require higher returns, and venture capitalists have to bear the risk of longer payback periods.

ACCELERATING AND FINANCING INNOVATION

How can this situation be changed? All of the propositions made during the Summit involve three main axes: (i) initiating a change in perception towards innovation, (ii) ensuring a stable environment that provides better incentives for innovative technologies, and (iii) breaking the boundaries between different players in the water sector to facilitate more frequent exchanges of experiences and best practices to catalyse innovation. If these can be achieved, it would be easier to attract increased financing for the water sector, and speed up the process of bringing new innovative technologies to market.

(I) INITIATING A CHANGE IN PERCEPTION

The first condition for creating an environment that favours innovative technologies is provoking a change of perception and behaviour towards innovation. This could be achieved through strong leadership and governance within municipal and industrial organisations, such as internal guidelines rewarding innovation. For instance, bonuses to motivate employees to develop innovative solutions will create an environment in which new ideas can thrive. Additionally, more space should be given to creative thinking and to the notion of "failing forward", where failure is considered an opportunity to gain experience and avoid future failures (please refer to the box overleaf for further suggestions on how organisations can encourage creative thinking and manage different types of innovation). However, where consumers' safety and well-being are concerned, organisations should look into establishing measures to assess and mitigate any risks involved.

(II) ENSURING A STABLE ENVIRONMENT

Another key condition to spur innovation would be a stable and transparent regulatory framework that incentivises innovation in utilities. This could include economic regulation which compels utilities to make investments that would improve their services. Utility leaders could also be given more autonomy over their own balance sheets, so that they can make decisions based on the return on investment rather than on budgets allocated by their governments. Including a surcharge on the water bill could help utilities finance innovative projects.

Public authorities also play an important role in supporting and financing innovation, especially at a stage where private investors consider financing too risky. For instance, PUB, Singapore's national water agency, has spearheaded the growth of a vibrant water industry through its role in the multi-agency Environment and Water Industry Programme Office (EWI). EWI administers various funding schemes to drive R&D activities from idea conceptualisation to commercialisation (see **Case Study 15** on page 64). In the US, the federal government is investing in early-stage water technology companies through the US Environmental Protection Agency (EPA)'s Small Business Innovation Research Programme.

It is important for utilities to not just be open to innovation and technology but also build up their internal competence to manage associated risks. One way to do this would be to create an international network of pro-innovation utilities willing to exchange experiences and best practices, and interested in being early adopters of new technologies, such as PWN Water Supply Company of North-Holland in the Netherlands (see **Case Study 16** on page 66). This would ease the problem of market fragmentation, and include utilities' experiences in working with other key stakeholders to mitigate risks involved in innovation, such as through test-bedding.

HOW ORGANISATIONS CAN THINK OUT OF THE BOX AND MANAGE DIFFERENT TYPES OF INNOVATION

The first step towards generating innovation involves generating positive, prolific and playful ideas through the following process:

- Set out some rules – clarify the focus of your thinking using a focus statement.
- Put down some ideas – start individually to avoid groupthink.
- Use random stimuli – generate a random word, followed by a word that you associate with this word. Generate further ideas[1] related to the stimulus words.
- Decide on the best ideas – some criteria include: most interesting, greatest potential, boldest.

While innovation can be generally defined as something that is new or improved that is able to add value for the customer, it can also be understood to include different types, such as:

- **Incremental innovation:** the most usual form of innovation, which involves gradual improvements by building on existing technologies, and selling to existing customers. However, solely relying on this could mean cycles of up and down.
- **Architectural innovation:** putting together existing technologies in new ways; while more challenging, it has more lasting impact.
- **Discontinuous / radical / disruptive innovation:** involves brand new technology that completely shakes up a particular industry, meaning that a new value chain could be created

Going down the list, innovation becomes more difficult due to changing customer wants and needs. To create truly sustainable success, organisations would have to both incrementally improve what they have and explore how they can make radical changes for the future. One way of managing the tensions between the exploitation of existing technologies and the exploration of the new would be to adjust the organisation of companies so that they become “ambidextrous”: with a strong senior leadership team at the top that provides a clear vision of what should be achieved, and assigning different teams to work on the two different sides of innovation – incremental and radical. Thus, the two approaches can be separately and simultaneously rewarded.

[1] A concept is a general approach to doing something, linking related ideas. An idea is a specific way to carry out a concept. For example, in a restaurant, the seating might be a concept while an idea might be to have gold chairs.

(III) BREAKING BOUNDARIES BETWEEN DIFFERENT PLAYERS

As collaboration is usually the key to innovation, there should also be deeper cooperation between the different players of the water industry such as academics, technology suppliers, utilities, industrial water end-users and investors. Water clusters driven by strong leadership and long-term views are important in bringing these actors together and leveraging their diversity and strengths, to create commercialisation ecosystems dedicated to accelerating market access. For example, collaborations between utilities, companies and academia can lead to R&D and more technologies oriented towards the industry's needs. Heightened awareness of water risks could pave the way for more collaborative relationships between industrial water end-users and technology suppliers to develop less-water-intensive production processes (see **Case Study 17** on page 68, on Coca-Cola in the US). Industries that are part of a strong cluster environment also tend to register higher growth of existing industries and of start-up activity.

Examples of clusters given during the Summit included Pôle EAU, the French water cluster (see **Case Study 18** on page 70), and the efforts of the US EPA to support the development of innovation ecosystems. The EPA has long supported innovation in water through programmes such as its Environmental Technology Verification Program, a public-private partnership between the EPA and non-profit testing and evaluation organisations which ran between 1995 and 2014. The goal of the programme was to assess the performance of different technologies. The agency has also gone further in supporting innovation, by connecting people from both the public and private sectors. This led to the creation of about 14 water clusters in the USA. Some specific difficulties related to water clusters were discussed. For instance, replicating the "Silicon Valley model" with a fully integrated supply chain is not really feasible for the water industry as water-related technologies require too many components. However, the multiplication of water clusters over the world was perceived as a positive sign of a growing interest in the water sector. This also serves as an avenue for all actors in the water sector to better communicate the benefits of innovation and successful experiences of it to customers, in order to obtain stakeholder buy-in and funding. This is also important for investors, such as SKion in Germany, which focus on supporting water companies with technologies that can truly make a difference (see **Case Study 19** on page 72). In the longer term, we should also look into technologies that better allow us to understand the true nature of cross-industry financial eco-systems and risk eco-systems, to quantify the risks across those industries.

The public sector could also help to promote partnership and procurement models that give greater scope for innovation. These can involve co-funding the adoption of new technology to help spread risk between several parties. Australia was cited by many participants as one of the best places for bringing new technologies into the market, owing to its "alliance" model which is commonly used by state utilities in the country for contract procurement. It consists of establishing a framework for upstream cooperation between utility, consulting engineers, contractors and solution suppliers. The alliance formed allows the different stakeholders to work more closely together on the best available solution. The final decision and choice of the technology is the result of a consensus. Consequently, risks associated with new technologies or innovative processes are shared equally between all the stakeholders. In the case of a concession contract over many years, relations between the partners are flexible enough to allow objectives to be regularly reconsidered. Utilities can also consider performance-based contracts which emphasise the progress achieved through innovation. In this case, the utility does not choose a technology in particular, but contracts a company which is paid proportionally to the progress made.

Besides public funding, large water companies also have a role to play in financing innovation. The Suez Environnement group accesses new technologies through partnership and acquisitions, as well as through a special fund called Blue Orange, which complements in-house research and development. The fund not only invests in start-ups to help them to develop their products or services, but also gives them the opportunity to work with the different entities of the group. This establishes a partnership between a large company and smaller ones, thereby enabling the latter to tap international business opportunities. Such support is vital to help young companies develop differentiated value propositions and the capacity to move from small niche markets to achieve credibility and scale up to larger markets.

Crowdfunding could also be a way to finance projects that are too small to interest established investors and to encourage public interest in innovation. If the public is allowed to provide feedback at an early stage, they would better understand and support the purpose of the entire investment when the technology reaches a mature stage, which could also attract more investors.

CASE STUDY 15

GROWING AN ECOSYSTEM THAT INSPIRES BREAKTHROUGH WATER INNOVATION

PUB, Singapore's National Water Agency

It can be said that in Singapore, necessity has been the mother of innovation. For PUB, Singapore's national water agency, the reality of water scarcity has always been the underlying driver of its search for sustainable solutions. PUB had surmounted its earlier challenges to establish a highly efficient water management system that demonstrates clear vision, firm political resolve, sound governance, effective implementation as well as an innovative mindset. This system has undergirded Singapore's development, and transformed its water vulnerability into a strength.

Despite global recognition of PUB's achievements in managing its water resources, there is no room for complacency, as Singapore's water demands will continue to increase in tandem with current and future challenges. These include population and economic growth, climate uncertainty and rising energy costs. As such, there is a need to continue planning and implementing water infrastructure well in advance, to provide an adequate and affordable supply of water for future generations in an increasingly urbanised environment.

A hallmark of PUB's efforts is undoubtedly NEWater — high-grade reclaimed water, which enabled Singapore to close its water loop in 2003 and develop a diversified and robust water supply. Together with desalination, this has proven to be an important source of water for Singapore, particularly in light of climate uncertainty. The success of NEWater has since spurred PUB to widen its exploration of how R&D can help achieve 3 key outcomes: increasing water resources; lowering production costs; and improving security and system resilience. Guided by its Technology Roadmap which identifies key areas to enhance its operations, PUB continues to invest considerably in cutting-edge R&D, such as that which can reduce energy consumption in water production and used water treatment.

While it can be challenging to keep the momentum of research and innovation running, adequately manage the various risks that come

R&D at PUB

with research into cutting-edge technologies, and ensure continuous investment, water represents a source of abundant economic opportunities in Singapore.

The National Research Foundation has, through the multi-agency Environment and Water Industry Programme Office (EWI) established in 2006 and led by PUB, committed S$470 million to foster leading-edge water technologies and grow the research community in Singapore. EWI administers various funding schemes to drive R&D activities from idea conceptualisation to commercialisation. Singapore is a veritable 'living laboratory' of integrated urban solutions, and test-bedding opportunities in PUB's facilities are a major draw card for companies looking to test new technologies under actual operating conditions.

One example of such test-bedding opportunities is Canada-based Anaergia's collaboration with PUB and the National Environmental Agency on Singapore's first co-digestion demonstration plant in 2014. The project aims to produce more biogas for energy generation by co-digesting used water sludge and food waste. Used water sludge from the Ulu Pandan Water Reclamation Plant (WRP – or wastewater treatment plant) will be mixed with food waste collected from the Clementi district and treated in a co-digestion demonstration facility. This new combined treatment of used water sludge and food waste has the potential to produce more biogas due to the higher calorific value in food waste. The co-digestion plant will adopt the Omnivore™ process patented by Anaergia, which makes use of anaerobic digestion, a biological process that breaks down organic materials without requiring oxygen to produce biogas, to treat up to 40 tons of combined food waste and used water sludge. This demonstration plant aims to validate the efficacy and cost-effectiveness of co-digestion implementation in Singapore, and provide the opportunity for WRPs to generate more electricity for process usage. This could potentially allow the WRP to achieve energy self-sufficiency, which is using only as much energy as the treatment process itself generates.

> **"Securing Singapore's future water needs is a challenging process that requires cooperation from multiple stakeholders. By sustaining the rapid growth of Singapore's water industry, PUB can benefit from a vibrant water cluster that provides innovative water solutions."**

The initiatives of the past 10 years have brought promising outcomes and knowledge resources that few utilities in the world can boast of. Today, there are 180 water companies and 26 research centres in Singapore. In early 2013, the National University of Singapore (NUS) and Nanyang Technological University (NTU) – the host universities of some of these research centres – were ranked as the top 2 universities for water research globally. Singapore's vibrant and flourishing water ecosystem enables collaboration between key local and global players to advance water research and generate new solutions, and PUB's many international links also include MOUs with other regulatory bodies, research centres and companies to advance water R&D. Widespread recognition of PUB's expertise in water technology is further underscored by its membership of the Global Water Research Coalition, and participation in advisory entities of key international water organisations. In addition, once every 2 years, global water leaders gather at the Singapore International Water Week (SIWW), a key initiative by EWI to grow the water industry, develop water technologies, and facilitate exchanges and collaboration on innovative solutions. SIWW 2014 welcomed over 20,000 participants from 133 countries/regions, with over 800 participating companies, S$14.5 billion in total value of announcements on projects awarded, tenders, investments and R&D MOUs concluded at the event.

"Securing Singapore's future water needs is a challenging process that requires cooperation from multiple stakeholders. By sustaining the rapid growth of Singapore's water industry, PUB can benefit from a vibrant water cluster that provides innovative water solutions," said Maurice Neo, Director of Industry Development, PUB.

CASE STUDY 16

A TRADITION OF EXCELLENCE IN SUSTAINABLE INNOVATION

PWN Water Supply Company and PWN Technologies

The Dutch water sector is made up of ministries, municipalities, and institutions, each with its own individual role in managing drinking water, sewerage, wastewater treatment, and environmental protection. Dutch drinking water quality is rated highly both by its customers and by legal benchmarks, and provided at reasonable tariffs. In addition, the Netherlands has among the lowest reported rates of non-revenue water in the world at 5%. With efficient and innovative utilities being an exception rather than the norm, one might wonder how the Dutch have been able to achieve this level of success.

Andijk III water treatment plant produces 120 million liters per day from surface water, using suspended ion exchange (SIX®) and ceramic membranes (CeraMac®)

PWN Water Supply Company of North-Holland, which supplies water to 1.5 million customers in the province, is one of 10 water utilities owned by Dutch municipalities. According to the 2013 Reflection on Performance report by the Association of Dutch Water Companies (Vewin), PWN garnered one of the highest customer-satisfaction ratings and the second highest investment in R&D per connection when compared with industry peers.

One of the key challenges Dutch water companies face is maintaining the integrity of their water supply, which they source mainly from the rivers Rhine and Meuse. After the failure of the International Commission for the Protection of the Rhine against Pollution to address the issue of heavy salt pollution in 1988, PWN had to develop its own technologies to treat its compromised water source, as no practical implementable solution was available on the market. PWN's technological innovation has thus been driven by two main goals: enhanced management of degraded water sources, and improved quality of drinking water piped to customers.

PWN recognised at an early stage in its 95 years of existence that the main barrier to innovation historically was resistance within the organisation itself; hence innovation could only

> "PWN's mission in delivering top quality water at the tap sustainably to our customers would not be possible without the excellent teamwork between us and our subsidiary PWNT through the shared values we have of cultural openness and technological innovation. It is a winning formula I am confident will lead to even better solutions to address the world's water needs."

be achieved with an organisational culture that enables people to create new ideas. PWN thus separated its R&D unit from the day-to-day running of the organisation and placed it directly under the purview of the board of directors, responsible for the vision and strategy of the company and resource allocations. In this way, R&D would enjoy the board's full support, as well as the space and capacity to focus on creating solutions tailored for the company's problems.

“PWNT takes great pride in the full support we have from PWN, our parent company, for all of our efforts in developing and promoting ever more innovative solutions... Internally, the strong relationship we have between our R&D and Marketing team helps us bring our innovations to market more quickly. There has never been a better time, with current access to multiple resources available, to develop and implement better solutions to the world's water problems.”

This change has allowed PWN to be bold in developing major technologies, such as the first large full-scale combined ultra-filtration (UF) – reverse osmosis (RO) plant in the world, UV-based advanced oxidation, Suspended Ion eXchange (SIX®) and CeraMac® – efficient ceramic membrane treatment. PWN has implemented them at full-scale, thus also making it possible for thousands of utilities to adopt these highly efficient and environmentally friendly technologies.

The development of new applications and solutions opens new income streams for PWN and it is for this reason that its subsidiary PWN Technologies (PWNT) was established not just to conduct R&D for PWN, but also sell, brand and deliver the resulting technology in international markets. The profits are then used to sustain PWN's cycle of innovation by starting new technology development programmes to improve efficiency and identify more sustainable solutions in terms of natural resources; water quality and accessibility; energy consumption; brine treatment with minimal or no discharge and by-products recovery. In 2012, PWN expanded its R&D facility, which is one of the biggest water treatment R&D centres in the world today.

To share their experiences in sustainable and cost-effective innovations with a wider audience, exchange ideas and ensure that staff remain inspired and challenged, PWN and PWNT encourage their experts to actively network with the international water community through participation in forums, summits and conferences. Such external platforms also facilitate the commercialisation of new technologies, as they allow better understanding of local market conditions and competition which drives fine-tuning of innovations. The two organisations also tell their story of water technology innovation based on test results through their own social media and collaboration with the media.

As PWN's CEO Martien den Blanken puts it, “PWN's mission in delivering top quality water at the tap sustainably to our customers would not be possible without the excellent teamwork between us and our subsidiary PWNT through the shared values we have of cultural openness and technological innovation. It is a winning formula I am confident will lead to even better solutions to address the world's water needs.”

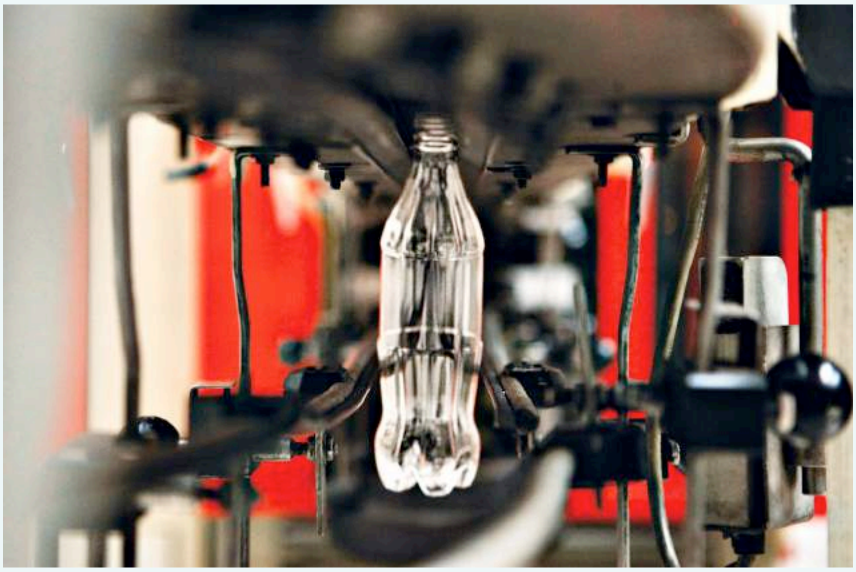
“PWNT takes great pride in the full support we have from PWN, our parent company, for all of our efforts in developing and promoting ever more innovative solutions,” affirms PWNT's CEO Jonathan Clement. “Internally, the strong relationship we have between our R&D and Marketing team helps us bring our innovations to market more quickly. There has never been a better time, with current access to multiple resources available, to develop and implement better solutions to the world's water problems.”

CASE STUDY 17

A CORPORATION'S ROLE IN INNOVATIVE WATER STEWARDSHIP

Coca-Cola

When you consume almost 300 billion litres of water every year to make drinks, conservation of your key ingredient becomes a matter of survival. The Coca-Cola Company is a leader in the area of "water stewardship", an approach where businesses take greater responsibility for the impact that their activities have on the quality and sustainability of water resources. This entails a corporate policy for continuous innovation to achieve improvements in production processes that contribute to reducing water consumption and more efficient treatment of wastewater generated from manufacturing operations.



Increasingly, Coca-Cola's plants are replacing rinsing of their beverage packages with ionised air instead of water to further reduce the water used in its manufacturing process and increase its overall water efficiency

Coca-Cola's Director of Sustainable Operations, Safety & Environmental Sustainability, Paul Bowen, cites a number of reasons driving such a policy: water scarcity, deteriorating water quality, the rising price of water, a growing beverage portfolio, greater efficiency, and a pledge it made to replenish the amount of water equal to what it uses by 2020.

Coca-Cola has made significant investments in new technologies and operating procedures that replace or reduce water use, for example, through working with suppliers to develop water-efficient equipment and retrofitting existing equipment to become water and energy efficient. "Innovative technologies are developed in-house and in collaboration with external companies. Much of our progress is the result of our partnership with World Wildlife Fund (WWF) and our focus on improving water and energy efficiency in our plants globally," Bowen says. Coca-Cola also continues to examine technologies to determine if alternative applications exist for innovations. Technologies and initiatives that Coca-Cola has implemented for efficiency advancement include using ionised air instead of water to rinse beverage packages and dry lubrication in place of soapy water for bottling conveyors; reuse of treated wastewater for landscape irrigation; and advanced monitoring of water use and efficiency.

Cumulatively, Coca-Cola's efforts have resulted in improving system-wide water efficiency for 12 consecutive years. In 2004, Coca-Cola reported needing 2.7 litres of water per litre of product – 1.7 litres went into equipment cleaning and manufacturing processes, the other 1 litre into its product. As of

2015, efficiency efforts have driven that volume down almost 25% to 2.03 litres per litre of product. By 2020 it expects to lower this 16% further to 1.7 litres per litre of product. In many parts of the world where it operates, Coca-Cola is well ahead of schedule in meeting that target with some facilities operating below 1.4 litres of water per litre of product.

As for its commitment to replace the water it uses, Coca-Cola announced in August 2015 that it was ahead of schedule. In 2007 the company said it would replenish roughly 300 billion litres of water (equivalent to its annual volume of drink sales and water used in production) to the environment. To achieve this, it has invested more than US $1 billion to build wastewater treatment facilities at bottling plants across the world, ensuring compliance at 862 of 863 plants. The water is treated to a minimum Company standard according to parameters which it arrived at through consultation with multiple stakeholders, even when not required by local law. It has made public six of the 20 parameters. These include:

- 5-day BOD: <50 mg/litre
- pH level: 6.5–8
- Total suspended solids: <50 mg/litre
- Total dissolved solids: <2000 mg/litre
- Total nitrogen: <5 mg/litre
- Total phosphorus: <2 mg/litre

“While ethical imperatives drive our water stewardship, we also have a vested business interest in helping preserve and improve local water sources across the 207 countries where we operate. Doing so requires partnership, commitment and innovation.”

The Company also replenishes the equivalent amount of water used in its sales volume to communities and nature through local partnerships focused on watershed protection, safe water access and reforestation.

The support of its top leadership has enabled Coca-Cola to incorporate innovative water stewardship into business planning and encouraged its more than 250 bottling partners to adopt high standards in their operations. Coca-Cola has also further contributed to promoting water efficiency improvements by jointly developing a Water Efficiency Toolkit with WWF. This toolkit contains over 60 best practices that Coca-Cola bottling partners can implement within their plants, communities, or basins where they operate. It is estimated that such system-wide improvements in water efficiency will save approximately 50 million litres of water use annually by 2020.

Bowen notes the challenge of implementing new technologies is that they are always received with caution and hesitation, and need to be fully understood, evaluated and justified. “We overcome challenges by stressing the business risks associated with water access and the importance of being good stewards of this critical resource,” he says.

In a move that was perhaps less expected of the private sector, Coca-Cola took the decision in 2011 to share its data on water scarcity trends with Aqueduct, the open source water research organisation of the World Resources Institute. Data from Coca-Cola and other sources have been collated to produce an atlas of emerging water risks around the world. This would help companies, investors, governments, and other users understand where and how water risks and opportunities are emerging worldwide.

“While ethical imperatives drive our water stewardship, we also have a vested business interest in helping preserve and improve local water sources across the 207 countries where we operate. Doing so requires partnership, commitment and innovation,” said Bowen. “Every day at Coca-Cola, we are seeking innovative ways to be responsible stewards of our world’s most precious resource.”

CASE STUDY 18

PÔLE EAU, FRENCH WATER CLUSTER

Pôle EAU

Based in Southeast France, Pôle EAU™, a competitiveness national cluster, was appointed in 2010 by the French Government to facilitate and fund innovative R&D projects on water and wastewater management based on the cluster's four strategic axes covering the whole water cycle:

- Identification and exploitation of water resources
- Cooperative management of water resources and usage
- Reuse of wastewater from all sources (including domestic and industrial)
- Social, economic and institutional approaches to water management

Pôle EAU coordinates a national network "France Water Team"[2] bringing together around 450 academics, public research organisations and private companies that specialise in these aspects of the water sector. Public money currently represents about half of the financial resources of the cluster, with the remaining coming from the contributions of its members and services billings. While Pôle EAU's projects often address specific local needs, the goal is also to develop solutions which are dedicated to overseas markets.

Hence, Pôle EAU also facilitates the commercialisation of new innovative solutions created through collaborative projects (including pilots and demonstration testing), while accelerating the development of local companies with good innovative potential. All such projects usually necessitate forming consortiums including private companies and public laboratories, and are ideally driven by a major group, in order to generate synergies between different actors to create an ecosystem that favours collaboration and ensures project public co-financing[3]. A project typically runs for a period of 2 to 3 years before being completed; over 360 R&D projects have been evaluated by the 3 national water clusters, of which 111 have been financed for the period 2011 to 2015, with a total budget of €188 million.

An example of such projects is Now-MMA, which ran from 2011 to 2014 and aimed to develop a process to optimise

The demonstration site for the Now-MMA project in Mauguio, France

wastewater reuse for the irrigation of crops and vineyards, watering of green spaces, vehicle washing and street cleaning in the French municipality of Mauguio. Such a process should also be easily replicable and adaptable to different local situations, including the whole Mediterranean area. Achieving such ambitious objectives required the realisation of a pilot and a strong team to lead the project.

The main difficulty with reuse is to adapt the treatment line to the re-usage of the treated wastewater. Three different treatment lines were tested: micro-filtration, sand filtration and ultra-filtration, with the latter two options being combined with UV

> "Larger corporations such as Veolia, Suez and other world leaders in water business, are invited to promote and integrate smaller innovative companies along with academic laboratories in mid-term projects, with the aim to market operational products and services."

[2] "France Water Team" includes 3 national water clusters: Pôle EAU, Dream & Hydreos; 4 regional clusters: Swelia, Ea-écoentreprises, WSM & Ecoentreprises-MP; and an academic cluster: IM2E. (Please refer to www.pole-eau.com for more information.)
[3] All parties must be established in France to benefit from national funding.

disinfection. International private water utility SAUR was the project leader, coordinating a team of both local and national companies. Both consulting engineer BRL Engineering and system integrator FARMEX-Technologies had strong knowledge in combining different technologies to deliver efficient solutions. The advanced technologies involved were sampling methods from ApoH-Technologies, disinfection from Bio-UV and monitoring devices from Aqualabo-PERAX. The National Research Institute in Science and Technologies for Environment and Agriculture (IRSTEA) and two engineering schools (ARMINES-Alès and INSA-Toulouse) were also involved in the project.

Pôle EAU has also approved public financing for the MATRICS project on smart grids, which aims to develop innovative tools for network management at various stages of the water treatment cycle (including networks of raw water, drinking water and wastewater), and to integrate them in a global information and steering system. The goal is to provide network operators and clients with a real-time overview of their networks, making operation easier and more efficient. The project brings together French consulting engineers Veolia Water, BRL-Exploitation and EGIS-Eau, along with famous software company IBM and sensor providers YZATEC.

The MATRICS project's proposed global information and steering system

“We also have to convince the academic sphere to cooperate in short-term innovation for market developments, which will generate public money through business in order to finance more fundamental studies, and to keep a constant competitive advantage: it is well known that an innovation is generally “obsolete” within, say, five years.”

Through such projects, smaller companies can also tap bigger companies' wider international networks to identify markets for their innovations, and can further sharpen their competitive edge by honing their business and management skills, and marketing approaches. Furthermore, to address the difficulty of securing financing for innovation due to the risk-averse nature of the water sector, Pôle EAU is currently looking into developing specialised funding to support small and medium water sector companies' development.

“Larger corporations such as Veolia, Suez and other world leaders in water business, are invited to promote and integrate smaller innovative companies along with academic laboratories in mid-term projects, with the aim to market operational products and services,” said Jean-Loic Carré, General Manager at Pôle EAU. “Basically, we also have to convince the academic sphere to cooperate in short-term innovation for market developments, which will generate public money through business in order to finance more fundamental studies, and to keep a constant competitive advantage: it is well known that an innovation is generally “obsolete” within, say, five years.” Some specific areas which deserve more attention and could offer opportunities for innovation include the need for better monitoring of water-quality, due to emerging pollutants and endocrine disruptors.

Furthermore, Pôle EAU is currently developing partnerships with other organisations, such as the Milwaukee (USA) Water Council, PUB (Singapore's national water agency), the Dutch Water Alliance, the Catalan Water Cluster and the German Water Partnership, so as to help its companies identify other collaborative projects, as well as platforms to exchange ideas and technologies. Other opportunities are offered through the European Commission programmes which encourage cross-cooperation between European and other countries.

CASE STUDY 19

DELIVERING INNOVATION TO THE WATER MARKET

SKion GmbH

SKion GmbH is a privately-owned investment holding that is based in Germany. Founded in 2006, SKion's investments are characterised by a long-term perspective. Over the last years, SKion has invested significantly in innovative companies active in the water and wastewater market.

The first step in SKion's investment strategy is to define target segments within the water sector. These segments should possess significant potential for technical or business model innovation, and SKion should be able to add value with its investment approach. Such segments are aligned with key technological trends expected to drive future innovation in the water sector, and include biological wastewater treatment, biosolids management, and decentralised solutions for wastewater treatment and recycling. Within these segments, SKion focuses on key themes such as energy efficiency, nutrient recovery and innovative biological treatment processes. Moreover, SKion has defined two main criteria to assess whether to invest in a company:

- Companies and technologies should have direct end-user interaction, as opposed to merely manufacturing components
- Likewise SKion should also be able to support the commercialisation of the technology through technical expertise and customer access; this is done through its portfolio of established companies in the water sector

Another aspect SKion considers before investing in a company is the management team, which should have an in-depth understanding of water market dynamics, such as sales cycles, risk-aversion or procurement processes. Since the water sector is relatively slow in adopting new technologies, and factors such as fund durations and investment models tend to be geared towards faster growth than the sector can offer, it is important for investors to manage the team's expectations. In this way, both parties can develop a reasonable business case for a technology or company, including the most appropriate start-up business models.

SKion's goal is not to fully integrate all new companies as one consolidated group into its portfolio, but to create synergies within the portfolio by fostering collaboration between the different companies involved. A crucial element is the fact that SKion's portfolio contains large established companies, with extensive experience in a broad

New Pyreg 500 unit

> "There is always an investment opportunity if somebody finds a new solution that is significantly better than the current one to solve an existing problem."

range of solutions, references and a large network of customers, like Eliquo Water Group in the municipal sector, and the EnviroChemie group in the industrial sector. Whenever SKion invests in a novel technology or a start-up technology company, SKion can enlist the help of its established companies to accelerate and smoothen the commercialisation of new technologies.

This approach can entail partnership between larger and smaller companies on projects. For example, in 2014, SKion invested in Pyreg, a young German company which had developed a thermal biomass disposal technology. Seeing the potential to apply this to process biosolids, Pyreg conducted extensive tests which confirmed that such technology was not only financially competitive with large-scale incineration, but also allowed for recovery of valuable phosphorus at no additional cost. However, the company alone would have found it difficult and costly to adapt its offerings to the more stringent engineering requirements of municipal wastewater treatment plant operators, such as robust process automation. In addition, many utilities might have been reluctant to award a relatively large investment project to a young company with a limited track record.

Such challenges were solved through close collaboration between Pyreg and Eliquo, with its extensive experience in developing biosolids treatment processes. While Pyreg focuses on providing the core thermal treatment technology, Eliquo provides the other process steps such as sludge dewatering, low-temperature drying and supports Pyreg on engineering matters in all biosolids projects. Pyreg also benefits from Eliquo's stronger financial position, market reputation and international network. In September 2015, the first municipal biosolids processing plant based on the Pyreg technology was successfully put into operation at the municipal wastewater treatment plant in Linz-Unkel, Germany. A second plant is already under construction, with many more in the sales pipeline.

The Pyreg plant at Linz-Unkel in Germany

"[SKion's challenge is] always to be at least 30% better than current technology, because in anything new there are uncertainties and existing solutions can also be improved. Many utilities won't incur extra risks for a 5 to 10% benefit so the bar has to be set this high."

"There is always an investment opportunity if somebody finds a new solution that is significantly better than the current one to solve an existing problem," says Dr. Reinhard Hübner, Investment Manager of SKion. However, he points out that SKion's challenge is "always to be at least 30% better than current technology, because in anything new there are uncertainties and existing solutions can also be improved. Many utilities won't incur extra risks for a 5 to 10% benefit so the bar has to be set this high."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Water quality analytics
Network asset management
Man-less systems/Automation
Industrial water technologies
Effort/Resource


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Singapore International Water Week
SIWW Technology and Innovation Summit
Developing a Global Blueprint for Water Solutions
16-17 June 2015
Session 5:
ncing Full-Cycle Innovation
Spotlight Series
SIWW Technology and Innovation Summit
Developing a Global Blueprint for Water Solutions
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Session 5:
Financing Full-Cycle Innov


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