WATER SERVICES
ASSOCIATION OF AUSTRALIA

TRANSITIONING THE WATER INDUSTRY WITH THE CIRCULAR ECONOMY

UTS Institute for Sustainable Futures

Research Team

Prof Pierre Mukheibir
Dr Melita Jazbec
Andrea Turner

About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures.

We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

For further information visit: www.isf.uts.edu.au

Citation

Jazbec M, Mukheibir P and Turner A, 2020 Transitioning the Water Industry with the Circular Economy, prepared for the Water Services Association of Australia, Institute for Sustainable Futures, University of Technology Sydney, September 2020

Acknowledgements

This publication was co-ordinated by the Water Services Association of Australia and supported by:

- City West Water
- Coliban Water
- Hunter Water
- Icon Water
- Melbourne Water
- SA Water
- South East Water
- Sydney Water
- Urban Utilities
- Water Corporation
- Yarra Valley Water

ISBN: 978 0 6489 242 3 4

Disclaimer
The authors have used all due care and skill to ensure the material is accurate as at the date of this report.
ISF and the authors do not accept any responsibility for any loss that may arise by anyone relying upon its contents.

Institute for Sustainable Futures

University of Technology Sydney
PO Box 123 Broadway,
NSW, 2007

www.isf.uts.edu.au

Contents

Foreword	**1**
The circular economy	**2**
Circular economy and integrated water servicing	**6**
Circular economy opportunities in the water industry	**10**
Transitioning to a circular economy approach	**26**
Evaluation and measurement	**34**
Supporting the transition to a circular economy	**40**
Taking action in the water sector to transition to a circular economy	**43**
References	**44**
Abbreviations	**46**

Many utilities are now considering the benefits of unlocking the circular economy to better manage resources, make and use products and to regenerate natural systems.

Foreword

It's hard to find a more circular business than water. All water on Earth is used and reused in an endless cycle. Urban water utilities manage an essential part of the water cycle that creates healthy, liveable communities and simultaneously manage a significant proportion of the liquid and solid waste created by those urban communities.

In our urban cities and regions, the essential services of water, energy and waste have traditionally been managed in a linear way. With water utilities providing essential drinking water for use by communities and taking away and treating wastewater to return safely to the environment, and valuable and renewable waste and energy sources used and disposed of in a similar linear way.

It's fair to say that the traditional linear approach will be a relic of history. The technologies, some yet to be invented, the enthusiasm, the investment potential, the long term sustainability outcomes are all there to create a new future of circularity rather than linearity.

Many utilities are now considering the benefits of unlocking the circular economy to better manage resources, make and use products and to regenerate natural systems. Nitrogen, phosphorus, hydrogen, cellulose, heat, plastic, organic waste and biosolids are some of the fundamentals of urban living. Many of these pass 'through the hands' of skilled urban water managers who have the ability to transform the way these nutrients and waste products are used and used again.

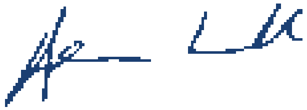
The transformation to a circular economy approach brings many challenges and the shift requires a multi-pronged and widespread cross-sector collaborative approach.

This paper seeks to outline the key building blocks required for a utility to transition to a circular economy as well as discussing the value proposition and the many benefits to customers and the broader community, the environment and to utilities themselves. It collates existing knowledge on the contribution of the urban water industry (with leading international examples) in a circular economy and recommends the next steps to help utilities pivot to begin or further advance their approach.

The paper recommends we need to move beyond 'sustaining' to 'restoring' the material balance and then actively go further with 'regenerative' actions that will ensure the planets health, resilience and ability to adapt.

The Sustainable Development Goals (SDGs) set out challenging and ambitious outcomes that encapsulate the circular economy. Many urban water businesses have committed to the SDGs and envisage the future as very different to the past. The COVID-19 pandemic is a critical juncture for us to establish that new normal. I'm urging all water utilities to research, plan and invest in a new circular future.

The paper is intended for use by water utilities and the broader water sector to better understand the challenges and transformation required to implement a circular economy approach. It is supported by 15 international and Australian case studies showcasing the future possibilities for the urban water industry.



Adam Lovell
EXECUTIVE DIRECTOR

The circular economy

The concept of the circular economy has been gaining traction globally over the past decade. This is in response to the serious impacts caused by the prevailing linear economy practice of take-make-use-dispose which has pushed the demands of our society beyond the limits of our planet.

As the Planetary Boundary analysis from 2015 makes clear[1], we are witnessing a significant reduction in genetic diversity, phosphorus and nitrogen stocks have been seriously depleted and other earth systems are rapidly moving in the same direction. Over the past 50 years alone, human use of synthetic nitrogen fertilizers has increased more than 9-fold globally, while phosphorous use has tripled. At the same time, the efficiency of nutrient use for food production is poor, with over 80% of nitrogen and 25-75% of phosphorus ending up lost to the environment (rivers and oceans).[2]

If we are to have any chance of reversing these impacts and returning the planet to a state that can continue to support our societies, with current growth projections, the way in which we manage resources, make and use products, and dispose of materials needs to be transformed. Such an approach would design out waste and pollution, keep products and materials in use for as long as practicably possible, and regenerate natural systems[3]. That is, we need to **move to a circular economy approach in its broadest sense.**

The circular economy is not new. It is based on diverse, but related, ground-breaking ideas that have been emerging since the 1970s. These include for example: Regenerative Design[4], Performance Economy[5], Industrial Ecology[6], Cradle to Cradle[7], Natural Capitalism[8], Biomimicry[9], Blue Economy[10] and Doughnut Economics[11]. Several interpretations and definitions of circular economy abound.[12,13]

The Ellen Macarthur Foundation is a globally leading, influential advocate for the circular economy.[3,14] The Foundation uses the following definition, which includes three key principles:

PLANETARY BOUNDARY ANALYSIS

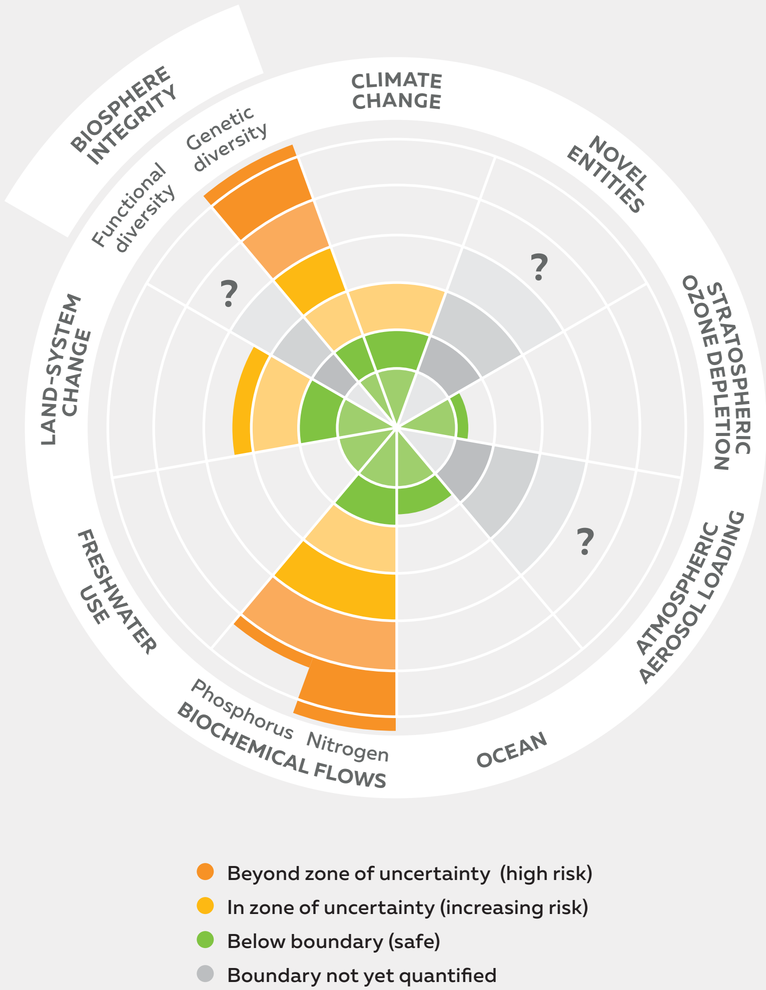


Image adapted from Steffen et al (2015) [1]

Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: ***design out waste and pollution; keep products and materials in use; and regenerate natural systems.***

In line with this definition circular economy actions so far have predominantly focused on circularising material flow, which intrinsically includes socio-economic benefits. However, in the future as our understanding and practice of the circular economy deepens, we expect the focus will expand to feature socio-economic principles more strongly, and the definition and practice to shift accordingly.

The shift from a linear to a **circular economy has multiple economic, social and environmental benefits.** It allows companies to create more value while reducing their dependence on scarce and costly resources. A circular industrial system that is regenerative by design, which restores material, energy, and labour inputs, can only be good for both society and business.[15]

THE REGENERATIVE DESIGN FRAMEWORK

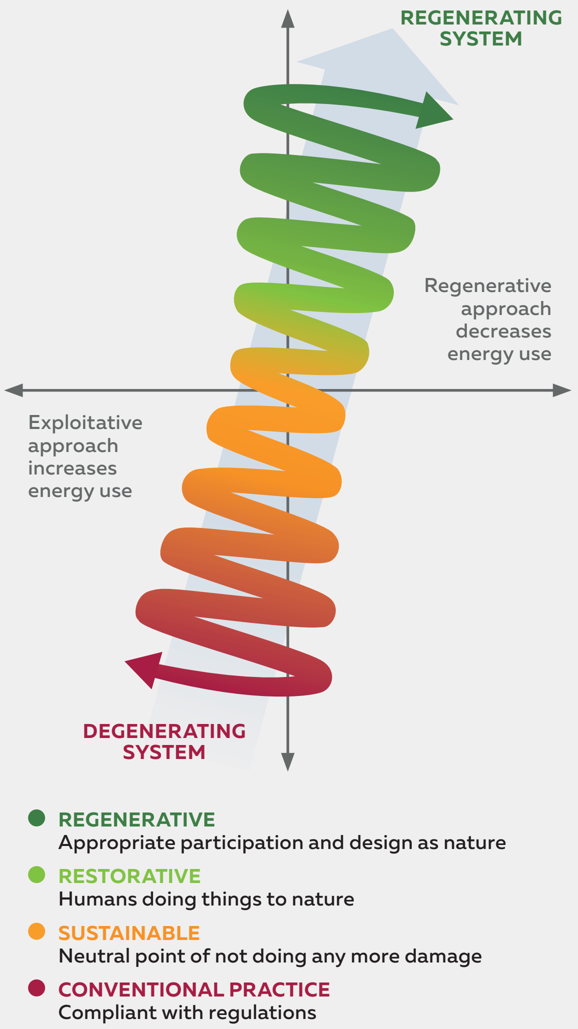


Image adapted from Reed (2007)[17]

Faced with declining resources globally, together with rising demand due to population growth and urbanisation, ecosystem functions will continue to be eroded through our current take-make-use-dispose economy and lifestyles. Simply doing less damage to the environment will only slow this rate of decline. A single faceted approach such as this is not sufficient as our natural environment is the ultimate determinant of our health and wellbeing.[16] The approach requires a shift from a fragmented worldview to a whole system thinking model and understanding the living system interrelationships in an integrated way.[17]

Designing for sustainability is to design for human and planetary health; to maintain the planet in a condition where life as a whole can flourish. However, as we push the planet beyond the planetary boundaries, **sustaining** is no longer enough, we need to consider **restoring** the material balance and then to actively go further with **regenerative** actions that will ensure the planets health, resilience and ability to adapt. As illustrated in the regenerative design framework[17], sustainable actions are at the energy neutral point of not doing any further damage, and are considered in this document as resource efficiency initiatives that can and are currently being implemented within the control of the business. Restorative solutions focus more on resource recovery with a broader material flow influence which may require new business models. Moving towards the regenerative state where actions are designed in line with nature, solutions seek to integrate a wider influence on social and environmental systems, with the aim of **doing more good, not just doing less harm.** It requires thinking, designing and doing things differently, possible to include disruptive technologies and governance approaches that enhance our natural, urban and social environments.[3] This might mean considering the "problem" from an entirely different perspective, such as considering waste products as resources, moving away from end-of-pipe solutions, or **starting with the outcome in mind** and planning services around those.

The conversation on how to transition to the circular economy has now entered corporate boardrooms around the world. A range of platforms for rapid exchange of information and knowledge have been established, with emerging case studies demonstrating best practice and processes e.g. CE100.[3] What has become clear is that the transformation to implement the circular economy approach locally, regionally and globally, can only occur if it is driven by widespread cross-sectoral collaboration with the following characteristics[5]:

1 The smaller the loop (activity), the more profitable and resource efficient it is. The aim is to not generate one global economy, rather, scale-link multiple circular economies at local, regional and global scales.

2 Loops have no beginning and no end, they require continuous collaboration along the entire value chain.

3 The speed of the circular flows is crucial: the efficiency of managing stock in the circular economy increases with a decreasing flow speed. Companies need to rethink and create high-quality, durable products.

4 Continued ownership is cost efficient: reuse, repair and remanufacture without change of ownership save double transaction costs. It creates an incentive for companies to sell or lease the use or service provided by their products, rather than the products themselves.

5 A circular economy needs functioning markets.

A stable functioning of the Earth system is a prerequisite for thriving societies around the world, which means addressing the Planetary Boundaries framework. Here the achievement of targets such as those outlined in the UN Sustainable Development Goals (SDGs) can help.[18,19,20] Circular economy thinking can be used by different countries, social agents, and institutions to achieve some SDGs, specifically SDG[12], Responsible Consumption and Production. Other goals such as Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities, Climate Action, and Life on Land can also benefit from a circular economy approach. At sub-target level, circular principles play a role in efficient resource use, redesign, and the extended use of materials.

Water (SDG 6) is the single most important shared resource across all aspects of our lives. Opportunities abound to apply circular economy principles across the roles that water takes: **as a resource, nutrient carrier, source of energy and service.** The demands on these roles are set to increase exponentially with population increase, urbanisation and climate change. It is therefore timely that this document explores the opportunities and transition pathways toward a more efficient and regenerative approach for the water sector to deliver water services and products.

UN Sustainable Development Goals

Circular economy and integrated water servicing

Water utilities are moving towards a vision of integrated resource recovery due to a combination of expanding sustainability and liveability aspirations, operational challenges, network constraints and emerging contextual factors.

There is **value** in adopting a circular economy approach for integrated water servicing for water utilities, society as a whole, and our natural environment; as illustrated opposite.

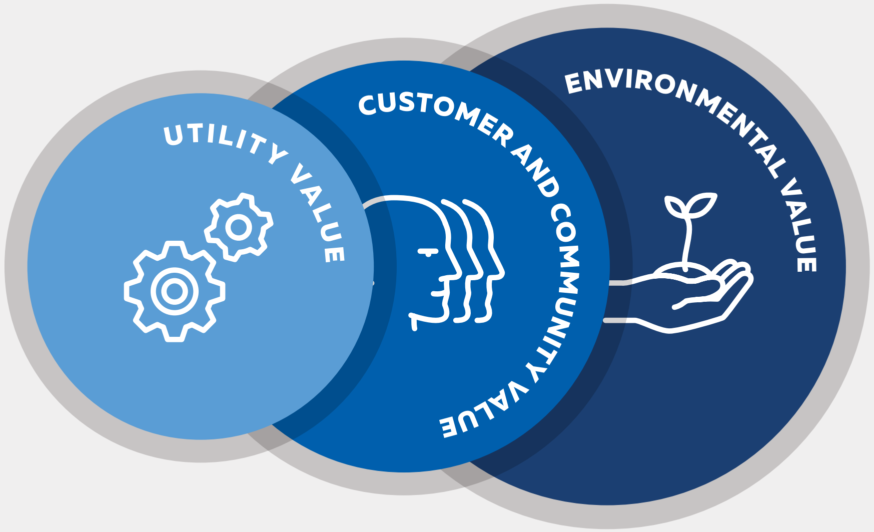
The long-standing, linear approach of extracting freshwater, treating it, using it, collecting it, and disposing of it is no longer viable. This approach does not easily allow for the realisation of this value. This is particularly true in the Australian and New Zealand context, where most urban centres are vulnerable to variable and declining water resources and the disposal of biosolids to landfill or the oceans is no longer acceptable.

Over recent decades, the water industry has transitioned from the delivery of basic centralised water, sanitation, and stormwater services as discrete and separate systems, towards the protection of waterways and in some cases towards a whole of water cycle approach, which includes water recycling.

Since the turn of the 21st century, the focus has been on integrated water planning that considers how we view, value and manage water on multiple scales – from local communities to the national level.

The approach now is on achieving multiple benefits, watershed-scale thinking and action, supply and demand planning, cross-sector partnerships and engagement of all.

THE VALUE IN ADOPTING A CIRCULAR ECONOMY APPROACH



UTILITY VALUE

- Leaders in innovation
- Drivers of transformational change
- Optimised operational cost
- Deferred capital investments
- Resilience to resource shocks
- Revenue opportunities
- Business diversification opportunities
- Increased adaptability
- Inspired workforce
- Community trust

CUSTOMER AND COMMUNITY VALUE

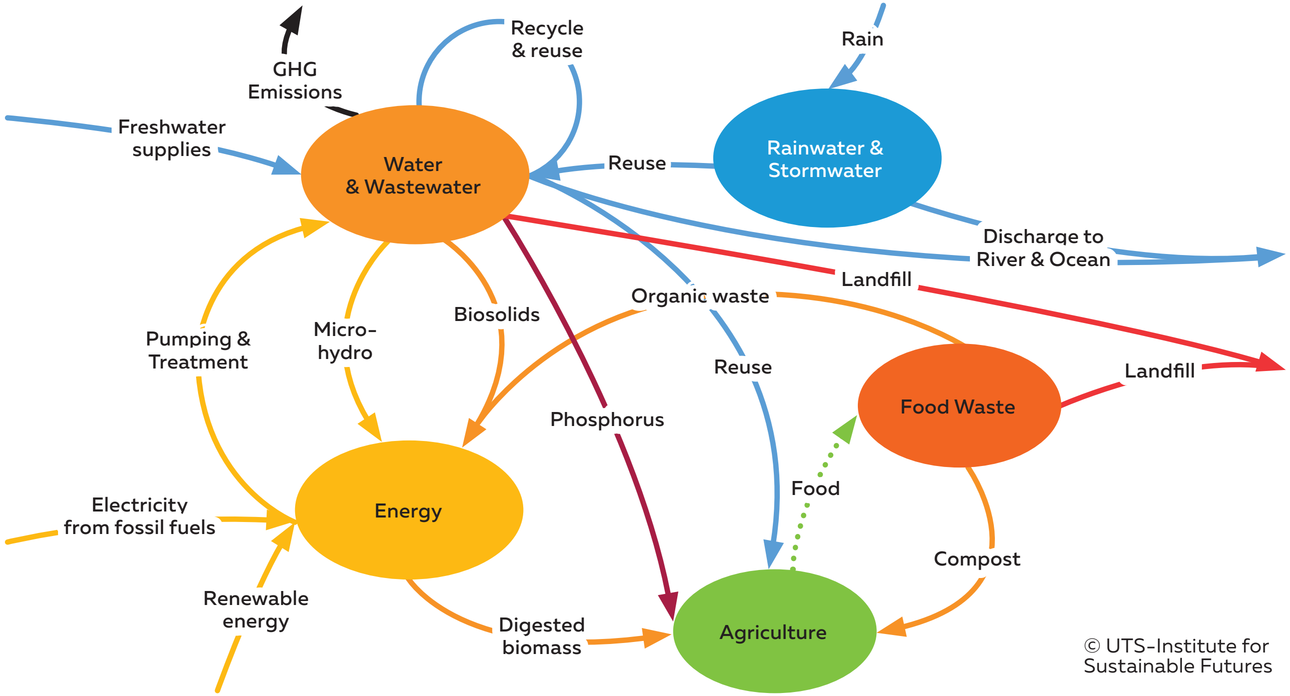
- Affordable services
- Reliable and resilient services
- Liveability outcomes – greening and cooling
- Increased local jobs

ENVIRONMENTAL VALUE

- Lower GHG emissions
- Reduced landfill disposal
- Improved waterways and ocean health
- Sustainable resources through reuse
- Ecosystem protection and regeneration
- Increased nutrient capture and soil health

Water utilities can become agents for the circular economy and have an opportunity to play an important role as resource stewards. If we expand our systems view beyond water services, opportunities in other resources become inherent in a circular economy approach. Based on the three key circular economy principles, the following table provides water servicing examples where considering water use and the associated resources together (energy, nutrients and minerals) reduces impacts and helps to move towards delivering restorative and regenerative outcomes.

CIRCULAR ECONOMY PRINCIPLES (FROM ELLEN MACARTHUR) [21]	CIRCULAR ECONOMY EXAMPLES IN INTEGRATED WATER SERVICING
DESIGNING OUT WASTE EXTERNALITIES	• Designing for the most efficient amounts of energy, minerals and chemicals to be used in the delivery of water services. • Optimising the amount of water used to deliver efficient customer services and benefits. • Designing best value use of water whenever possible.
KEEP RESOURCES IN USE	• Maximising the reuse and recycling of water and input resources. • Optimising the use and extraction of energy, nutrients, minerals and chemicals.
REGENERATE NATURAL CAPITAL	• Maximising environmental flows by reducing consumptive and non-consumptive uses of water. • Returning treated wastewater to waterways where viable and best value. • Preserving and enhancing the natural and urban environment by maintaining water in the landscape for greening and cooling. • Minimising disruption to natural waterways through preventing pollution and improving the quality of discharge effluents.

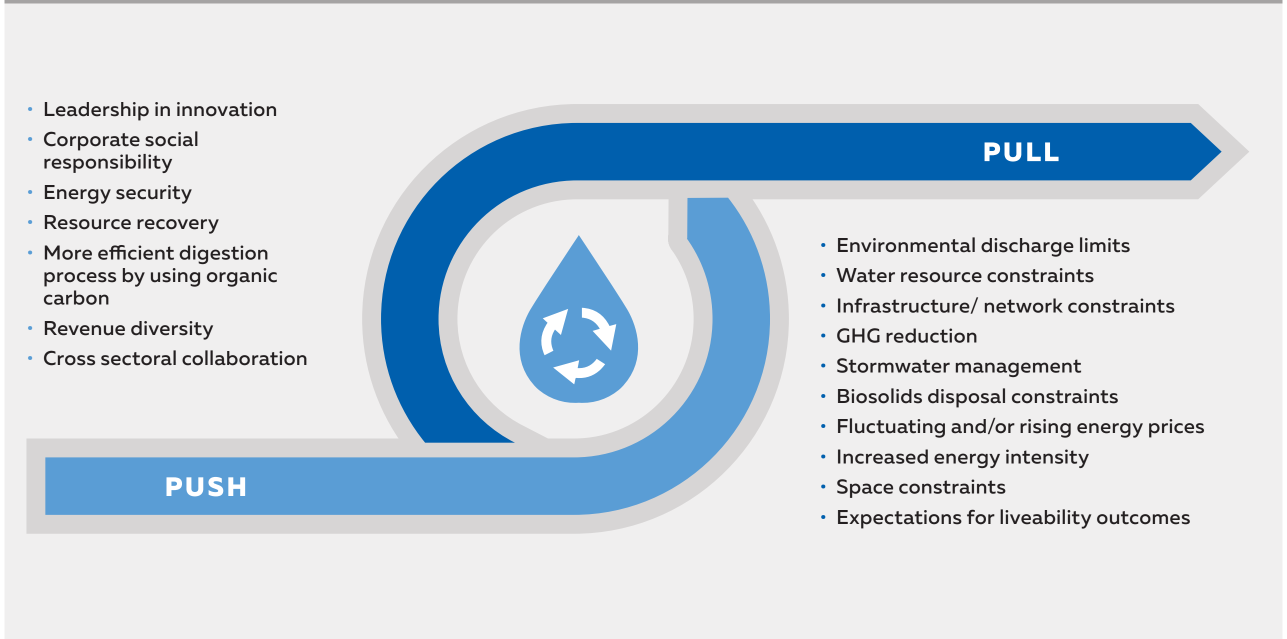


Urban water servicing is closely associated with five of the Planetary Boundary indicators (discussed earlier) – freshwater use, biogeochemical flows (nitrogen, phosphorus), climate change, biosphere integrity, and land-system change – and implicated in a sixth: novel entities.[1]

All, except freshwater use, already exceed the safe operating space at a global level, and freshwater use is increasingly moving beyond extraction limits at the local level.

Using a **systems thinking approach** to understand the integrated water servicing cycle and the associated resource flows, the intricate interrelationships between various resource flows (illustrated above) can be better identified and their efficient use optimised. The associated benefits to the economy, society and environment can be maximised, and the inflows and outflows of resources, such as energy from fossil fuels, freshwater extraction, and the disposal of waste to the ocean and landfills, can be minimised.

CIRCULAR ECONOMY DRIVERS



The key drivers for a circular economy come from both the opportunities (pulls) and the need to respond to current regulatory and economic barriers, and challenges (pushes).[22]

Opportunities include economic benefits and showing leadership in innovation. On the other hand, emerging environmental, operational and business constrains, driven by regulations and community expectations for liveable urban environments are key push drivers for change.

The circular economy approach offers organisational value beyond the direct delivery of water services. There is scope to shift paradigms across the whole organisation, including the policies and practices pertaining to infrastructure design and construction, operation and maintenance processes, and equipment and material procurement and disposal. For example, a circular economy approach considers the imbedded carbon in new assets, or the associated management of construction waste. This is discussed further in the section *Evaluation and Measurement*.

The transition to a circular economy is not without its challenges; due mainly to the linear economy setting within which the water sector operates. The industry is characterised by infrastructure systems with large long-life assets which are difficult to modify or repurpose, and where *new investment decisions are currently predominantly based on least financial cost not best economic value.*

Further, the current institutional structure has resulted in complicated governance and regulatory arrangements across public and private service providers, where no one party has full responsibility for managing all aspects of the urban water cycle in an integrated way.[23] Too often the separate water services are planned independently, and are not undertaken in conjunction with land-use and development growth planning. This approach has hampered greater adoption of systems thinking and new innovative practices.

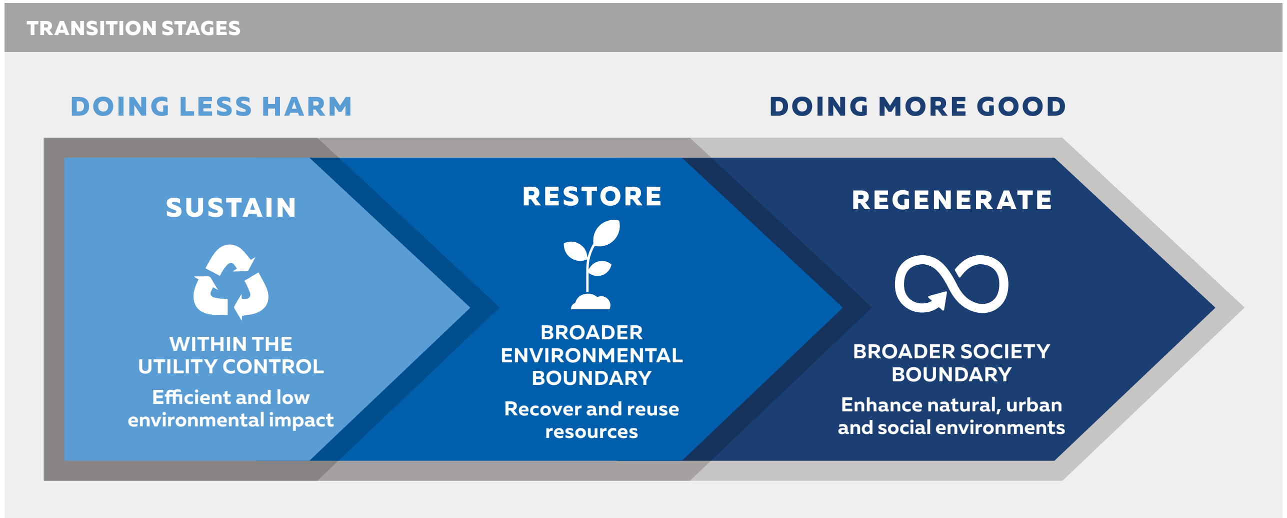
The following sections explore the steps to transition to a circular economy approach within the Australian and New Zealand water sectors.

Circular economy opportunities in the water industry

Transition to a circular economy can be characterised by how far we have moved from business-as-usual practices - **sustainable solutions** that can be implemented by utilities within their sphere of operation and knowledge; **restorative solutions** that consider a broader material systems view; and **regenerative solutions** that seek a net-positive outcome for our environment and society.

Using these transition stages, this section provides a selection of examples to illustrate how water utilities can help us move towards a circular economy. These stages aim to explain how the spatial and socio-technical boundaries of influence expand with each transition, broadening the analysis of costs and benefits to ultimately include broader societal and environmental considerations. They complement the earlier work by the IWA on the three interrelated pathways of water, materials and energy.[22]

Water utilities in Australia and New Zealand range in size, deliver a wide range of services, and respond to a variety of drivers, and so are understandably at different stages of the circular economy transition. Some are likely to already be well advanced in adopting sustainability initiatives, as discussed below. However, in the current environment of rapid technological advancement, there is often scope for further optimisation to provide enhanced benefits.



Sustainable solutions

In addition to water resource constraints, water utilities might be responding to regulatory and operational drivers emerging from disruptors like an increase in energy demand and costs, from alternative water supply sources such as desalination, or from finding new ways of thinking about water and sewage services to help reduce greenhouse gas (GHG) emissions and achieve associated targets. Some utilities have set procurement policies to consider the scope 3 GHG emissions embedded in purchased products and infrastructure materials. These actions would be considered as sustainability responses.

In terms of water use, minimising water losses in the system and increasing customer efficiency is a utilities first step. Reducing usage by residential and non-residential customers not only minimises the water used, but also the energy needed for abstraction, treatment and pumping before use and the associated wastewater pumping and treatment after use. Focusing on the service, or end use, helps to determine whether more efficient technologies such as showers, washing machines and toilets can reduce water demand. Due to the Millennium drought, Australia became a leader in water efficiency, source substitution and recycling.[24] New efficient devices and water quality opportunities are continually presenting themselves, which can be used to further drive down freshwater demand.[25]

Further, considering the energy-water nexus, reducing shower times creates energy savings in heating that are tenfold those of the energy savings from reduced volumes in the water and wastewater networks.[26] From a broader systems thinking perspective, a study found that by putting in place a regulatory framework that required Chinese manufacturers to meet best practice standards for pumps and refrigeration units, energy savings could be expected that would obviate the need for the Three Gorges Dam.[27] These examples demonstrate how interconnections between systems and actions outside water utilities affect the opportunity for the sector as whole to perform.

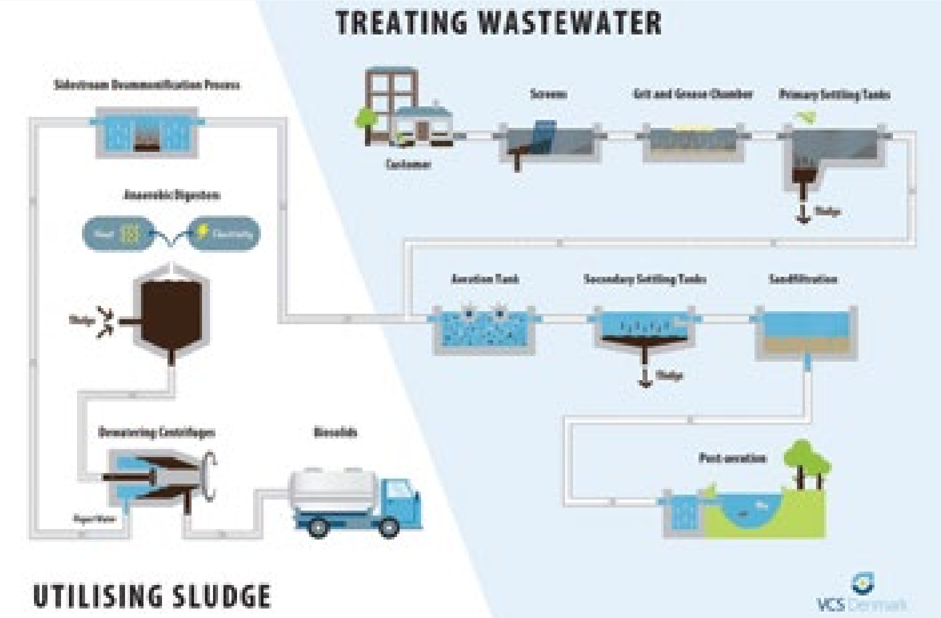
Energy use accounts for a large portion of the operating costs and the GHG profile in wastewater treatment plants (WWTPs). A benchmarking study in 2015 comparing the energy use of 245 WWTPs across Australia and New Zealand, found that while there had been significant improvements in energy efficiency, there were still opportunities to go even further for the majority of the WWTPs.[28]

A key step towards sustainable solutions therefore, is to identify how to increase energy and process efficiency by reducing energy consumption and by increasing energy generation through network micro-hydro and biogas generation. Opportunities exist along all stages of the traditional wastewater treatment process: in the primary treatment, by identifying efficiency and combining steps of solids separation, sludge thickening and dewatering;

EXAMPLE 1

Beyond energy neutral – Ejby Mølle WWTP (Denmark)

WWTP transformed from a large electrical power consumer into a producer of electricity and heat (180% of its demand) to achieve carbon neutrality.



Graphic illustration of the Ejby Mølle process

CONTEXT – Ejby Mølle WWTP is VandCenter Syd (VCS)'s (publicly owned) largest water resource recovery facility (WRRF) that transformed from a large electricity power consumer into a net producer of energy (electricity and heat) and achieved carbon neutrality in just 5 years.

DRIVERS – VCS (a water and wastewater company) with more than 150 years of operational experience) implemented the "Beyond Energy Neutrality" program in 2009, aiming to improve resilience, sustainability, and energy self-sufficiency goals in 5 years.

BUSINESS CASE – $2 mil USD cost in capital expenditure. Additional income from production of energy and "know-how" solutions achieving carbon neutrality and energy self-sufficiency.

SOLUTION – VCS implemented changes in the facilities and operations of the plant and achieved 77% energy self-sufficiency of Ejby Mølle WRRF with 410,000 P.E. capacity while still meeting stringent nutrient limits (6.0 mg total N/l; 0.5 mg total P/l) without needing external carbon feedstock, to discharge into a small local river in Odense. In 2012, it engaged a consultant to identify additional energy optimisation opportunities that have resulted in generation of 180% of the plant energy demand through:

1. Ammonia-based aeration control for biological nutrient removal.
2. A nitrous oxide (N_2O) probe for continuous measurement of emissions from the liquid process.
3. First full-scale granular side stream de ammonification process control to minimise N_2O emissions while maximising ammonia removal (allowing utilisation of specialised bacteria).
4. Full-scale application of induced granulation process to improve biomass settleability in activated sludge bioreactors.
5. Full-scale application of facilities to leverage mainstream de-ammonification as part of a biological nutrient removal system.
6. In development – demonstration plant using a membrane aerated biofilm reactor (MABR) to further reduce GHG emissions and requiring smaller facility footprint.

In the MABR, gas transfer membranes are used to deliver oxygen directly to the biofilm attached to the membrane surface, making this step energy efficient. Based on modelling, 50% of ammonia will be oxidised in the MABR and will bring 40% of aeration savings, 45% increase in peak wet weather flow capacity through secondary treatment, 20% reduction in effluent total nitrogen and 5% increase in biogas production.

OUTCOMES – The plant now generates 180% of its energy demand (electrical and heat) and has evolved the mindset from a WWTP to become a WRRF.

Surplus electrical energy is fed back into the power grid and hot water is used in the district heating system serving locations up to 12 miles away.

Reduced generation of biosolids that are transported offsite as fertiliser to farmland.

Selling expertise on technical solution around the world.

REFERENCES

https://www.vcsdenmark.com/services/advanced-wastewater-treatment/ (accessed 26/05/20)
https://www.jacobs.com/projects/ejby-molle-water-resource-recovery-facility (accessed 26/05/20)

in the biological treatment, by adopting technologies that provide more efficient O_2 use and access (e.g. membrane aerated biofilm reactors); and in the sludge treatment, by using advanced anaerobic digestion systems that utilise pre-treatment or co-digestion.

Transitioning to sustainability, Ejby Mølle (Denmark VCS's largest WWTP) needed to shift the mindset from WWTP to water resource recovery facility (see Example 1). This transition highlighted the importance of process monitoring and data collection for optimising the process, reducing energy consumption and identifying opportunities to increase energy generation. Ejby Mølle sought further additional energy savings by modifying the process to perform de-ammonification treatment in the side stream. In addition to generating surplus energy, they have developed knowledge that can be shared and sold.

Energy generation can be enhanced by the addition of other organic streams, such as food waste, agricultural waste or industrial waste, with the additional benefit of diverting these flows from landfill. The financial and economic benefits of co-treatment can, however, be countered by unfamiliar technical, commercial and financial risks.[29]

Fats, oil and greases (FOG) have proven to be an extremely valuable organic feedstock to increase the generation of biogas when co-digested with sewage sludge[30] (see Example 2). This approach has been adopted in many WWTPs in the USA and also in New Zealand, and the following key learnings have been reported: [31,32]

- Although FOG feedstocks have inconsistent quality, they have the highest biomethane potential compared to other feedstocks.
- FOG have low S, N and P content compared to other feedstock, lowering process instability and equipment corrosion.
- In biogas plant design it is necessary to consider the introduction of FOG feedstocks, unloading facilities, receiving facilities and introduction of additional waste feedstocks into anaerobic digestion (AD).

EXAMPLE 2

Co-digestion with fats, oils and greases – Gresham WWTP (USA)

FOGs are energy rich organic material with three-times higher potential for CH_4 generation than sewage sludge. When co-digested with sewage, the addition of FOG as a feedstock benefits generation of biogas in anaerobic digestion and assists the WWTP to reach energy neutrality in addition to additional revenue from the gate fee for FOG disposal. .

FOG receiving station at the Gresham WWTP

CONTEXT – FOG are used in co-digestion at WWTP to increase generation of biomethane and assist reaching net zero energy operation of Gresham WWTP – 13 mil gallons per day (MGD)+FOG; (20 MGD WWTP capacity).

DRIVERS – Achieving energy self-sufficiency and FOG tipping fee revenue

BUSINESS CASE – Project cost 9.1 mil USD, 500,000 USD energy saving/year.

SOLUTION – Potential efficiency and renewable energy generation opportunities were identified in 2010. A 395 kW biogas fuelled Caterpillar reciprocating engine was installed meeting almost 50% of WWTP annual electricity load. Additional renewable energy was sourced from a 420 kW ground-mounted solar array. Further energy savings were obtained by installing high efficiency turbo-blowers and aeration basin fine bubble diffusers. To increase biogas generation, a FOG receiving station was later added including tipping fee revenue. Co-digestion of FOG doubled biogas production and an additional 395 kW CHP was added. Gresham has been an energy net positive producer since 2015. FOG is stored in storage tanks and addition to AD is metered. Biogas is treated to reduce H_2S below 100 ppm and undetectable levels of siloxanes and chilled to reduce moisture.

OUTCOMES – Energy efficiency should be done first, but FOG co-digestion substantially increases biogas generation.

REFERENCES

http://www.chptap.org/Data/projects/Gresham_WWTF-Project_Profile.pdf (accessed 26/05/20)

- Ease of disposal, availability and logistical efficiency of the disposal facility were key determinants in defining the gate fees for commercial viability, and for ensuring the consistency of the waste supply stream.

An additional risk is the security of the feedstock availability, as discovered during COVID-19, when FOG volumes suddenly dropped due to the downturn in tourism, public events and people dining out.[33]

Restorative solutions

Restorative actions are aimed at material feedback loops through the generation and reuse of energy and other recycled materials, that restore nutrients and minerals back to the environment, or reduce organic waste disposal to landfill. Water utilities can influence sustainable and restorative outcomes beyond their business boundary. For example, influencing people to drink tap water instead of bottled water, and sponsoring water bubblers in public spaces, reduces the need for single use plastic bottles, and consequently their disposal to landfill or potential for littering. This results in helping to minimise environmental degradation and restore oceans and rivers to their original state.

Restorative opportunities can also be found in the management of wastewater. As WWTPs optimise and modify their processes, they can generate an energy surplus, that can be sold as electricity to the grid, used in transport, or used for heating/cooling at nearby industries or residential districts. To generate excess biogas, the anaerobic digestion systems are regularly upgraded with the addition of pre-treatment methods that aim to achieve higher biodegradability of the sludge by employing thermal, mechanical or chemical treatment depending on the feedstock. Most common technologies applied for the pre-treatment are based on thermal hydrolysis, using higher pressures (4-6 bar), elevated temperatures (140-160°C), and steam, to breakdown the cell walls enhancing anaerobic digestion and increasing biogas yield by 30-50%. Both, Cambi[34] (series of sequential reactors) and Veolia[35] (BioThelys – batch and Exelys – continuous process) technologies also produce less biosolids (30%) as a result, which are pathogen free and can accommodate a range of feedstock types, including FOG. In addition to the investment in generators to convert biogas to electricity on site (depending on the external application and the geographical location), biogas requires additional treatments such as the scrubbing of H_2S and moisture, and concentrating the CH_4 before it can be injected into the natural gas grid or used as a biofuel in transport.[36]

By integrating WWTPs locally, they can become the heart of circular economy hubs.[31] Billund Biorefinery in Denmark (see Example 3), in addition to exporting electricity and heat, is also recovering nutrients, phosphorus (P) and nitrogen (N) that would have been lost through wastewater which is restored to the farms (biological cycle). The plant has also been established to produce bioplastics for the production of bio-degradable plastics (technical circular economy cycle).

With the shift from *removal-and-treat* to *recovery-and-reuse*, a large number of technologies have been developed with particular focus on P recovery at different access points of wastewater treatment processes (a few examples are summarised in the Table below[37]), while N recovery has received less attention due to lower operational need and economic motivation.

The drivers for change are operational benefits, increased environmental awareness, and stricter discharge limits of these nutrients to the environment.[38]

PHASE	AQUEOUS PHASE	SEWAGE PHASE	SEWAGE SLUDGE ASH
TECHNOLOGY	• REM-NUT® • Air-Prex® • Ostara Pearl Reactor® • DHV Crystalactor® • P-RoC® • PRISA®	• Gifhom process • Stuttgart process • PHOXNAN • Aqua Reci® • MEPHREC®	• AshDec® • PASCH • LEACHPHOS® • EcoPhos® • RecoPhos® • Fertiliser Industry • Thermphos (P4)
METHOD	• Ion exchange • Precipitation • Crystallisation	• Wet-chemical leaching • Wet-oxidation • Super critical water oxidation • Metallurgic meltgassing	• Thermo-chemical acid • Acid wet-chemical • Leaching • Extraction • Thermo-electrical
PRODUCT	• Struvite (magnesium ammonium phosphate) • Calcium phosphate • Magnesium phosphate		
APPLICATION	• Fertiliser		

To achieve more sustainable P use, a 5R Strategy has been proposed including: Re-align P inputs, Reduce P losses, Recycle P in bio-resources, Recover P in wastes, and Redefine P in food systems.[39]

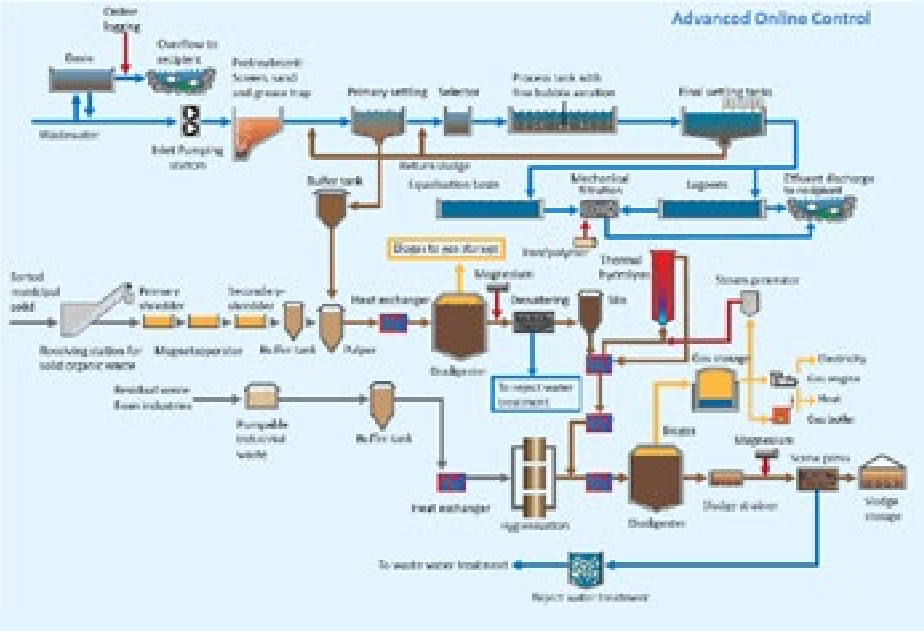
In response to recent studies that indicate the potential pollution of soil with microplastics, nanoplastics, synthetics, and heavy metals when applying biosolids to land[40], the recycling and use of biosolids in fired clay bricks (Bio-Bricks[41]) have been proposed. In circular economy solutions for construction materials, organic waste is often used in furniture, internal finishing and bricks, since they can be returned to the biosphere at the end of their useful life.[42]

Biological technologies provide significant opportunities and prospects for resource recovery from wastewaters in terms of the generation of bioenergy, carbon recovery and chemical and bio-electrochemical systems.[43] Biological methods that use bacteria, microalgae and terrestrial plants are capable of recovering heavy, precious or radioactive metals, pharmaceuticals, enzymes, hormones, fertilizers and bioplastics found in wastewaters. Purple phototrophic bacteria for example, has been shown to simultaneously assimilate carbon and nutrients at high efficiencies by growing photoheterotrophically under anaerobic conditions, while using light as the energy source.[44] While a significant number of microalgae species used for animal and human nutrition are non-toxic, caution should be exercised where mixed cultures can occur posing a risk of contamination of toxin producing cultures.[43]

EXAMPLE 3

Development of BioRefinery – Billund WWTP (Denmark)

WWTP transformed from a large electrical power consumer into a producer of electricity and heat (180% of its demand) to achieve carbon neutrality.



CONTEXT – Billund BioRefinery is a publicly owned company providing services in water supply and waste management to the municipality of Billund. It was established in 1997 as a WWTP co-digesting industrial and municipal bio-waste with wastewater sludge. The plant was upgraded to a Bio-Refinery in 2016 to increase biogas production, minimise energy consumption, enhance process control and improve effluent quality.

DRIVERS – Combine strong environmental technologies in water purification and biogas in full-scale demonstration project.

BUSINESS CASE – Krüger A/S (environmental company) and Billund Water A/S (owned by citizens of Billund Municipality) realised the project, that took 4 years to develop. Total investment in biogas plant was 9.4 mil USD (2017), the operation cost for biogas production is 1.8 mil USD/year. In 2016, 30 people were employed, and the company turnover was 14 mil USD.

SOLUTION –The new processing plant for organic material was commissioned in 2015 with advanced online control at the WWTP for optimal treatment processing, energy consumption and production, and introduction of a cleaning process for overflow water.

Process elements:

1. Feedstock to AD – organic fraction of municipal solid waste (OFMSW) collected in paper bags (13%), industrial biowaste (37%) and wastewater sludge (50%).
2. Pre-treatment of feedstocks – OFMSW shredded, thermal hydrolysis and industrial biowaste pasteurised.
3. Thermal hydrolysis – Veolia's Exelys continuous thermal hydrolysis plant using high pressure (6-8 bar), elevated temperature (165°C) and steam to breakdown the cell walls enhancing AD and increasing biogas production by 50% and decreasing amount of biosolids by 30%.
4. Anitamox – converting ammonia to nitrogen using annamox bacteria without using any additional carbon substrate – increased capacity for nitrogen treatment by 35,000 PE.
5. Wastewater treatment – performed entirely without dosing of chemicals and the treatment is so effective that the effluent concentrations are no more than 25% of the maximum effluent requirements.

OUTCOMES –

1. Biogas – CH_4 and CO_2, currently used to produce electricity and heat, CH_4 and H_2 may be used for operation of fuel cells in the future. Biogas can be used as biofuel in cars, for production of biodegradable bioplastic, protein production, storage of CO_2 in algae production etc.
2. Heat – heat for its own consumption and supplies excess heat to the public district heating system and to local customers such as industry and farmers.
3. Electricity – electricity supplied back to the community.
4. Phosphorus – has a large commercial value and is applied in the production of artificial fertiliser (95% captured).
5. Bioplastics – plastics that are biodegradable, that can be used instead of plastics, but are still too expensive to produce.
6. Contracts to export sustainable technologies and projects.

REFERENCES

http://www.billundbiorefinery.dk/en/ (accessed 26/05/20)

The opportunity lies in identifying new by-products which have higher value than the raw energy content of the wastewater, and that can feed into commodity chemical industries (e.g. organic acids and alcohols, CO_2, purified nutrients and metals). From a circular economy perspective, the opportunities are in the extraction of bio-hydrogen, biodiesel, biopolymers, single cell proteins and in the recovery of metals. The main challenge however remains in finding products with real advantages over traditional production systems (i.e. petrochemistry and highly efficient sugar-based processes). When applying and choosing technologies for WWTPs, the decision should be based on the technologies that remove a contaminant and that also allow formed by-products to be fed into the circular economy. Sometimes even a slight modification of the process can make it possible for the products to feed into the circular economy (e.g. use of activated sludge in granular form). While nutrients and metals as elemental inputs to the circular economy may not be currently economically viable, their scarcity over time will likely drive up their demand in the future.

As an example of use of microalgae for wastewater treatment process is highlighted in Example 4. While still at concept stage, it presents enormous opportunity especially with the ability to capture carbon and has received extensive research interest in academic literature.

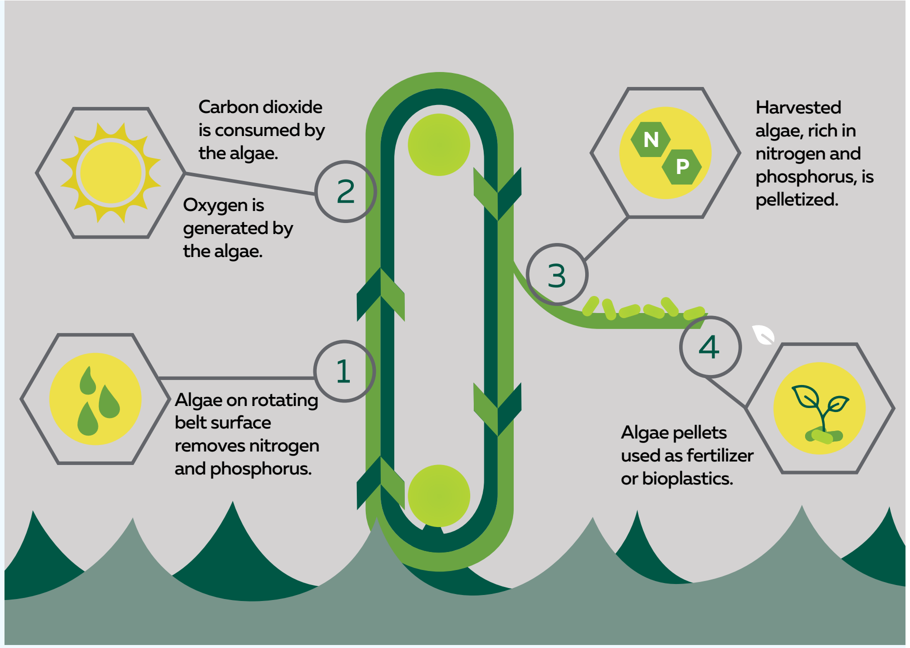
EXAMPLE 4

Microalgae wastewater treatment

CONTEXT – Microalgae's ability to perform photoautotrophic, mixotrophic, or heterotrophic metabolism represents promising biological systems treating a variety of sources of wastewaters in the context of circular and bio-based economy and development of biorefinery concepts.

DRIVERS

1. Direct uptake or transformation of water contaminants
2. Improving purification performance of bacterial systems by providing O_2 from photosynthesis, reducing energy costs and O_2 supply.



BUSINESS CASE – Lower energy and operational costs, no costly carbon or chemical inputs, produced algae can be sold and offset operational costs.

SOLUTION – Algae's ability to fix CO_2 using light as the sole source of energy makes algae's cell factories producing bio-based energy carriers and products. Algae can grow sugars and sugar alcohol, can remove NH_4, N and P, accumulating lutein, fatty acids and protein (biomass source for animal feed or biofuel production).

Technologies – Stirred ponds (suspended system) and photobioreactor (PBR) system (immobilised system). The focus is to increase surface area for light exposure and development of a method to harvest the microalgae. In addition to suspended culture, microalgal biofilm technologies can be used. For example, Gross-Wen Technologies have validated this in a demonstration plant, process where algae biofilm attached to vertically oriented rotating conveyor belts. Photoautotrophic growth is in the gaseous phase, the attached microalgae fix N and P producing biomass that is sold as fertilizer or feedstock for bioplastics.

OUTCOMES – Potential bioproducts such as proteins, fatty acids, pigments, biofertilizers/biochar and animal feed.

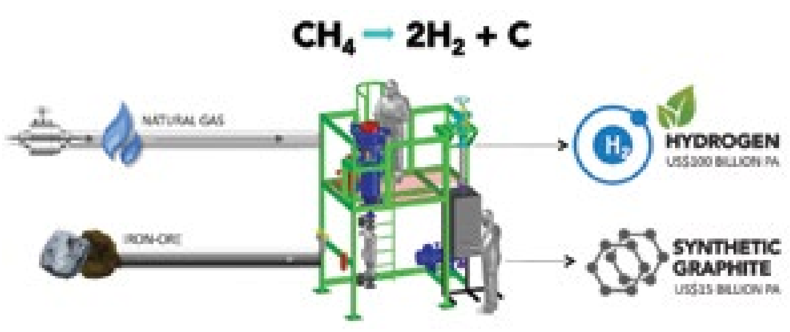
REFERENCES

Wollman, R. et al (2019) Microalgae wastewater treatment: biological and technological approaches, Engineering in Life Sciences, 19 (12), 860-871.
https://algae.com/pdf//Brochure-V4.pdf (accessed 26/05/20)

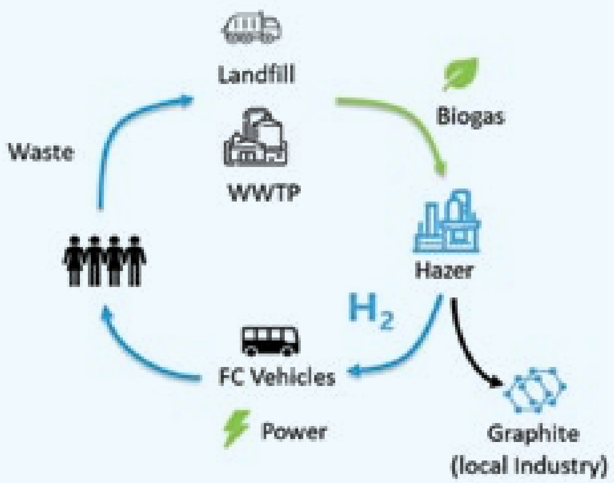
EXAMPLE 5

Hydrogen from biogas – Hazer, Woodman Point WWTP (Western Australia)

Capturing carbon, producing two highly desirable commodities, hydrogen as a fuel and graphite to be used in batteries.



From https://www.hazergroup.com.au/about/



CONTEXT – The Hazer process will be constructed to convert bio-methane generated at Woodman Point WWTP in Munster, WA, to hydrogen and graphite using an iron ore catalyst and creating an alternative pathway to the traditional approaches of steam methane reforming and electrolysis.

DRIVERS – Use of waste or low value biogas streams from WWTP or landfills or other industrial locations to product high value hydrogen and graphite.

SOLUTION – The process utilises methane as feedstock to produce H_2, without producing CO_2 and capturing carbon instead in solid graphite. The reaction producing fuel grade H_2 is carried in a fluidised bed reactor, at 900°C, over an iron ore catalyst, which does not need to be recovered as it is cheaply available, allowing this process to be financially feasible under the current context. The structure of graphite can be controlled by adjusting reaction conditions.

The technology was developed at the University of WA and has successfully undergone pilot testing using a fluidised bed reactor.

Hazer has completed the negotiations with BOC to supply storage, logistics and refuelling services to deliver H_2 to end users.

Ammonia could also be used in the transportation oriented H_2 value chain.

The construction will start in December 2020 and begin operation in January 2021.

BUSINESS CASE – $22.6 million for 100 tonne H_2 and 380 tonnes graphite per annum demonstration facility funded by ARENA ($9.41 million), grant from WA government ($250k) and from public listing on Australian Securities Exchange (market capitalization of $45 mil as of January 2020)

Capex budget – $16.65 mil. Estimated payback less than 4 years.

Use of cheap iron ore catalyst does not make it financially viable to recover the catalyst in the current market.

OUTCOMES – Renewable hydrogen, for industrial application and as transport fuel, and graphite for possible carbon black, activated carbon and battery anode application.

Demonstration site to also promote uptake of technology nationally and internationally and capitalise on selling the licence.

There is an opportunity to set up Australia as an exporter of hydrogen by replicating the technology across Australia

REFERENCES

https://arena.gov.au/news/world-first-project-to-turn-biogas-from-sewage-into-hydrogen-and-graphite/ (accessed 26/05/20)
https://www.ammoniaenergy.org/articles/hazer-group-advances-low-carbon-hydrogen-from-methane/ (accessed 26/05/20)
https://www.hazergroup.com.au/about/ (accessed 26/05/20)

Energy generation in WWTP normally takes the path via formation of CH_4, but recently the interest has shifted to the potential of H_2 generation and processes for capturing carbon to reduce carbon footprints, circular economy principles, and restorative approaches taken in resource recovery transformation. An example of attempting to convert CH_4 to H_2 and generation of graphite as a by-product is shown in Example 5.

Regenerative solutions

Taking sustainable and restorative steps alone will only result in slowing down the rate at which we exceed our planet's limits. Regenerative practices recognize current impacts on natural systems and the need for management techniques to restore these systems to improved functionality. For life to flourish we need to be regenerative and flip the value proposition, by improving our health, resilience and adaptability, and to better replicate nature.[15]

For example, regenerating urban environments for human and ecological purposes can provide stormwater attenuation, improve waterway water quality, greening and cooling properties, and a social environment for the local community (See Example 6). The focus is on the outcomes, and not on the treatment processes.

EXAMPLE 6

Daylighting stormwater creeks – Seattle (USA)

CONTEXT – The former stormwater creek was previously a large underground pipe buried under an abandoned carpark, that diverted the stormwater from a highly paved commercial area (275ha) directly into a creek.

Developers had proposed to develop the site for mixed commercial and residential use.

DRIVERS – All the runoff, largely from the neighbouring roads and carparks, carrying pesticides, oils and other pollutants was flushed through a pipe and ultimately ended up in Lake Washington – the source for local drinking water.

Local residents strongly opposed any option for a new development in their neighbourhood that did not regenerate the natural environment and transform the carpark and stormwater pipe into a local stream.

SOLUTION – The Seattle City Council convened a stakeholder group of business, community and environmental interest groups to propose a facility that would improve the creek water quality, while also promoting open space, liveability and economic development. Consensus was reached on a natural biofiltration swale that is now the anchor for private development.

Seattle Public Utilities (responsible for water services and storm water management) designed the channel to naturally filter pollutants in stormwater runoff from streets and parking lots. Sediment and pollutants are captured by settling chambers and the subsequent wetlands system, allowing less polluted water to enter the lake.

Total budget was US$14.8M (2019) for the stormwater management solution.

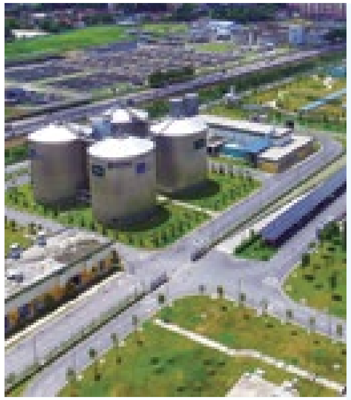
OUTCOMES – The Thornton Creek Water Quality Channel is a water treatment facility that filters the runoff and provides public open space to connect the surrounding community, while regenerating the environment and downstream ecosystems.

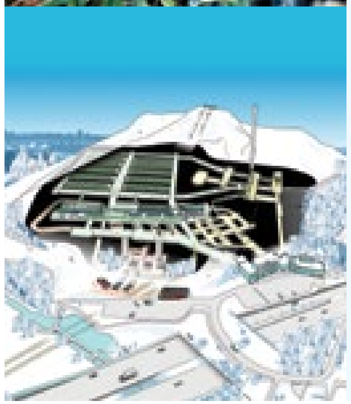
REFERENCES

https://urban-waters.org/en/projects/thornton-creek-water-quality-channel (accessed 20/6/2020)

EXAMPLE 7

Moving WWTP underground





Pantai 2 WWTP, Kuala Lumpur, Malaysia
with 320,000 m3/day capacity
"The landscape here is nice now, and we have a park for recreation. It is really nice!"

Sludge treatment facility above ground (AG), underground multi-layer (17m deep) sewage treatment facility. Pantai Eco Park (12 ha) above ground. Solar panels and bio-gas generator supply 10-15% of plant's energy needs. Use of aquatic skylight for underground lighting. Heat generated during process is used for cooling.

They are exploring circular economy initiatives such as use of effluent water in industry, application of sludge for reforestation, increasing gas production to become self-sufficient.

Sunken WWTP Nanxiang Town, China

Public private partnership built WWTP demonstration plant that looks like a garden and treats 150,000 t/day with the recycled water supplying local river. Dehydrated silt is used to generate electricity, biofiltration is used to abate odour and gas emissions, generated heat in treatment is used to heat offices, science museum and other surrounding buildings. Treated sewage is used to irrigate the plants in the park.

Henriksdal WWTP, Stockholm, Sweden

The first WWTP in the world built in rock in 1930s (as it was cheaper) required expansion below the ski slopes. Built in several levels, with treatment basin deeper than usual as they are blasted out of rock using naked rock, saving costs. The plant produces sludge used on agricultural land, biogas to run city buses and heat for district. The plant will use modern membrane technology able to treat more water over a smaller area with the focus to reduce emissions of P, N and pharmaceutical pollutants to the Baltic Sea. In addition to sewage sludge, food waste, FOG and other organic matter are used to generate energy.

CONTEXT – WWTPs are built underground to free precious space in dense urban environments. Although not a new concept, when the space above ground is integrated with community use, it is regenerative with the integration of parks, wetlands, community gardens, and it provides localised solutions based on circular economy principles.

DRIVERS – Better utilisation of space in densely populated areas and precincts, as well as addressing noise and odour issues from not-in-my-backyard community sentiment as the urban sprawl is reaching once peripheral facilities.

BUSINESS CASE – Underground WWTPs are expensive to build due to more sophisticated planning, construction and environmental assessment. An emphasis is placed on reduction of operating and maintenance costs employing innovation and process optimisation.

Average investment in construction – 564-848 $\$/m^3$ (AG: 282-424 $\$/m^3$), main savings are in land acquisition and pipeline costs due to central location. Total investment is estimated to be 706-1,177 $/m3 (AG: 1,031-1,625 $\$/m^3$).

Operating/maintenance costs estimated to be 0.20-0.24$\$/m^3$ (above ground: 0.15-0.17$\$/m^3$).

SOLUTION – The most widely applied process is anaerobic/anoxic/oxic (A/A/O) and membrane bio-rector (MBR) which has an advantage in scale and process capacity. MBR also has the best upgrading opportunity in addition to high N and P removal efficiency, stable operation, little residual sludge generation and fully automatic control, which makes it (in combination with A/A/O) the best suited process for underground WWTPs. Integration of the outputs of the underground WWTP with the surroundings makes this system circular.

OUTCOMES –

1. Efficient use of space and opportunity for regenerative integrated system with environment and community.
2. Opportunity to take advantage of modern technology delivering high quality resources at competitive costs.
3. Opportunity to locate WWTP in densely populated urban environment and save on piping and associated pumping.

REFERENCES

Sun et al. (2019), Underground sewage treatment plant: a summary and discussion on the current status and development prospects, Water Sci Technol 80 (9), 1601-1611.
https://www.iwk.com.my/cms/upload_files/files/English%20Brochure-Pantai%202.pdf (accessed 26/05/20)
https://www.shine.cn/news/metro/1902260075/ (accessed 26/05/20)
http://www.stockholmvattenochavfall.se/en/sfa-start/about-the-project/#!/material (accessed 26/05/20)

Current technology practices need to go beyond sustainability and restorative solutions. We need to embrace innovation and think and act more systemically, this could include understanding the interconnectivity of WWTPs within the whole system. Integrating WWTPs with the surroundings can be guided by ecological principles and the ability to design like nature – which is fundamental to circular economy thinking. For example, placing the WWTP underground in dense infill locations and returning the aboveground space to communities providing them with a recreation area, a green oasis in the urban environment and restoring connection with nature (see Example 7). While building underground is often driven by spatial limitations, and limited by cost, evolving technological solutions can be more compact and energy efficient, enabling better integration with the surroundings in a regenerative way.

Learning to design by replicating nature means learning from living systems and to biologically inspire innovation.

WWTPs already rely on bioreactions to perform their operations, and designers have looked for answers in nature to extract products (nutrients, pollutants). However, this has often been with a single focus and in segregated steps in sequential order - for example identifying a microorganism or microalgae species that will extract the maximum amount of P. However, nature's approach to design solutions involves an intricate symbiosis and adaptive system approach. BioMakery (see Example 8) attempts to do exactly that, using thousands of organisms to perform the water treatment process. It uses software control and sensor's to read and direct flows through the modular "reactor" system that looks more like a botanical garden than a WWTP.

As already stated above, H_2 is currently gaining strong interest as a fuel. A research group (shown in Example 9) has looked to nature, not only to find a solution to a problem but also to take advantage of the electroactive bacteria generating H_2, whilst also treating wastewater in the "microbial fuel cell". Another potential source for H_2 is ammonia formed in the nitrification and denitrification processes, which releases nitrous oxide (N_2O), a potent GHG gas and major source of total global N_2O emissions, and accounts for around 6% of the total anthropogenic emissions[36]. To avoid the formation of N_2O and to capture ammonia, the Hong Kong WWTP[45] produces ammonia that can be either used directly in a fuel cell or as a carrier of H_2 (for the transporting H_2).

Looking to nature on a larger scale, agricultural land can be regenerated by facilitating the adsorption of nutrients and restoring the soil's capability to retain water.

There are limitations on how much the soil can absorb nutrients through the application of synthetic fertilisers under the linear approach to farming. In response, agencies such as the Savory Institute[47] and the Drawdown project[48] have demonstrated holistic soil management practices.

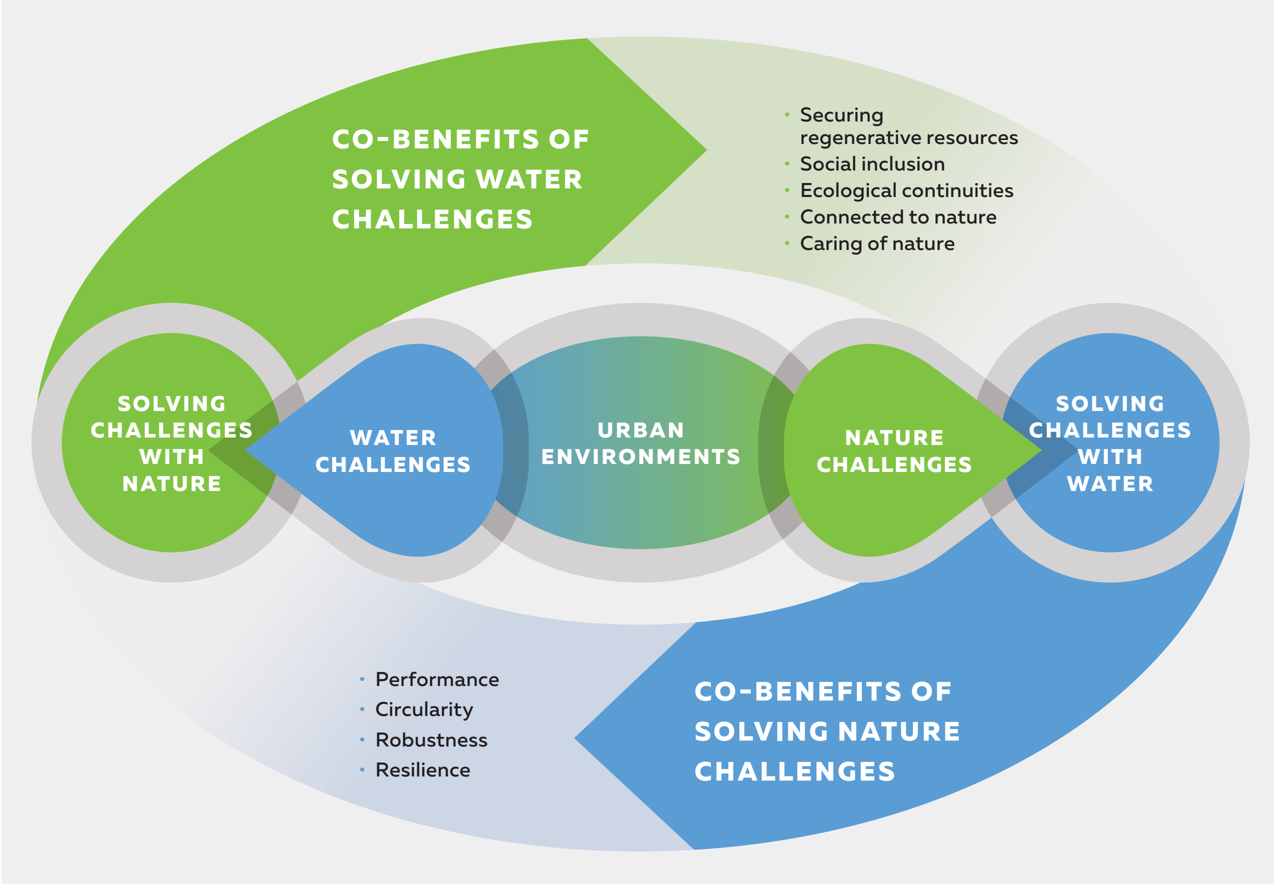
Drawing on nature in the urban context, the concept of sponge cities has emerged as a potential regenerative solution that in addition to solving stormwater issues, they restore water in the landscape and regenerate urban living environments to provide both benefits to natural water systems and liveability co-benefits (see Example 10)[46].

Historically we have developed solutions for our cities from a technological perspective and have viewed cities as sitting within nature, rather than working with nature. Nature based solutions not only green the landscape, they should respond to social needs through the design and outcomes of our system.

As an integral part of nature base solutions, water contributes to healthier ecosystems, which in turn provide solutions for water, social and pollution related issues. It can be a tool to recreate the emotional connection between people and nature[49].

The benefit of this emotional connection with water drives usage behaviour and social norms, as was demonstrated in Australia during the Millennium Drought, for example, when people adopted water saving practices to become part of the solution.

WORKING WITH NATURE



Adapted from Trommsdorff (2020) [49]

We cannot protect something well if we are not emotionally connected to it
– Sofia de Meyer, circular economy thought leader.

EXAMPLE 8

BioMakery at La Trappe Brewery (Netherlands)

"Our ambition comes from an inner conviction and is crystal clear: no more drops and grams of raw material will leave our premises, unless processed into a sustainable product." Father Isaac, Prior of Koningshoeven Abbey

Another application of BioMakery Technology: Concept design for the city centre of the WWTP in Kitakyusu, Japan.

CONTEXT – The Koningshoeven brewery is the second largest brewery in the Netherlands producing 7.5 million hectolitres of beer a year. The Koningshoeven BioMakery water treatment facility is fully integrated into an historical monument of the Koningshoeven Trappist Abbey and Brewery.

SOLUTION – The facility treats industrial wastewater from the brewery and municipal wastewater from the Abbey and Visitor centre to re-use quality with a Metabolic Network Reactor (MNR), using 2000-3000 different species of organisms (from bacteria to plants). The underlying principle behind MNR technology is based on the natural phenomenon, where microbial biofilm develops on the roots of aquatic plants. Biomass is attached to submerged carriers – either natural root systems, or to artificial roots developed by Biopolus. The treatment process takes place on an array of MNR reactors (modular and expandable, vertical or horizontal) allowing the development of separate, specialised ecologies to mature in different tanks. As water flows through the reactors it is continuously cleaned as various species breakdown different contaminants. The path and volumetric distribution of wastewater between the reactors is controlled by process management software and dynamically adapted to the changing loads, optimising the process.

BioMakery (facility housing MNR technology) can integrate water treatment and recycling with a range of other functions, including biological manufacturing, food production, energy recovery, and community functions, to become a true hub for urban circularity. Odour free, compact, and modular, with a garden-like atmosphere, it can be placed into any urban environment through creative architecture.

OUTCOMES – The facility provides a long-term sustainable solution for water management, with space to study and showcase water circularity. It also serves as a demonstration site for next generation reuse and recycling for the NEXTGEN H2020 project.

BioMakery returns purified water back into the production process minimising water waste, with the system reducing the amount of water used to brew La Trappe beer by 80%.

BioMakery produces phototropic organisms. Possible use of Single Cell Proteins as slow release fertilizer for plant nursery, as fish fodder, or as human food will be evaluated.

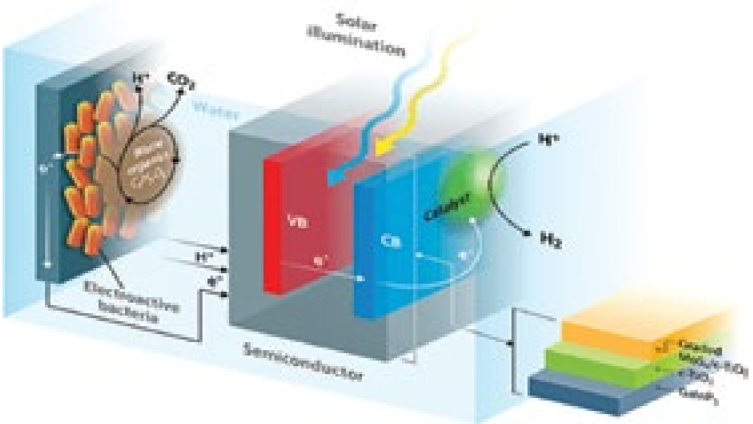
REFERENCES

https://www.biopolus.net/project/trappist-abbey-brewery-koningshoeven-the-netherlands/ (accessed 26/05/20)

https://www.latrappetrappist.com/en/news/biomakerij-wins-circular-award-2019/ (accessed 26/05/20)

EXAMPLE 9

Hydrogen biofuel cell



CONTEXT – A self-sustaining microbial photoelectrosynthesis system is paired with photoelectrochemical water reduction for energy efficient H_2 generation. In other words, bacteria treating wastewater, generates electrons that are used to generate H_2 from water.

DRIVERS – Generation of H_2 by electrolysis is an energy intensive process requiring ultra-clean water. Treating wastewater and generating H_2 is an alternative.

BUSINESS CASE – The concept has been developed in the laboratory and researchers are in the process of commercialization of their technology.

SOLUTION – H_2 generation from water takes two steps:

1 oxidising H_2O to O_2 while generating hydrogen ions (H-), and

2 reduction of hydrogen ions into H_2.

The O_2 reaction is thermodynamically unfavourable requiring light or electrical power. In this concept this is coupled with WWT utilising electron generating bacteria from the treatment process. A bioactive anode is coated with a naturally occurring mix of electroactive bacteria and a photoactive gallium-indium cathode. When light shines on the cathode, excited electrons reduce H- in the wastewater to form H_2, leaving positively charged holes. These are then filled with electrons from the anode, produced by the electroactive bacteria treating organic waste.

REFERENCES

https://cen.acs.org/energy/hydrogen-power/Turning-organic-waste-hydrogen/97/i14 (accessed 28/05/20)

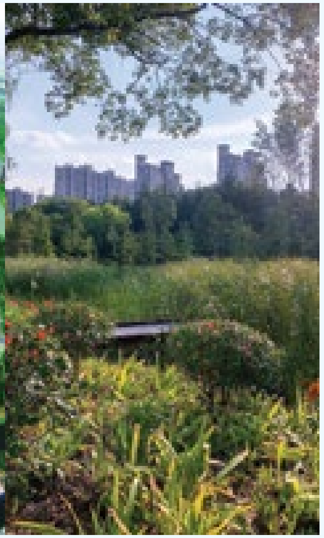
Lu, L, et. al. (2017), Microbial Photoelectrosynthesis for Self-Sustaining Hydrogen Generation, Environmental science & technology, Vol.51(22), pp.13494-13501

EXAMPLE 10

Designing circular cities

Redefining growth through society-wide benefits, incorporating environmentally sustainable practices, minimizing waste and pollution, capitalising on sustainable and renewable resources and regenerating natural systems.

SPONGE CITIES *– Kunshan Jiangsu, China*



SOLUTION – Sponge cities managing water quality with riparian restoration, streetscape interventions, resource recovery, stormwater treatment tree pits, swamp forest wetlands and wetland integration. The example is one of 16 sponge cities in China that has also become a National Urban Wetland Park with significant ecotourism.

This case study was planned and constructed by Chinese governments with international partners to accommodate initial lack of expertise. The project was financed (AUD $16 million) by Kunshan Provincial Government supported by the Central Government.

OUTCOMES –

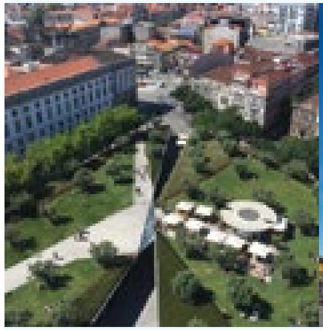
1. More clean water for the city – replenished groundwater provides greater accessibility for water resources
2. Cleaner groundwater – due to naturally filtered stormwater
3. Reduction of flood risk – due to permeable spaces for natural retention and percolation of water
4. Lower burdens on drainage systems – wastewater recycling in community gardens
5. Greener, healthier more enjoyable urban spaces – pleasant landscape aesthetics and recreational areas
6. Enriched biodiversity – due to open spaces, wetlands, urban gardens and green rooftops
7. Restored riparian zones – diversity of ecological transition from aquatic, deep march and shallow marsh to terrestrial plants
8. Nutrient cycling – nutrient recovery for glass house that recycles resources from WWTP.

REFERENCES

https://www.worldfuturecouncil.org/sponge-cities-what-is-it-all-about/

https://watersensitivecities.org.au/wp-content/uploads/2018/10/15-China-Sponge-City-Inovation-Park_FINAL.pdf

GREEN DESIGN *– greening building walls and roofs*



Green roof at Praça de Lisboa, Porto, Portugal

Central Park, Sydney, Australia

SOLUTION – Using the city buildings and infrastructure to minimize the negative effect on human health and the environment. They address stormwater management, urban heat stress and pollution. Toronto has made green roofs obligatory since 2009 to manage stormwater, which is then used for irrigation and flushing toilets.

OUTCOMES –

1. Green roofs – absorb rainwater, mitigate overflow-induced toxin spills, recycle water to feed gardens, regulate building heat, improve air quality and biodiversity. Greening roofs increase the longevity of the infrastructure (e.g. Berlin some green roofs are over 100 years old).
2. Green walls – reduce maintenance requirements and consequently reduce waste generation and energy consumption in the buildings
3. Reduced energy consumption and carbon sequestration (uptake of air pollutants such as N_2O, SO_2 and particulate matter)
4. Appealing environment and protecting human health

REFERENCES

https://theconversation.com/circular-cities-of-the-world-what-can-green-infrastructure-do-119273

Transitioning to a circular economy approach

Shifting from the traditional linear approach of water service planning can be challenging and requires a multi-pronged approach.

For the circular economy approach to be accepted and integrated into services planning, appropriate institutional and governance structures need to be in place. These include the planning decisions made by various institutions that affect the management of resources at different governance scales. Where these are not in an organisation's direct control to change (such as in the regulatory environment), they should endeavour to strongly influence them, as suggested for some items below.

Key building blocks for a circular economy transition:[50]

- **Strong leadership** at the senior level (the Board and senior executives) is crucial to drive the circular economy vision, to make funding available to build capacity and incentivise the transition, and to support new servicing approaches, partnerships and business opportunities. This may include articulating a **commitment to circular economy in the company purpose,** and reporting on the achievements to shareholders on how they are doing in relation to key environmental, social and ethical activities that go beyond their regulatory and financial obligations (See Example 11).
- **Partnerships and collaborative planning** across internal divisions and external organisations are key to grappling with the complexity of bringing together independent services, products, data sets and technologies. This requires **shifting from siloed planning to integrated systems thinking,** and bringing together all those planning urban services (including land-use, water and wastewater, stormwater, energy, waste) at the various scales.

The first step is to identify all the relevant stakeholders, collaborators and beneficiaries, which may potentially include internal stakeholders and decision makers, external government departments and regulators, customers and the affected community. It is important to set up the collaboration framework and clarify who should lead the planning, who is accountable, risk sharing arrangements, and the funding arrangements (including who should ultimately pay for the benefits).[51,52]

- **Economic** evaluation frameworks that incorporate the broader costs and benefits of circular economy planning approaches could support the business case of such initiatives. The externalities such as GHG emissions and nutrient loading on the environment, need to be made transparent and included in the decision making. **Not all externalities can or should be monetised,** rather multi-criteria decision analysis methods may be more appropriate for assessing qualitative costs and benefits.

Often single stand-alone systems may not stack up financially or economically. However, by considering the cumulative impact and effectiveness of a number of decentralised schemes, the business case may have a stronger argument. This is especially true when considering financial and technological flexibility, and determining the impact on social and environmental indicators.[53]

Public capital funding should be allocated to key bulk infrastructure schemes to create an enabling infrastructural environment and market to encourage the private sector to invest in local initiatives. Such infrastructure might include bulk recycling networks for participants to discharge and receive recycled water in a decentralised manner.

Explore and support the development of innovative financing and sustainable business models that provide multiple benefits to the customers and that could cross-subsidise the creation of liveability benefits. This should be supported by frameworks that **clearly resolve who benefits, who pays, and the timing of both.** The timing of the costs, particularly when the costs are realized in relation to the benefits, will also influence the decision to invest, for example in local recycled water systems upfront costs may need to be covered by developers before the lots are sold.

Understanding the market for recovered resources is an important consideration. In many cases biosolids are given away to farmers since it is considered a waste product and it is cheaper than the cost of landfill, so flipping the value proposition in this case may be difficult. Also, it has been revealed that for some recycled water schemes, the levels of treatment for various end-uses were in excess of the Australian Guidelines for Water Recycling due to an over estimation about the future demand and quality.[54]

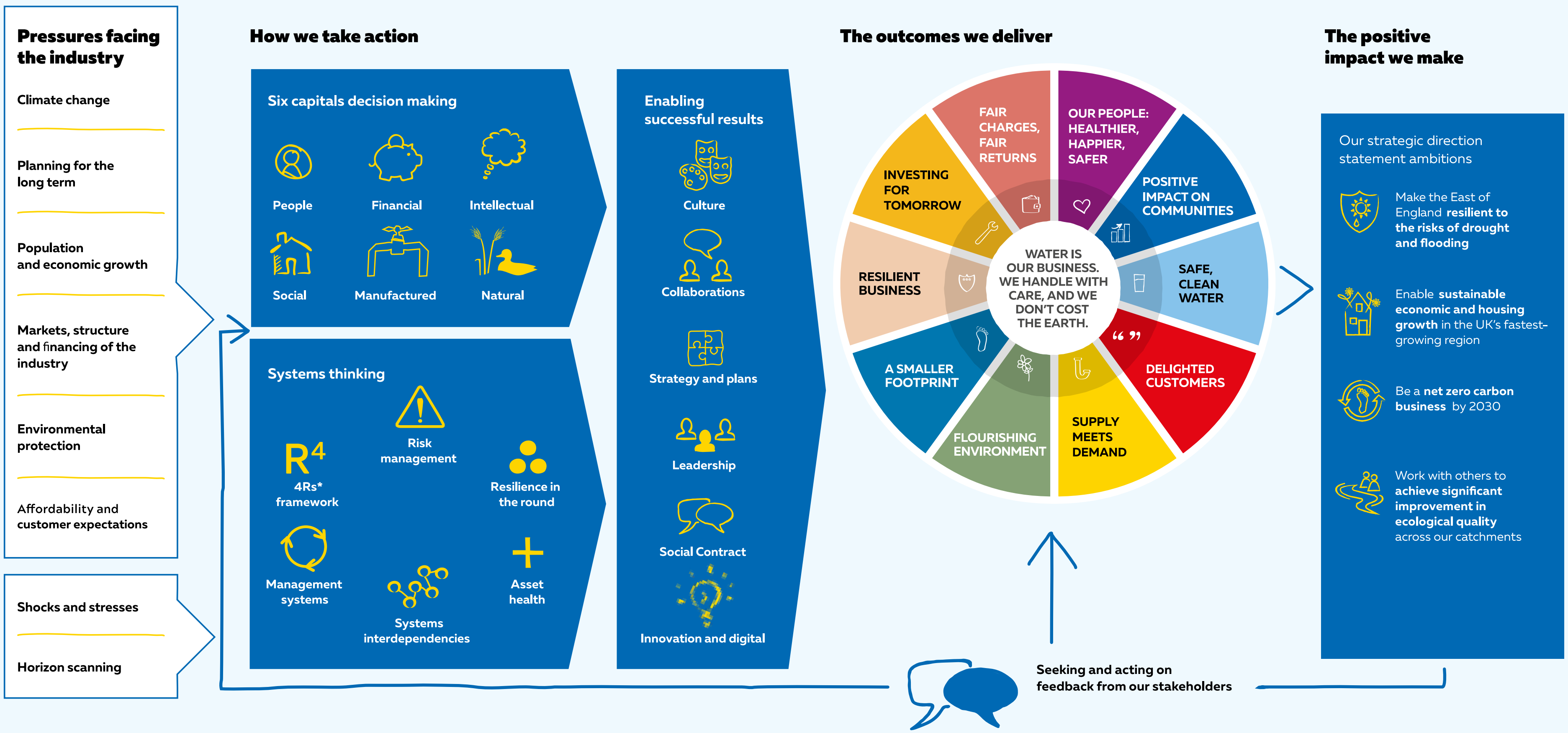
CIRCULAR ECONOMY SHIFT

Stakeholder engagement and communication is key for confirming the vision and to support the implementation of the strategy. The use of clear branding and vocabulary can help reflect a positive message of the benefits provided by utilities (i.e. from waste to resource, or from recycled water to clean water). This allows for a different conversation with customers, stakeholders and policy makers.

Early and meaningful consultation with the community and customers avoids confusion and can often help in acceptance of potential costs, and the understanding of the benefits.

EXAMPLE 11

Commitment to public interest – Anglian Water (UK)



EXAMPLE 11

Commitment to public interest – Anglian Water (UK) *continued...*

CONTEXT – Water is considered vital to the health, wellbeing, and economic prosperity of the East of England, and to maintaining a thriving natural environment. Population growth in the region and the escalating climate emergency are challenging reliable supplies.

Anglican Water state that they "have always recognised the special responsibility they hold as a monopoly provider of an essential public service", and that they "have a duty to deliver wider benefits to society, above and beyond the provision of fresh, clean water".

In recent years they have played a leading role in driving industry-wide discussions around circular economy and the associated social and environmental purpose of a water company.

DRIVERS – While Anglian Water has striven to minimise their impact on the environment while positively contributing to local communities, they had no way of codifying and measuring their approach. The senior leadership of Anglian Water sought a mechanism to take account of the wider impact they were having on their customers, communities and the environment, as well as delivering a fair return for their shareholders.

The UK water industry published its shared Public Interest Commitment, in April 2019, in which the members each committed to enshrining public interest in their company's purpose and signed up to five ambitious goals to tackle leakage, carbon emissions, plastics, affordability and social mobility. Anglian Water was instrumental in this development.

THE RESULT – Not only did Anglian Water enshrine public interest in their purpose, but went even further. In July 2019 Anglian Water became the first water company to lock public interest into the way they run their business, both now and for future generations. With the support of their shareholders and Board, changes to their company constitution (the Articles of Association) were made to ensure that Anglian Water conducts its business and operations for the benefit of shareholders while delivering long-term value for the company's customers, the region and the communities it serves, and seeks positive outcomes for the local environment and society. This is summed up in their Statement of Purpose:

"Our Purpose is to bring environmental and social prosperity to the region we serve through our commitment to Love Every Drop."

As part of the change, the Board of Directors have made an explicit commitment to consider:

- the impact of our operations on communities and the environment;
- the interests of the company's employees;
- the need to foster good relationships with customers and suppliers;
- the need to maintain our reputation for high standards of business conduct; and
- the consequences of decisions in the long term.

The business now has a mandate to work with their customers to develop a two-way social contract to set out how they can work together to protect and enhance the environment and deliver social prosperity to the region.

To deliver on the social contract and their commitment to public interest, they are working to embed it into decision making. With the Board's endorsement, they will be using the six capitals framework to support their decision making.

OUTCOMES – Each year they intend to publish a statement which sets out how they are doing in relation to key environmental, social and ethical activities that go far beyond their financial obligations. Even though water companies are not defined by the UK government as Public Interest Entities, their reporting will be aligned with best practice reporting standards across Europe, where Public Interest Entities are required to publish a non-financial reporting statement.

They are now backed by pension funds representing local authorities and other public-sector workers in the UK and overseas and their Articles should continue to attract responsible long-term investors (sustainable financing) who share their values.

REFERENCES

https://www.anglianwater.co.uk/about-us/ (accessed 28/6/2020)

Adopting a systems approach to understand who your stakeholders may be and expanding your boundary of consideration could reveal synergistic outcomes (see Example 12). Approaches such a community design charrettes or citizen juries[55] are powerful mechanisms for engagement and decision making.

- An **organisational culture** that is comfortable with working in an appropriate level of complexity and uncertainty, is one that encourages learning and innovation without fear of failure. This links to strong leadership and a clear vision, together with improving the **knowledge and capacity of staff,** to undertake relevant data analysis, market assessments, and risk identification associated with the new systems and circular economy focus, and to shift the bias from maintaining the status quo.

Before circular economy is mainstreamed into everyday practices and thinking, it may be necessary to set up a dedicated team to drive and communicate the strategy, and manage related pilots and projects.

Engagement is a vital component of implementing circular economy initiatives because of its complexity and the large number of stakeholders that play a role in delivering the outcomes. This forms a complex social network, where people operate and make decisions at various scales. Facilitating conversations about circular economy is important because circular economy means something different to each person and company, and common ground

EXAMPLE 12

Collaborative watershed solutions – NEW Water (Green Bay, USA)

CONTEXT – In Wisconsin, drivers for integrated planning across the water cycle are weak due to the abundance of water in the region. However, integrated planning across the region around wastewater management is high due to concerns around P discharges and their impacts on waterways.

DRIVERS – NEW Water had issues with phosphorus loading of its freshwater bodies. They were required by the Department of Natural Resources (DNR) to further reduce the amount of phosphorus it discharged, to less than 3% of the overall phosphorus in the bay of Green Bay. They were faced with potentially huge financial costs (more than US$110M) to upgrade plant treatment capabilities as part of their permit requirements to address point source discharges of phosphorous.

APPROACH – NEW Water decided to use a collaborative, watershed based, adaptive management approach to address their phosphorous problem. They began an innovative regional watershed collaborative program, called the Silver Creek Pilot Project, with non-traditional partners including the agricultural community and non-government groups, with the aim of reducing the cumulative P load. These stakeholders were not managing the run-off of nutrients from their land.

The adaptive management initiative was designed to test an alternative watershed based regulatory compliance framework that could more cost-effectively address regional water quality issues. The pilot provided operating information so they could make an informed decision to pursue full-scale adaptive management.

NEW Water has no regulatory authority over the farmers, and have needed to convince them that conservation practices to reduce phosphorus run-off into the waterways are in the farmer's or landowner's best interest. Further, NEW Water has leveraged additional funding to support the farmers with their conservation measures.

OUTCOME – An alternative phosphorus compliance strategy was made available for point source dischargers to achieve regulatory compliance through partnering with farmers and local councils in the watershed, at a lower cost to the community.

REFERENCES

http://newwater.us/programs-initiatives/new-watershed-program/ (accessed 26/6/2020)

EXAMPLE 13

Social network analysis – Melbourne Water

CONTEXT – Around 2012, Melbourne Water was focussed on building internal capacity and capability for integrated water management. This was being delivered through a broad and innovative engagement program. MW recognised that employees had a variety of motivations and barriers to adopting a new way of thinking and working.

DRIVERS – The challenge for MW's Integrated Water Strategy team was to focus on capacity and capability building within the organisation rather than 'service provision', so that IWM became embedded in other planning and operational teams as well, and the dependence upon the Integrated Water Strategy Team would decrease accordingly. If they were not successful, there is a high risk that if the Integrated Water Strategy lost resources the IWM change program would lose momentum because of insufficient organisational capability.

APPROACH – As a first for the water industry, social network analysis (SNA) was used to provide data and metrics that has allowed the engagement plan to be strategically targeted and measured. SNA is a quantitative method for mapping and measuring relationships and interactions between people through the use of a social network map. MW teamed up with a consultancy with experience in SNA to understand the roles that people play within a network and to analyse the value and information flows between people.

Two surveys led to 285 people (or 1 in 3 employees) being placed on the social network map indicating that they were actively engaged and contributing to IWM outcomes. Individuals could be identified by the attributes:

- Influence - who others believe can influence IWM outcomes (positively/negatively)
- Advocacy - who are strong positive spokespeople for IWM.
- Attention - who are highly visible in their IWM efforts and who people listen to.

OUTCOMES –

- Influential people in the network could be recruited to help communicate new initiatives
- Opportunities to build individuals confidence in IWM and connect people who have similar interests were identified
- Quantitative metrics such as the key player index and dependency balance could be used as a measure of success for the engagement plan and how well IWM is embedded across the organization.

REFERENCES

Crossin, R. and Naylor, K (2013) "Using Social Network Analysis as Part of an Innovative Engagement Program for Integrated Water Management"

needs to be found. Social network analysis (SNA) can be a valuable internal tool for understanding an organisation's complex social network, building cross-organisational capacity and embedding knowledge across an organisation (see Example 13).

- **Regulations**, together with policy and institutional frameworks, can play a positive role in creating change. However, current policy and regulatory settings have evolved over a long period of monopoly service provision and centralised infrastructure with often unintended and oppositional consequences.[56] Utilities and WSAA need to advocate for **state governments to provide clarity on the expectations, funding and delivery responsibility for liveability-related and circular economy outcomes.**

  State and local governments could promote the right metrics for planning approvals to incentivise resource recovery, such as BASIX (NSW) which requires residential dwellings to be 40% more energy and water efficient than an average home.[57] However, the timing of capital payments to meet this condition can drive perverse outcomes. For example, if recycled water is used to meet these requirements in a new development, the developer may be required to pay developer charges to the supplier upfront before the lots are sold. If rainwater tanks are used to meet the requirements the cost is covered by the property purchaser when building the home, thereby providing a disincentive for utilities to invest in recycled water options.[58]

  In addition, BASIX does not currently specify solid waste requirements meaning it will need to be adapted for circular economy purposes. Other regulatory tools, such as Development Control Plans (DCP)[59], based on performance outcomes, provide greater flexibility and adaptability for transition and evolving circular economy targets.

Some water utilities have adopted roadmaps to initiate their own internal transition, and for influencing the external environment. Two key components of such a roadmap would be to:

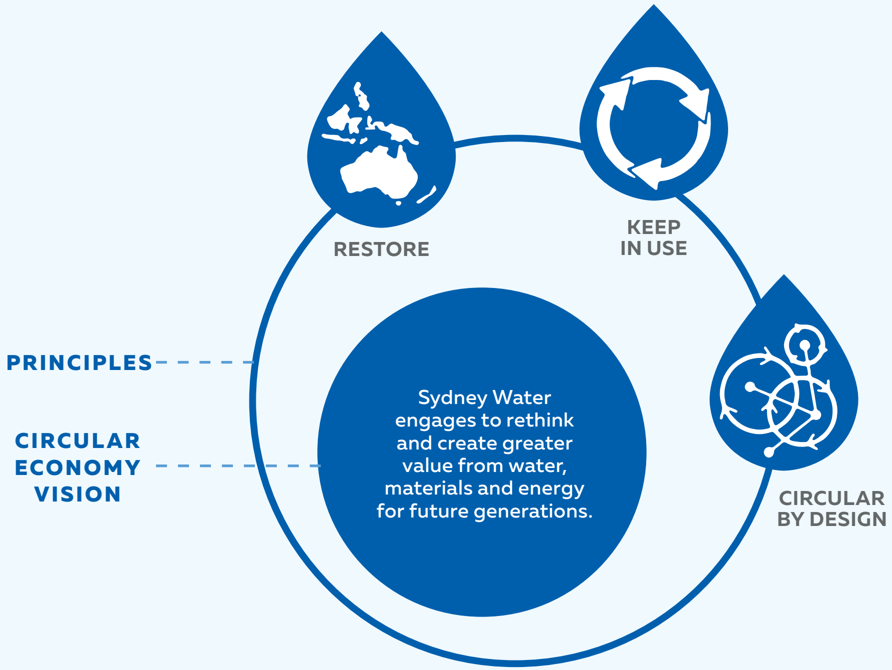
Set and adopt a corporate vision

Set and adopt a corporate vision and strategy at the Board and Executive level, that includes circular economy goals, and outlines the principles by which the organisation aims to achieve the vision, as illustrated by Example 14. Three circular economy principles that apply to the water sector include[21]:

- **Designing out waste** disposal and negative social and environmental impacts, such as landfilling solid waste and biosolids, discharges to the environment and emissions to the atmosphere.
- **Keeping resources in use** for as long as possible through recovering, reuse, upcycling and recycling. This would include water and biosolids from delivering water services, but also consideration of other operational and maintenance activities, such as paper, chemicals, and replaced equipment.
- **Regenerating the natural environment,** such as waterways or urban landscapes, to achieve the social and environmental dimensions of liveability and ecosystem health outcomes.

EXAMPLE 14

Circular economy vision & principles – Sydney Water



PRINCIPLES

- Restore and regenerate natural systems
- Keep resources in use at their highest value
- Design for circularity

CONTEXT – Sydney Water recognises that a circular economy approach offers solutions for the unprecedented pressures on water, and expectations of water resilience, for Greater Sydney. Sydney Water master planners are working with Water NSW to shift the water planning framework from a supply approach to a water sensitive approach.

DRIVERS –

- A single use of water no longer makes sense in the face of severe drought, physical limits to growth and growing population.
- The 1.5-degree limit to global warming cannot be achieved without circularity.

APPROACH – In early 2019 Sydney Water employees workshopped a circular economy vision for the company to sit within Sydney Water's Lifestream Strategy and long-term vision.

Sydney Water then reviewed a number of international frameworks to develop a simplified set of circular economy principles. These principles map closely to the NSW Government Circular Economy Policy and those of the Ellen MacArthur Foundation.

By adapting the IWA Circular Economy Pathways, four strategic directions have been recommended:

- Promote an ambitious Circular Economy approach to water planning and operations
- Renew, refocus and scale restoration
- Collaborate with industry to recover, use and market materials
- Harness renewable energy within the system

PROOF OF CONCEPT – The benefits of the circular economy approach were then demonstrated by mapping the resource flows for three of the planning pathways of the Western Sydney Master Plan.

OUTCOMES – The benefits identified were many, and were above and beyond what can be achieved through the water sensitive design applied to the adaptive planning within the Western Sydney Master Plan. It showed that Sydney Water can achieve increasing water resilience highlighting opportunities to increase self-sufficiency through recycling, increased stormwater capture, demand management and reuse and decreased discharges in a Circular Economy Pathway.

Further, Sydney Water have translated their Circular Economy vision into a Roadmap with 76 identified opportunities, which they are implementing.

REFERENCES

WB Solutions 2019 Circular Economy Roadmap, prepared for Sydney Water, Aug 2019

REGENERATING THE NATURAL ENVIRONMENT

Define a program of work to implement the vision and strategy:

- **Draw together existing initiatives that align with the circular economy approach to show how the organisation is actually contributing to the vision.** Sustainability initiatives that are already underway, such as water recycling, biosolids reuse or biogas production, are an obvious starting point. So too are current campaigns that directly engage the community by providing water bubblers in public spaces and advertising that discourages the use of plastic bottled water.
- **Identify how these existing initiatives could be expanded to be more collaborative and integrated.** Consider which stakeholders and beneficiaries could be included in the planning on how to broaden the initiatives or pilot projects, both in terms of scale and scope. How could they contribute to or benefit further from this process?
- **As a first step, identify new circular economy initiatives that would not be too much of a stretch from business-as-usual** – such as resource recovery (water, energy, nutrients). These could be approved using existing triple-bottom-line sustainability assessment frameworks and business models. It is important to adequately determine the market demand and willingness to pay for the recovered resources as part of the business-case analysis. See the examples discussed under "sustainable solutions" in the previous section, and those proposed by the IWA.[22]
- **Bring together potential internal partners** from across your organisation – especially those who do not normally work together, with the aim of moving from a siloed thinking approach to one that considers the broader servicing system (and the systems within systems). This will foster internal collaboration and lead to more efficient operations, integrated planning and the identification of new opportunities.
- **Target specific research or pilot studies to demonstrate a new restorative or regenerative concept.** Secure research and development funding from internal budgets, external partnerships or grant making bodies to develop proof of concept designs and projects.
- **Identify potential local external partners and networks** to share the innovation costs and risks, and the knowledge that is gained through the collaboration. Further knowledge sharing could be done through industry networks such as WSAA.
- **Develop new planning frameworks** and processes (especially for regenerative initiatives) to guide circular economy planning and approvals, internally and by the economic and environmental regulators.
- **Set metrics and targets** for assessing the circularity of projects and programs, and for tracking the transition progress (see next section). Key performance indicators should be Specific, Measurable, Achievable, Realistic, and Time-bound (SMART).

Evaluation and measurement

Measuring the circular economy, either to determine future projects or to evaluate the progress in the transition process, requires a shift in both the boundary and value definitions, and the introduction of new metrics.

The inherent nature of the circular economy and the inter-relationship between systems and sub-systems requires **expanding the boundaries of analysis.** For water utilities this means focusing beyond the company operations and customer services, to include society and the environmental value more broadly. Further, the current **value evaluation** process, which is based mainly on linear productivity, needs to decouple economic growth from the negative outcomes of resource depletion and environmental degradation, and go beyond monetary evaluation to a more holistic economic approach accounting for the impact on the health and wellbeing of the planet as a whole.

Financing circular economy projects that are assessed based on the benefits of the circular approaches together with the risks associated with the business models remains a challenge. There is still a perception by the financial sector that circular economy projects applying new innovative technologies and business models are too risky[60]. The main challenge remains how to assess the true value of the benefits that are not reflected in the current monetary measures developed for the linear economy. Assessments need to go beyond monetary evaluation of all costs and benefits to a more holistic economic approach, accounting for the health and wellbeing of the environment and society.

Circular economy metrics and indicators

Circularity metrics and indicators should provide an indication of how well the principle of the circular economy is applied to a product or service. Circular economy metrics need to represent the progress of the circular economy and need to be consistent, robust, transparent, and easy to implement. However, despite the abundance of indices and frameworks, arguably due to unclear and diverse understanding of the circular economy concept, they present contradictions in form and content and consequently fail to comprehensively and consistently capture the performance [61].

The circular economy metrics developed so far either:[61]

1) express a value of ***how circular the system is*** (circularity measurement indices, using a numerical scale from 0 to 100%), or
2) analyse the **contribution made by the circular economy strategies,** rather than inherent circularity, using *assessment indicators* (single or aggregated score) or *assessment frameworks* (assessment tools providing multiple assessment indicators).

Indicators used are quantitative and either burden based (e.g. GHG emissions, energy demand) or value based (e.g. resource efficiency, longevity). The frameworks to assess against these indicators have used tools such as:

- *Life Cycle Analysis* (LCA) tools to determine the environmental impact of a product or service along its entire life – they are used to quantify and evaluate the benefit/impact of a circular economy strategy and assists in selection between different circular economy strategies;
- *Material Flow Analysis* (MFA) takes into account the state and changes of each material flow of a system, by the calculation of mass balances over time within a defined space;
- *Input output analysis* is analysis of the economic interdependence between different sectors

While the focus has generally been on the development of the metrics that measure environmental impacts and on economic metrics that are derived by combining environmental and productivity indicators, the social dimensions are practically absent.[62] Also missing are metrics that assess the circular economy features related to maintenance of value. For example, current measures of resource productivity and resource efficiency do not fully satisfy the circular economy objective, since they are solely based on producing more output from less input, missing one of the main goals of the circular economy, which is **to maintain the value of products, parts, and materials over a maximum period of time.**

Development of a framework to measure circularity

Considerable efforts have been undertaken to make the transition towards a more circular economy, however there is no generally accepted monitoring framework. Instead, there exist a large variety of measurement approaches aimed at assessing the progress[62] using metrics based on resource efficiency, material stock and flow, which are often product centric. Many of the frameworks currently used for monitoring at the macro, meso and micro scales were not originally developed or tailored for measuring the circular economy.

A scan of both grey and academic literature revealed that there is a limited number of circular economy measurement frameworks currently available. The EU have developed a Monitoring Framework for the Circular Economy at the country scale[63]. For companies, online tools such as Circulytics[64], were specifically developed to measure a company's circularity performance. Cradle to Cradle Certified™ standards[65], for example, can be utilised as a target or in procurement processes. A comprehensive circular economy measuring framework for water utilities does not appear to exist. Below is high level guidance for how to consider the development or adaptation of one for a water utility.

A common framework for measuring circularity at the water utility level should:

Modified from WBCSD (2018) [66]

1 Drive circular business performance

An important distinction the framework should make is to distinguish between circular performance within a utility's own operations (the processes for delivering the water services), and those of its products and services that enable their customers and others down the value chain (the community) to improve their circularity too. An effective circular economy measurement framework must therefore not only drive a water utility to become "more circular", but also deliver financial gains to the utility together with economic benefits to the broader community.

The processes and products have both impacts and dependencies on the environment and society, and therefore this accounting approach requires agreement on the attribution of those impacts and dependencies across the whole service life cycle.

2 Target specific audiences depending on the company objectives

The performance indicators need to be simple and easy to communicate to both internal and external stakeholders, such as regulators, boards, senior management, staff, and customers.

3 Cover a comprehensive sustainability scope

To honestly measure its circularity, a utility should account for the broader societal aspects – that is adopting a systems perspective. When considering circular economy through a narrow set of indicators and goals, it could lead to burden shifting from reduced material consumption by the utility from one location to increased environmental, economic or social impacts in another.[61] For example, by exporting materials for recycling in places with low environmental, labour and health standards, thereby increasing the social impacts somewhere else.

Similarly, the indicators should account for all resource inputs and outputs (such as minerals, waste generated, energy consumed, GHG emissions, and all forms of water) in its performance measurement along with all three traditional pillars of sustainability (economic, environmental and social).

It is important to set appropriate boundaries for the analysis, to ensure that the attribution of the impacts due to the business activities of utility is real.

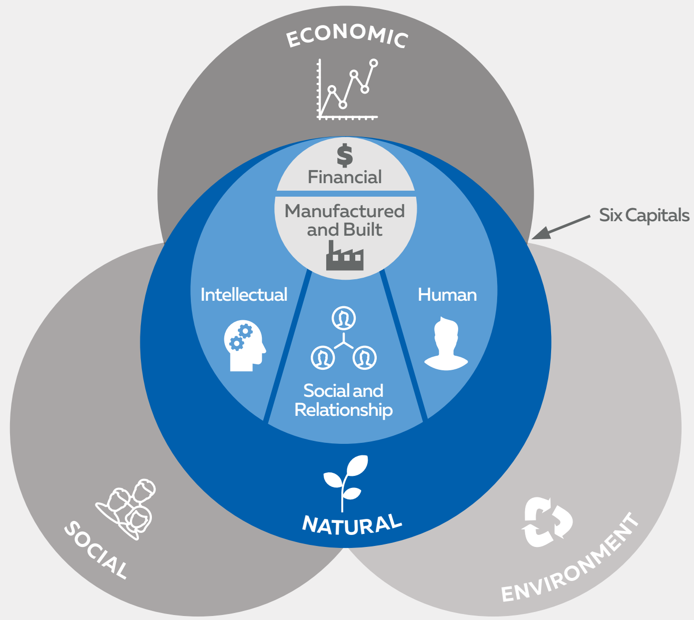
4 Build on existing frameworks and standards

Circular economy indicators should be integrated into existing company reporting protocols. A circular measurement framework should therefore recognize relevant existing standards and frameworks currently in practice and build upon them without contradiction or competition by expanding the scope. There are many circular economy indicator frameworks to draw from, some focusing on the internal circularity of the business processes for delivering water services (such as the six capitals[67] described below) and others that integrate broader societal costs and benefits of these services (as discussed) as far as practically possible.

The following six capitals could be considered as a structure for assessing the circular performance of the organisation and the processes for delivering its products and services (as adopted in Example 11).[67] Example 15 shows in more detail how a utility has used four of these capitals to measure the total value created through their business practices.

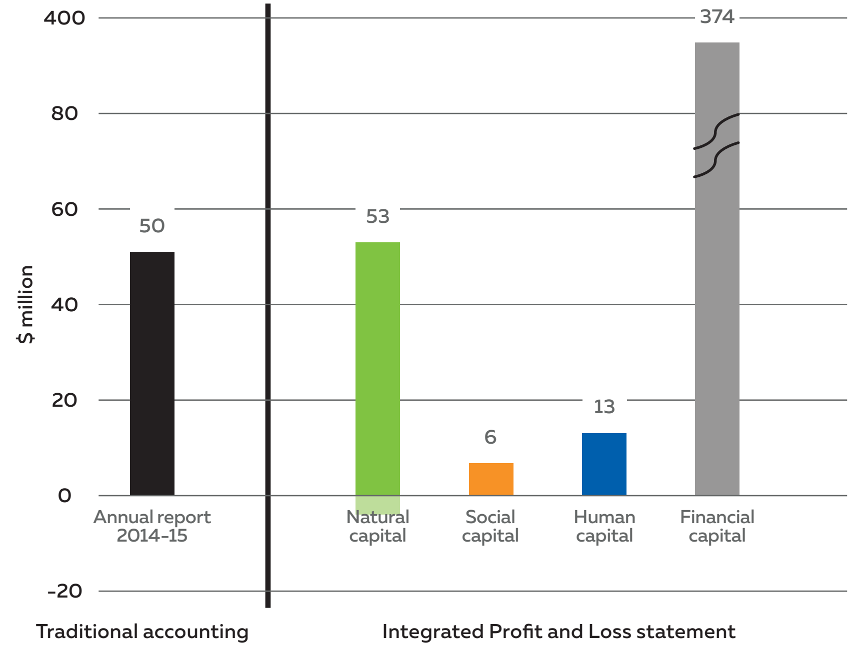
- **Financial capital**
  The financial health and resilience of the organisation and the access to and use of sustainable and ethical finance. This includes the financial resources available within the utility (or partnership) and the financial viability of the circular economy approach to deliver the services and products. The economic benefits can be assessed separately under socio-economic impacts below.
- **Natural capital**
  The health of the natural systems and resources that are relied on and impacted locally and beyond. A measure of all renewable and non-renewable environmental resources and processes that are used to provide the water services, and those resources that are created to restore and regenerate the natural and urban environment. These include air, water, land, minerals, biodiversity, and eco-system health.
  Indicators to measure the natural capital could include:
  - Resource use and scarcity evaluation
  - Natural resources that have been enhanced and created
  - Recycled content and recycling rates
  - Emissions levels and renewable resource share
- **Human capital**
  A measure of, or the improvement in, the employees' knowledge, competencies, capabilities and experience, and their motivations to innovate. Also included is their wellbeing, health, workplace safety and organisational culture.

SIX CAPITALS



EXAMPLE 15

Four capitals approach – Yarra Valley Water



CONTEXT – Traditional accounting profit and loss statements to measure success have served the water industry well to date, it only provides one perspective of value, and that is a monetary return to the shareholder. It doesn't provide a measure of the quality of the service that is provided. It also doesn't answer whether the company or a project is environmentally sustainable.

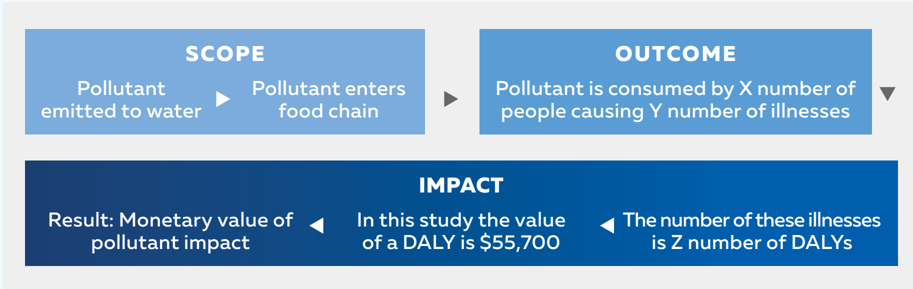
DRIVERS – The direction taken by today's water companies include liveability and sustainability and in some instances these take precedence in licences ahead of profit to shareholders. An example of how this manifests itself is seen in Yarra Valley Water's purpose statement, which is to '...contribute to the health and wellbeing of current and future organisations.' Adopting a broader company purpose accordingly requires a broader methodology for measuring value.

APPROACH – YVW has introduced an Integrated Profit and Loss (IP&L) statement that includes measuring impacts on four capitals (out of the six presented in this report) that best characterises YVW's value creation for stakeholders:

- Natural capital – Impacts on the limited stock of natural assets (both renewable and non-renewable, including air, water, land, habitats) from which goods and services flow to benefit society and the economy.
- Social capital – Third-party costs or benefits of the social impacts of an enterprise, resulting from its business model, Corporate Social Responsibility programs, and policies.
- Human capital – A measure of the increase in an individual's future earning potential. The increase is due to the training being provided by the employer, as well as the company brand value imparted to the individual.
- Financial capital – Elements of financial value added by the company (such as salaries, rents, and taxes paid) beyond shareholder profits.

PROOF OF CONCEPT – There are three fundamental steps associated with preparing an IP&L account. First, the scope is established, then outcomes are identified, and finally all impacts are calculated.

Scoping establishes the breadth and depth of the study – in YVW's case they decided to include sub-contracted maintenance activities since they manage these activities. For the outcomes, every significant change that occurs (good or bad) is measured. Finally, all material impacts are then determined. It is important to adjust for attribution and eliminating what would have happened anyway. For each impact, an economic value is then determined that reflects the cost or benefit delivered, together with the social return on investment (SROI). The diagram below shows how the method was applied to "water pollutants".



OUTCOME – Completing the IP&L has provided an additional three new strategic insights:

- Confirmed that GHG emissions are Yarra Valley Water's biggest impact
- Created interest within the business to further explore how we create social value
- Enabled a paradigm shift by embedding total value creation in what we do

REFERENCES

Pamminger F, Sukhdev P & Baldock C 2017 A new Way to measure the value a company creates, Water e-journal, AWA Vol 2 No 3. pp 1- 6

- **Social, economic and relationship capital**
  A measure of the economic value of the external social benefits and costs due to the service and product delivery business model. It is here that broader societal benefits could be included, such as safety, greening, cooling etc. Where it is difficult to monetise the benefits, qualitive indicators can also be used to assess these externalities.
  A measure of the relationships and trust within and between communities, groups of stakeholders and other networks, and the sharing of information to enhance individual and collective well-being.
- **Manufactured capital**
  The physical assets created and used by the utility to deliver resilient services, such as dams, treatment plants, buildings etc. These are usually reflected on the company balance sheet.
- **Intellectual capital**
  Organisational knowledge, such as intellectual property and tacit knowledge, systems and procedures that have been developed and shared within the business and with alliance partners.

We can't solve problems (or turn them into opportunities) by using the same kind of linear thinking we used when we created them.

5 Adopt a phased approach to incorporating capitals

Some of the aspects described above are easier to measure than others, therefore the development of circular economy indicators (both qualitative and quantitative) should be undertaken in a phased approach. This will allow the aspects that are better understood to be measured and monitored in the short term, while the other elements are explored and integrated over time – as has been illustrated by Example 14.

6 Drive culture change and provide guidance

The use of circular economy indicators should aim to drive organisational culture change – creating a "circular-mindset" driven from the top-down initially. Senior managers should be seen using the indicators and metrics to measure and guide circular economy outcomes at various scales – from the asset level, precinct level, through to master planning and strategy levels. Such a culture change needs to incorporate systems thinking rather than a linear siloed approach.

7 Establish a baseline using circular economy metrics

The baseline can be established by using **operating efficiency indicators** (e.g. tons of raw materials, volume of water, energy consumption, tons of waste), **circular performance indicators** (based on the efficiency, longevity, percentage of renewable materials and energy, use of secondary materials in the process) and **circular value creation indicators** (e.g. promotion of circular business models, investment in circular economy projects, liveability contribution). This allows the utility to assess its level of contribution to the circular economy, and assess its performance, based on economic, environmental and social criteria – both quantitative and qualitative criteria. It provides the bases to develop a vision and strategy (including targets), and a roadmap to transition to circular economy.

One of the main challenges in moving towards a circular economy is the development of the common measurement language that allows organisations set baselines using common metrics to compare their progress globally[68]. Most of the circular economy initiatives have been single-point interventions and small scale technological solutions, which currently hampers comparison across utilities.

Supporting the transition to a circular economy

For systemic change, transition requires several elements of the system to change simultaneously requiring governments at all levels, businesses, innovators, investors and consumers to participate in the transition process.

An example of such a planned attempt to transition on a country scale to a circular, regenerative and low-carbon economy is currently unfolding in Slovenia. This program, the first of its kind in the word, is a learning experiment to showcase what is possible, to identify and overcome the challenges, and to scale up what works (see Example 16).

While many challenges are evident when making such a transition, the pressing challenges related to building a circular economy business case and financing circular economy projects need to be addressed at a systemic level, and driven by government agencies, policies and programs. Specific targeted actions are suggested in the table below. (adapted from 60)

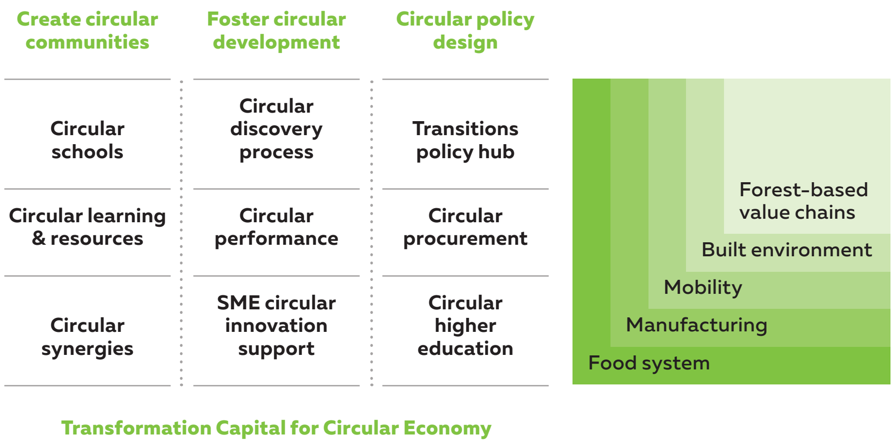
Governments supporting circular economy by:

LEVEL PLAYING FIELD	• Putting in place circular economy frameworks and policy actions that include metrics and indicators, and set targets. • Enabling market opportunities to decrease investment risk in circular economy projects and businesses. • Enabling equitable competitive conditions for circular businesses and development of circularity standards.
VALUE-CHAIN COLLABORATION	• Facilitating the collaboration and alignment of partners within the value chain to optimise the circularity of resources. • Enabling and rewarding value-chain collaboration.
LONG-TERM VALUE CREATION	• Disclosing environmental and social benefits through credible, standardised valuation methods. • Setting up actions to incorporate and reward product longevity, thereby ensuring their longer use.
MARKET PARTICIPATION	• Facilitating better participation of consumers or end-users in the market to optimise for the circularity of resources. • Implementing the National Hydrogen Strategy, and relevant state and territory plans for hydrogen from renewable resources, working together with the water industry and other sectors.
INTEGRATION OF THE PUBLIC GOOD	• Considering both the cost and benefits of externalities in consumption and production to achieve positive community outcomes.
CIRCULAR ECONOMY FINANCE KNOWLEDGE	• Creating tools to value circular business models correctly (credit risk, solvency, time, customer loyalty, breakeven and initial capital investment will be different to linear models) and use circular economy definitions and tools to measure "circularity". • Increasing awareness and knowledge of circular economy within the financial departments and institutions.
INCENTIVES FOR FIRST MOVER'S ACTION	• Removing policies that subsidise linear models, and replacing them with financial or fiscal incentives for circular economy. • Creating markets via public procurement policies based on circular economy principles.

The following actions are suggested as some of the ways in which **governments could support water utilities** to build circular economy cases.

EXAMPLE 16

Circular regenerative economies (Slovenia)



CONTEXT – In November 2019 the Slovenian government passed a motion to adopt an EIT Climate-KIC-led proposal called "A deep demonstration of circular, regenerative and low-carbon economy in Slovenia", which will design and deliver the smart and circular transition of local communities through a coordinated national approach with innovation tackling material production and waste flows across key Slovenian economic systems: forestry, the built environment, mobility, manufacturing and food systems.

DRIVERS – Circular economy, included in the key national documents and strategies: "Vision for Slovenia in 2050", " Slovenian Development Strategy 2030" and Slovenia's Smart Specialisation Strategy, is a cross-cutting topic.

SYSTEMIC CHANGE – To achieve systemic change through collaborative investment, innovation and learning, the scope of innovation needs to broaden to include finance, regulation, education, governance as well as creative arts, community and social movements. Advancing innovation across these multiple fronts at the same time in a joined, holistic way will help identify combinations of actions and investments to achieve pace and scale. People are stakeholders in this change. The focus is on communities, well-being and long-term prosperity including local communities, civil servants, students and younger generations, teachers and other change agents, researchers and academics, non-governmental and non-profit organisations, chambers of commerce and industry, associations and other representations of interest, strategic and innovation partnerships, start-ups, SMEs and companies as well as economic clusters.

SOLUTION – Deep Demonstration – identifying frameworks for whole system change, for rapid testing and learning about what does work and for rapid scaling in the context of uncertainty to achieve transformation to a circular economy.

Methodology – System Innovation

1. **Intent** – The circular economy has been identified by the Slovenian Government as one of the countries strategic development priorities and to become a European leader in harnessing circularity to create a net zero, regenerative economy by 2050. The goal is to decarbonise the economy and society while securing the well-being and prosperity for all Slovenians. This will require critical structural and exponential changes that must occur rapidly on multiple fronts simultaneously. For this purpose, appropriate partners have been identified, trust established, and a common language developed to work across a portfolio of innovations (education, finance, procurement, production systems, regulation, policy, behaviour and citizen engagement) and 8 ministers brought together with a commitment to apply the methodology.
2. **Frame** – Working with Slovenian government to marry up different disciplines and departments focusing on scoping, relationship-building, and defining high-level goals and outcomes. 5 key value chains (forestry, built environment, mobility, manufacturing and food systems) have been identified to trigger systemic transition. The Slovenian Centre for Smart and Circular Transition will deliver linked programs targeting communities, companies and policymakers. Founding needs to be mobilised from private and public sectors.
3. **Portfolio** – Design of a broad-based portfolio of interventions that combine budgets and programs across old siloes – covering various combinations of technology, policy, education, entrepreneurship, regulation, social innovation, citizen engagement and financial innovation.
4. **Intelligence** – Use of sense-making and learning to generate actionable intelligence to accelerate learning about how to achieve transformation at scale.

Impacts Framework – includes an evaluation and learning capability that draws on structured sense-making and frequent calibration of the portfolio of projects.

OUTCOMES –

1. Net zero-carbon economy
2. First country in the world with fully circular economy with no new virgin materials.

REFERENCES

https://www.climate-kic.org/wp-content/uploads/2020/06/CRE_DD_Factsheet_FINAL.pdf (accessed 26/05/20)

Taking action in the water sector to transition to a circular economy

In addition to facilitating regenerated and liveable environments for our cities and communities, Australian and New Zealand urban water utilities need to proactively position themselves as resource recovery enterprises

– focusing on the whole interconnected system of water, energy, nutrient and mineral flows. The transition pathways for utilities have been outlined in the preceding sections. The actions proposed in the table are for the water industry more broadly to support water utilities to embed circular economy principles and practices within their organisations.

Supporting the transition by:

LEADERSHIP	• Facilitating a sector-wide visioning process for the circular economy approach. • Showcasing leadership within the water industry on circular economy innovation and initiatives.
PARTNERSHIPS AND PLANNING	• Facilitating collaboration between urban, water and other planning professionals. • Developing and sharing best practice information with other sectors. • Develop collaborative policy and research opportunities with government agencies and initiatives, such as Queensland Circular Economy Lab, NSW Circular, Waste Authority WA and the newly announced National Food Waste Governance entity. • Supporting members in opportunities and planning for hydrogen production, including evaluating renewable hydrogen technologies, access to water supplies, oxygen generation and working with government agencies such as the Technology Investment Advisory Council, ARENA and the Clean Energy Regulator.
KNOWLEDGE AND CAPACITY	• Establishing a circular economy special interest group within WSAA. • Developing circular economy materials that provide guidance for water utilities transitioning to a circular economy approach. • Investigating opportunities under the Australian Government's new Product Stewardship Investment Fund, including working with water utilities' supply chains to better understand material flows, and to support the recycling of products used and produced. • Funding and commissioning collaborative research on current circular economy knowledge gaps, opportunities and challenges including ways to assist in circular economy decision making, evaluation and measurement at multiple scales. • Capturing and publishing case studies and lessons learnt that illustrate broad circular economy innovations, including technological advances, governance approaches, and institutional and financial models. • Building capacity in the urban water industry on the circular economy.
MEASURING BENEFITS	• Developing a comprehensive set of circular economy indicators for water utilities that include natural and social capitals. • Liaising with regulators to recognise the opportunity cost, capital offsets, and triple bottom line benefits associated with circular economy. • Continuing to engage with customers to understand their preferences and willingness to pay for circular economy outcomes.

The following actions are suggested as some of the ways in which **WSAA could support water utilities** to transition to a circular economy.

References

1. Steffen W et al., (2015) *Planetary boundaries: Guiding human development on a changing planet*, Science 347, Issue 6223.
2. Sutton M. A., et. al. (2013) *Our Nutrient World. The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management.* Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and International Nitrogen Initiative.)
3. Ellen MacArthur Foundation, https://www.ellenmacarthurfoundation.org (accessed 14/11/18)
4. Lyle, J. (1994). *Regenerative design for sustainable development*. John Wiley.
5. Stahel, W. (2014), *The Business Angle of Circular Economy*, in EMF Dynamic-Effective Business in a Circular Economy.
6. Lifset R and Graedel T.E (2001) *Industrial Ecology: Goals and Definitions*, In R. U. Ayres and L. Ayres (ed.), Handbook for Industrial Ecology, Brookfield: Edward Elgar.
7. W. McDonough and M. Braungart (2003) *Toward a Sustaining Architecture for the 21st Century: The Promise of Cradle to Cradle Design*, Industry & Environment, UNEP.
8. Hawken P, Lovins A and Lovins L (2008) *Natural Capitalism: Creating the Next Industrial Revolution*, BackBay.
9. Benyus J (2003) *Biomimicry: Innovation Inspired by Nature*, HarperCollins.
10. Pauli G (2010) *Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs*, Paradigm Pubns.
11. Kate Raworth, Doughnut economics, https://www.kateraworth.com/doughnut/ (accessed 16/07/20).
12. Korse, M. (2015) *A business case model to make sustainable investment decisions. Adding circular economy to asset management.* Master thesis. Industrial Design Engineering, University of Twente, The Netherlands.
13. Geissdoerfer, M. et al (2017), *The Circular Economy – A New Sustainability Paradigm?*", Journal of Cleaner Production 143, 757-768.
14. Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, Drawing from Braungart and McDonough, Cradle to Cradle (C2C).
15. Nguyen, H. et al. (2014), *Remaking the industrial economy*, McKinsey Quarterly.
16. Wahl, D. C. (2016) *Designing Regenerative Cultures*, ISBN: 978-1-909470-77-4.
17. Reed, B. (2007), *Shifting from sustainability to regeneration*, Building Research and Information, 35 (6), 61-76.
18. Rodriguez-Anton, J.M. et al. (2019), *Analysis of the relationships between circular economy and sustainable development goals*, International Journal of Sustainable Development and World Ecology, 26 (8), 708-720.
19. https://www.un.org/sustainabledevelopment/sustainable-development-goals/.
20. WSAA (2018) *Sustainable Development Goals Progress Report: Global goals for local communities*, Water Services Association of Australia.
21. Ellen MacArthur Foundation, anteagroup & ARUP (2018) *Water and circular economy: White Paper*, Ellen MacArthur Foundation.
22. IWA (2016) *Water utility pathways in a circular economy*, The International Water Association, London.
23. WSAA (2019) *Blue+green=liveability: The value of water to liveable communities*, Water Services Association of Australia.
24. Turner, A, White, S, Chong, J, Dickinson, M, Cooley, H & Donnelly, K (2016) *Managing drought: Learning from Australia*, The Alliance for Water Efficiency, the Institute for Sustainable Futures, University of Technology Sydney and the Pacific Institute.
25. Liu, A, Turner, A & White, S (2017) *Assessment of Future Water Efficiency*, Report prepared for City West Water, Yarra Valley Water, South East Water, Melbourne Water, Barwon Water and Dept of Environment, Land, Water and Planning, Institute for Sustainable Futures, University of Technology Sydney.
26. Fyfe, J, McKibbin, J, Mohr, S, Madden, B, Turner, A. & Ege, C, 2015. *Evaluation of the Environmental Effects of the WELS scheme Final Report*, report prepared for the Australian Commonwealth Government Department of the Environment by the Institute for Sustainable Futures, University of Technology, Sydney.
27. Rosenfeld, A.H. (2011) *California Enhances Energy Efficiency*, AIP Conference Proceedings 1401, 7.
28. De Haas, D. et al. (2018), *Benchmarking energy use for wastewater treatment plants, A summary of the 2015-16 benchmarking study*, Wastewater Treatment and Energy, Vol.3, No. 2.

29. Randall, L, Derkenne, D, Lokuge, C, Tawona, N, Hillis, P, Taylor, G, Brauer, D & Mukheibir, P (2019) *Realising the economic value of renewable energy from biosolids*, Water e-Journal, vol. 4, no. 4, pp. 1-13.

30. Long, J.H. et al. (2012), *Anaerobic co-digestion of fat, oil, and grease (FOG): A review of gas production and process limitations*, Process Safety and Environmental Protection, Vol. 90, Issue 3, 231-245.

31. Jazbec, M & Turner, A (2018) *Creating a circular economy precinct*, report prepared by the ISF, UTS, for Sydney Water.

32. https://arena.gov.au/assets/2017/02/uniwater-failure-report.pdf (accessed 26/05/20).

33. Moffat, C. (2020), *Grease trap industry challenged by shuttering economy*, Inside Waste, March 23 2020.

34. https://www.cambi.com/what-we-do/thermal-hydrolysis/ (accessed 26/05/20).

35. https://www.veoliawatertechnologies.com (accessed 26/05/20).

36. Jazbec, M & Turner, A (2020) *Wastewater gas recovery opportunities in a circular economy*, report prepared by the ISF, UTS, for Sydney Water.

37. Egle, L. et al (2016), *Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies*, Science of the Total Environment 571 (2016) 522-542.

38. Shaddel, S. et al (2019), *Sustainable Sewage Sludge Management: From Current Practices to Emerging Nutrient Recovery Technologies*, Sustainability, 11, 3435.

39. Withers, P.J.A. et al (2015), *Stewardships to tackle global phosphorus inefficiency: The case of Europe*, Ambio, 44, 193-206.

40. Mohajerani, A. and Karabatak, B. (2020), *Microplastics and pollutants in biosolids have contaminated agricultural soils: An analytical study and a proposal to cease the use of biosolids in farmlands and utilise them in sustainable bricks*, Waste Management Vol. 107, pp. 252-265.

41. Mohajerani, A. et. al (2019), *A proposal for recycling the world's unused stockpiles of treated wastewater sludge (biosolids) in fired-clay bricks*, Buildings, Vol. 9 (1), 14.

42. Arup (2017), *The urban bio-loop, growing, making and regenerating.*

43. Puyol, D. et al (2017), *Resource Recovery from Wastewater by Biological Technologies: Opportunities, Challenges, and Prospects*, Front. Microbiol. 7,2106.

44. Capson-Tojo G et al (2020) *Purple phototrophic bacteria for resource recovery: Challenges and opportunities*, Biotechnology Advances, Vol 43, online 36 May 2020.

45. Eden, R. (2019) *Stripping Ammonia in Anaerobic Digesters*, The Chemical Engineer, July/August 2019, p. 45.

46. https://watersensitivecities.org.au/content/fly-through-our-vision-for-the-jiangsu-victoria-sponge-city-innovation-park/ (accessed 17/07/20).

47. https://savory.global (accessed 17/07/20).

48. https://drawdown.org (accessed 17/07/20).

49. Trommsdorff, C. (2020) *Nature for cities or cities for nature?*, IWA, March 6 2020.

50. Howe, C & Mukheibir P (2015) *Pathways to One Water: A guide for institutional innovation.* Water Environment Research Foundation, USA https://www.waterra.com.au/publications/document-search/?download=1455.

51. Infrastructure Australia (2018), Planning Liveable Cities.

52. Productivity Commission (2017), *National Water Reform*, Report no. 87, Canberra.

53. Watson, R, Fane, S & Mitchell, CA (2013) *How sustainability assessments using multi-criteria analysis can bias against small systems*, Water, vol. 39, no. 8, pp. 69-73.

54. Mukheibir, P & Mitchell, C (2018) *The influence of context and perception when designing out risks associated with non-potable urban water reuse*, Urban Water Journal, vol. 15, no. 5, pp. 461-468.

55. https://www.yvw.com.au/about-us/our-strategy/price-review-and-determination/customer-led-price-submission (accessed 26/6/2020).

56. Watson, R, Prentice, E, Fane, S & Mitchell, C (2018) *Barriers and opportunities for recycled water and integrated water management investment: Synthesis Report*, Prepared for Hunter Water, University of Technology Sydney.

57. https://www.planningportal.nsw.gov.au/basix.

58. Watson, R, Fane, S & Mitchell, C (2016) *The Critical Role of Impact Distribution for Local Recycled Water Systems*, International Journal of Water Governance, vol. 2016, no. 4:12, pp. 5-21.

59. https://www.planningportal.nsw.gov.au/DCP (accessed 17/07/20).

60. European Commission (2019) *Accelerating the transition to the circular economy, Improving access to finance for circular economy projects.* doi:10.2777/983129.

61. Corona B, Shen L, Reike D, Carreon and JR, Worrell E (2019), *Towards sustainable development through the circular economy – A review and critical assessment on current circularity metrics*, Resources, Conservation & Recycling, vol. 151, 104498.

62. Parchomenko A, Nelen D, Gillabel J and Rechberger H (2019) *Measuring the circular economy – A multiple Correspondence analysis of 63 metrics, Journal of Cleaner Production*, vol 210, pp. 200-216.

63. European Commission (2018) *Monitoring framework for the circular economy*, https://ec.europa.eu/eurostat/web/circular-economy (accessed 17/07/20).

64. Circulytics, https://www.ellenmacarthurfoundation.org/resources/apply/circulytics-measuring-circularity (accessed 17/07/20).

65. Cradle to Cradle Certified™ https://www.c2ccertified.org/get-certified/product-certification (accessed 17/07/20).

66. WBCSD (2018), *Circular metrics – Landscape analysis*, prepared for Climate-KIC Europe and the European Institute of Innovation and Technology. May 2018.

67. IIRC (2013) Integrated Reporting, The International Integrated Reporting Council, London.

68. Ruiz E, Canales R and Garcia V, *La medición de la Economía Circular, Marcos, Indicadores e Impacto en la Gestión Epresarial.* Forética.

Abbreviations

AD	Anaerobic Digestion
BASIX	Building Sustainability Index (NSW)
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon dioxide
COVID-19	Coronavirus disease of 2019
DCP	Development Control Plans
EIT	European Institute of Innovation and Technology
EU	European Union
FOG	Fats, oils and grease
GHG	Greenhouse gas
H^-	Hydrogen ions
H_2	Hydrogen
H_2S	Hydrogen sulphide
H_2O	Water
IWA	International Water Association
LCA	Life Cycle Analysis
MABR	Membrane Aerated Biofilm Reactor
MBR	Membrane bio-rector
MFA	Material Flow Analysis
MNR	Metabolic Network Reactor
N	Nitrogen

NH_4	Ammonia
N_2O	Nitrous oxide
NSW	New South Wales
O_2	Oxygen
OFMSW	Organic Fraction of Municipal Solid Waste
P	Phosphorus
P.E.	Person Equivalent
PBR	Photo-Bioreactor
SDG	Sustainable Development Goals
SMART	Specific, Measurable, Achievable, Realistic, Time-bound
SNA	Social Network Analysis
SO_2	Sulphur dioxide
USA	Unites States of America
USD	United States Dollar
WA	Western Australia
WRRF	Water Resource Recovery Facility
WSAA	Water Services Association of Australia
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

WATER SERVICES
ASSOCIATION OF AUSTRALIA

UTS
Institute for
Sustainable
Futures