Creating a circular economy precinct

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PREPARED FOR:
Sydney Water

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.

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Contents

Introduction

This report

This brief report has been prepared for Sydney Water (SW) by the Institute for Sustainable Futures (ISF), University of Technology Sydney.

The report aims to assist SW with both internal and external dialogue on the potential of creating a circular economy precinct in Sydney including organics processing from wastewater and additional organics waste streams.

To assist in this dialogue, the report provides a selection of example case studies of where materials such as separated food waste, wastewater sludge or trade waste have been combined and treated with technology such as anaerobic digestion (AD) to create by-products for further use. Such by-products include for instance: biogas for hot water heating and electricity generation; and nutrient rich soil conditioner, created from the digestate, for agricultural application.

The example case studies, all international, have been generated from a review of available public literature and academic journal papers. A total of ten example case studies have been provided. There are many more similar examples available that are currently being developed incorporating the principles of the circular economy and including wastewater treatment components.

The Circular Economy

The term "circular economy" is rapidly gaining traction globally in business, waste policy and management practices such as in Europe[1] and within the water industry[2]. The UK based Ellen Macarthur Foundation (EMF[3]), founded in 2010, have assisted in raising the profile of the concept, which has many definitions. According to the EMF it is defined as:

> *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.*

Figure 1 illustrates the circular economy concept. An overarching principle is to separate the "biological" and "technical" materials to assist in retaining the highest values of those materials.

Whilst the term "circular economy" is relatively new, it stems from key principles highlighted in well-established approaches such as Industrial Ecology, which organisations like the Office of Environment and Heritage (OEH), through the Sustainability Advantage program, have used to work with their commercial partners for more than a decade[4].

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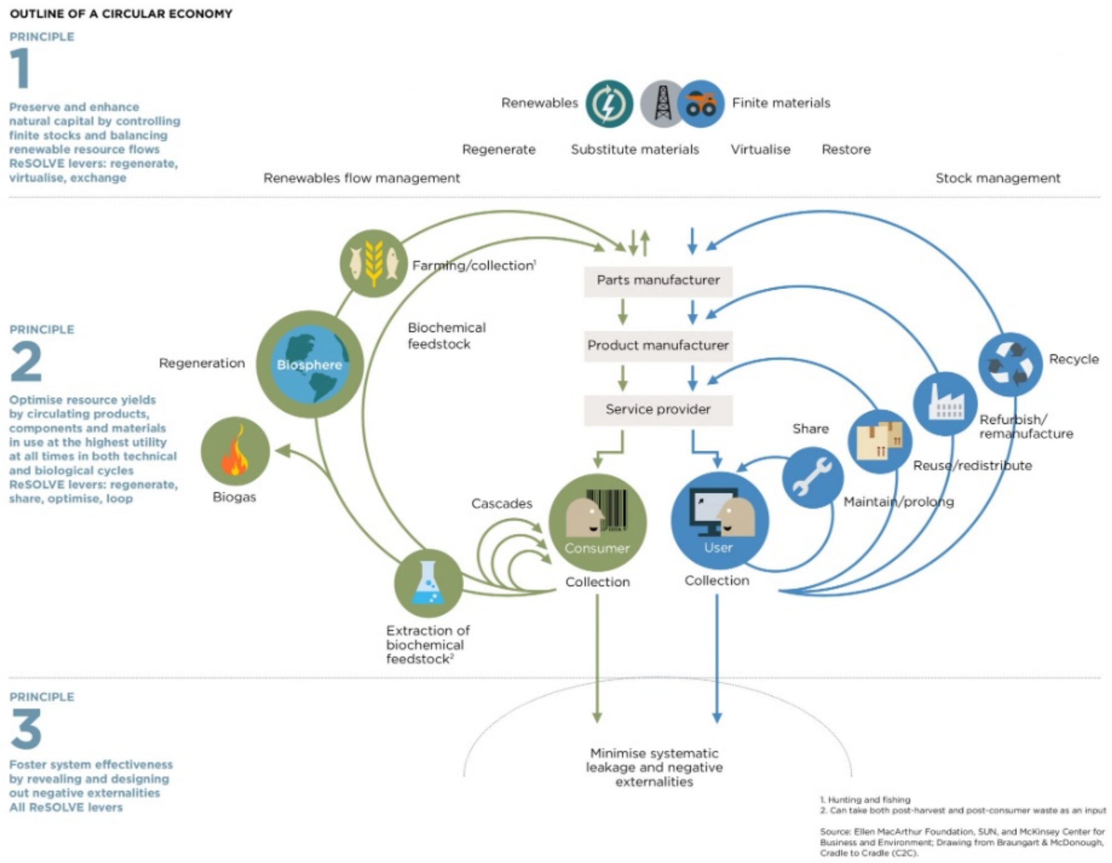
[1] http://ec.europa.eu/environment/circular-economy/index_en.htm (accessed 14/11/18)
[2] http://www.iwa-network.org/wp-content/uploads/2016/07/IWA_Circular_Economy_screen.pdf (accessed 14/11/18)
[3] https://www.ellenmacarthurfoundation.org (accessed 14/11/18)
[4] https://www.environment.nsw.gov.au/resources/business/sustainabilityadvantage/140840-circular-economy-wme.pdf (accessed 14/1/18)

Figure 1 – Illustration of the circular economy (EMF)



Global Circular Economy Principles[5]

- Materials are incorporated into the economy in such a way that they can be cycled at continuous high value and are never dissipated into the environment in unrecoverable form.
- All energy is based on renewable sources.
- Biodiversity is structurally supported and enhanced through all human activities in a circular economy.
- Human society and culture are preserved through human activities.
- The health and wellbeing of humans and other species should be structurally supported through the activities of the economy.
- Human activities should generate value in measures beyond just financial. Material and energy are not currently available in infinite measure, so their use should be an intentional and meaningful contribution.

Circular City Principles[5]

- Optimise for geographically short material cycles.
- Optimise the time scale of material cycles for material demand.
- Match the quality of resource availability to the type of demand.
- Preserve complexity and diversity in social, ecological, and physical flows.

[5] Gladek, E., Van Odijk, S., Theuws, P. and Herder, A., Circular Buiksloterham, Transitioning Amsterdam to a Circular City, Report. 2015.

- Balance overall material input and output of ecologically relevant flows.
- Focus on key impact reduction as a priority (e.g. health impacts in dense zones).

Barriers

- **Laws and regulations**: Policy often leads to unforeseen consequences in changing market conditions, e.g. legal definition of waste.
- **Culture**: As circular economy requires cooperation between sectors and chains, conservative culture and vested interests in sectors can be obstacles to forming efficient and successful cooperation.
- **Market**: Existing incentives, resource flows and quality, external pricing, financing of circular initiatives.
- **Technology**: Up scaling of pilots, complexity of bringing together independent technologies.

Policy can play an important role in removing these barriers.

Policy shifts

The incorporation of circular economy principles into Australian waste policy is currently gaining significant attention with two recent policy discussion papers, triggered by the China National Sword policy taking effect from early 2018[6].

At the national level "*Updating the 2009 National Waste Policy: Less waste, more resources*"[7] makes a commitment to update the National Waste Policy by the end of 2018 and move towards a circular economy. For organics it specifically identifies a target "*to halve the volume of organic waste sent to landfill by 2030*", an extension of the commitment made at the end of 2017 in the National Food Waste Strategy[8] to "*halve food waste by 2030*."

At the state level the NSW EPA has recently closed the exhibition on their discussion paper on a circular economy approach in "*Too Good to Waste*"[9] with the aim of leading towards modified policy and development of an implementation plan by 2020. The discussion paper specifically asks "*would you support zero food and garden waste to landfill?*" and identifies a series of potential actions such as: mandatory separation of food and garden organics for all householders; and mandatory separation and collection for all businesses that generate food waste over a certain amount.

In addition, the recently implemented temporary ban by NSW EPA[10] of mixed organic material to agricultural land, forestation and mining rehabilitation is setting a different set of challenges and prompting for new solutions. The ban does not currently apply to compost or biosolids.

These policy shifts in how food and broader organic waste might be managed in Sydney going into the future open a significant window of opportunity for SW, as the city water authority, to take a collaborative role in making such "wastes" valuable "resources". Such activities can be enacted through a combination of augmentation of existing SW assets and/or development of new facilities. That is, creating potential engines for organic circular economy precincts with existing and new infrastructure.

[6] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/response-to-china-national-sword (accessed 14/11/18)
[7] http://www.environment.gov.au/protection/national-waste-policy/consultation-on-updating-national-waste-policy (accessed 14/11/18)
[8] https://www.environment.gov.au/system/files/resources/4683826b-5d9f-4e65-9344-a900060915b1/files/national-food-waste-strategy.pdf (accessed 14/11/18)
[9] https://engage.environment.nsw.gov.au/circular (accessed 14/11/18)
[10] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/mixed-waste-organic-material-is-no-longer-in-use (accessed 28/11/18)

Case studies

Summary

The international case study examples provided have been obtained from publicly available information and academic articles. They have been chosen to provide an illustration of a spectrum of circular economy precinct applications actually in operation and one with ambitious vision. Case studies have been chosen based on the following criteria:

- Geographical spread.
- Diversity of size of operation from neighbourhood to city and even regional scale.
- Length of operation.
- Diversity of input and output materials (most of the input materials to the systems include food waste and either wastewater or wastewater sludge).
- Spread of output material applications.
- Diversity of treatment technologies included (however most of them include some form of anaerobic digestion).
- Diversity of business models and partners.

Figure 2 shows the locations of the case study examples and Table 1 a summary of the case studies and their key characteristics

Figure 2 – Case study map

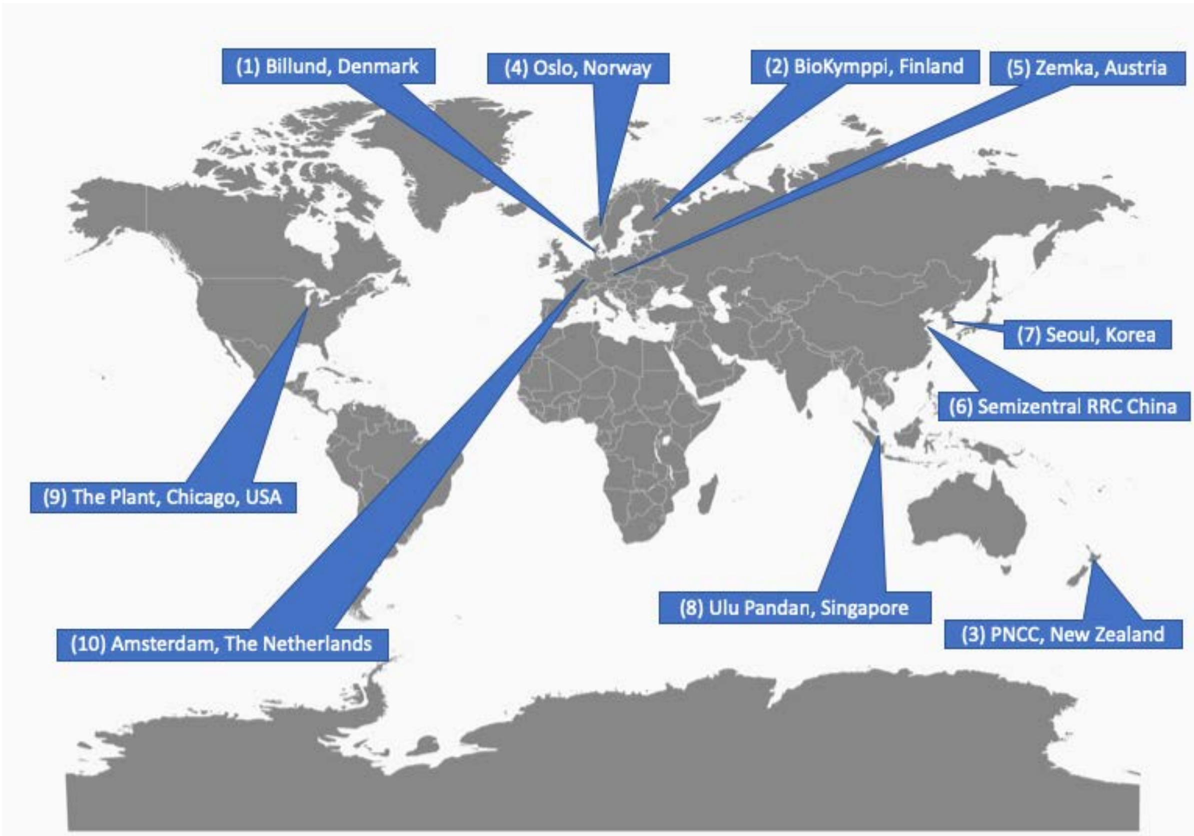
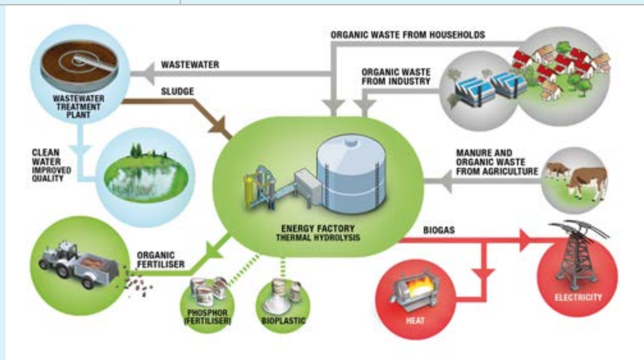


Table 1 – Case study summary

Case study	Name	Location	Scale (t/a)	Cost ($AUS)	Input					Output				
					Wastewater	Food waste	Industrial waste	Agriculture waste	Green waste	Biogas - electricity	Biogas - heat	Biogas transport	Fertiliser	Other products
1	Billund biorefinery	Denmark	4,200t/a	17 mil	✓	✓	✓	✓	✓	✓	✓		✓	✓
2	BioKymppi	Finland	19,000t/a	11 mil	✓	✓	✓	✓		✓	✓		✓	
3	Palmerston North City Council	New Zealand	12.9 bil. l	1.5 mil	✓		✓			✓				
4	Romerike/ Drammen - Oslo	Norway	50,000t/a 6,000t/a	_	✓	✓	✓					✓	✓	
5	Zemka	Austria	18,000t/a	18.6 mil	✓	✓	✓	✓		✓	✓			
6	Semizentral RRC	China	12,500 PE	_	✓	✓				✓	✓		✓	
7	Anyang Sewage Treatment Plant	Korea	27,000t/a	395 mil	✓	✓				✓	✓		✓	
8	Ulu Pandan	Singapore	12,500m^3/d	_	✓	✓				✓				
9	The Plant, Chicago	USA		_	✓	✓		✓	✓	✓			✓	
10	Amsterdam	The Netherlands		_	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Case study 1 – Billund biorefinery, Denmark

1	Billund BioRefinery – "wastewater treatment plant of the future"		
Location	Denmark	**Cost**	Total budget US $12 mil. (17 mil AUS$)
Established	2013, new construction	**Pop'/Capacity**	70,000 PE; 4,200 t/a
			
Input • organic and green household waste, • organic waste from restaurants and catering • organic waste from dairies, slaughterhouses and shops, • manure from farms, • fallen stock, other material from farming industry		**Output** • clean water, • biogas (electricity, heat, fuel cells, biofuel), • CO_2 (algae production), • organic fertiliser, • knowledge – visitor centre *To be expanded to phosphorus and bioplastics, protein production*	
Performance • 30 employees, • DKK 96 mil. (20 mil AUS $) turnover in 2016.		**Technology/Treatment** • Exelys™ (Continuous thermal hydrolysis); • STAR Utility Solutions® (optimised process control) • ANITA™Mox (MBBR-moving bed biofilm reactor) • BioPasueur™ technology (heating of sludge) • Hydrotech™ Discfilter	
Details – Billund biorefinery is more than just a wastewater treatment plant. It provides an ecological link in the cycle between society and nature and provides an improved water treatment facility with a lower energy consumption. The process is 50% more efficient than a conventional AD facility and generates 14 mil kWh of energy/year (equivalent to powering 1,700 homes). Also, nitrogen and phosphorus content in the produced fertiliser are increased by 18% and the absolute amounts of xenobiotics is decreased by 30% compared to conventional AD. Generated energy (heat) is used for its own consumption and the excess heat is dispatched to the public district central heating system, local customers (industry and farmers), or used for fuel cells and biofuel. Generated biogas can be used for the production of biodegradable bioplastics, protein production, storage of CO_2 in algae production (algae which is used to capture CO_2 can be subsequently harvested and utilised). The biorefinery is open to visitors, thus providing background knowledge and exporting technology, which has resulted in two contracts for plants with South Korea. This is an example of a good functioning public-private partnership where joint targets were clearly defined and have contributed to the success of the project. With the total budget of 17 mil. AUS$ the plant was constructed with financial support from the Ministry of the Environment and the Foundation for Development of Technology in the Danish Water Sector.			
Drivers	• established waste sorting-at-the-source, • desire for bio gasification of household food waste • need for highly-efficient and odourless fertiliser • ambition to be world leader of green solutions with potential to export the technology		
Environmental Impact	• ecological link in the cycle between society and nature • lower strain on the environment from transportation • discharge of nutrients decreased by 60% • reduced emissions of 12 t of pure nitrogen		
Partners/ Cooperation	• Billund Vand (bio gasification of organic waste from domestic households and industries) • Environmental company (Kruger A/S) - advanced water treatment within drinking water, process water, municipal and industrial wastewater, sludge, sewerage engineering, soil and groundwater, sophisticated control for wastewater treatment plants		
Sources	http://www.billundbiorefinery.dk/en/		

Case study 2 – BioKymppi, Finland

2	BioKymppi – "generation of safe fertilisers for farms"		
Location	Finland	**Cost**	Investment: 7 mil EUR (11 mil AUS$)
Established	2010, new construction	**Pop'/Capacity**	110,000 PE; 15,000 to 19,000 t/a

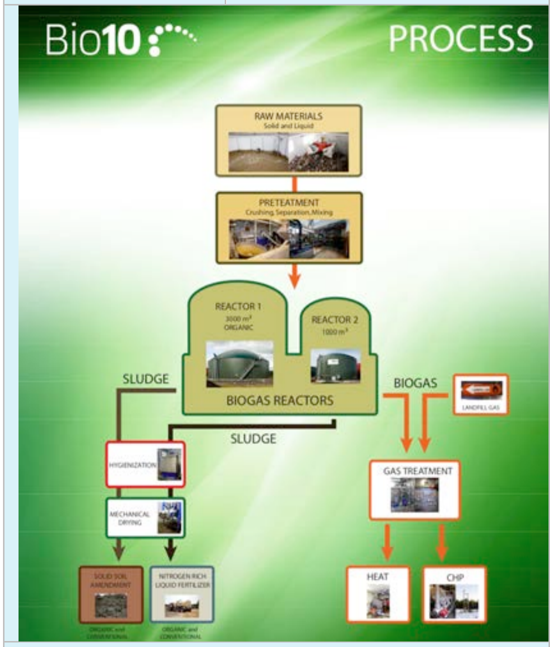



Figure 2.1.4. Biokymppi Oy's biogas plant in Kitee, Finland. Photo: Nikon Kuvauspalvelu.

Input • household biowaste, • packed biowaste, • side streams from food industry, • sewage, • waste cooking fat • fish, • manure	**Output** • biogas (heat and electricity) • liquid fertiliser • solid fertiliser *Plan for biomethane in future.*
Performance • turnover 1.5 mil EUR/a (2.3 mil AUS$); 5 employees • Heat production 8,000 MWh/a (about 1,000 households) • Electricity production 2,000 MWh/a (300-500 houses) • 1000 to 1500 ha of land uses the digestate from this plant.	**Technology/Treatment** • Mesophilic wet digestion; two lines of operation (as illustrated above): (1) sewage sludge (2) fertilizer production; combined heat and power (CHP)
Details – The biogas plant collaborates with local farms and other companies for the collection of raw materials and provision of the plant's end products. The gas from the plant is used together with the landfill gas collected nearby for the heat and power production. Although the plant has the CHP plant on the site, some of the gas is distributed via a gas pipeline to a nearby heat production plant to heat the district. The separated digestate is used as a liquid and solid fertiliser for organic farming and household gardens. The digested sewage sludge is also used for farming, covering 1000 to 1500 ha of land. The plant operates with two process lines. One line is for raw materials, which are accepted for organic fertilisers such as manure and separately collected bio-waste and the other line is for municipal sewage treatment sludge and other materials, which are not accepted for organic fertilisers. BioKymppi is aiming to start processing their biogas to vehicle grade biomethane, but at the moment the market (vehicles using biogas, gas distribution infrastructure and refuelling stations) is not fully developed in North Karelia. (Gasum announced opening of 10 new stations by the end of 2018 to supply biogas.)	
Drivers	• production of renewable energy and safe recycled fertilisers by bio gasification • favourable feed-in tariff • established collected bio-waste market • tightening legislation concerning bio-waste

Environmental Impact	• first biogas plant in Finland that produces fertiliser accepted for organic farming (separate stream)
Partners/ Cooperation	• local farms, • Doranova, • Oulun Energia • Finish Environmental Institute • Food industry companies providing organic waste • Restaurants providing waste fat • Supermarkets providing packaged biowaste • Fish companies
Sources	http://www.bio10.fi/etusivu/ https://www.biogaschannel.com/en/video/biomethane/7/ten-biogas-filling-stations-finland-end-2018/1440/ Fagerström, A., Al Seadi, T., Rasi, S., Briseid, T, (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 8, p.15.

Case study 3 – Palmerston North City Council, New Zealand

3	Palmerston North City Council (PNCC) – "high rate co-digestion"		
Location	New Zealand	**Cost**	Investment US$1.06mil (1.5 mil AUS$); simple payback 3.3 years determined based on savings of gate fees (US$21/t trade waste) (29AUS$/t)
Established	2012-2014, upgrade	**Pop'/Capacity**	75,000 PE; 12.9 bil. liters wastewater

Figure 5.7 (a) Digester with mixing system for co-digestion of primary sludge, grease trap waste, and dairy factory DAF sludge.
Source: Jürgen Thiele

(b) Recuperative thickening system – tripling biogas production

Input
- >90% water
- industrial and municipal trade waste with high FOG (fats, oils and grease) - (5-10%),
- dairy factory DAF sludge,
- grease trap waste;

Output
- biogas

Performance
- Potential for production of up to 10 mil kWh gas in 330 days/a.

Technology/Treatment
- high rate co-digestion;
- mesophilic sludge digesters retrofitted with recuperative sludge thickening

Details – PNCC target is to generate 100% of city's energy needs from locally available energy resources. In addition to an existing mini hydro and wind electricity generators, the renewable energy target is met by utilising landfill gas and biogas to generate electricity. By upgrading the existing mesophilic sludge digesters (2x1350m^3) by retrofitting them with recuperative sludge thickening to achieve digester stability has tripled the biogas production capacity of the plant. Biogas is used to replace natural gas for cogeneration with electricity exported into the grid. A stable loading rate of 1.5kg FOG/m^{3}digester/day was achieved in 3 years. Biogas productivity in m^{3}biogas/m^{3}digester/day was in excess of 320% of equivalent maximum biogas productivity when operated with municipal sludge alone.

Drivers	• development of renewable energy sources for the PNCC to meet the 100% of city's energy needs from locally available energy resources • increasing natural gas and electricity cost • increasing landfill levies
Environmental Impact	• diversion of 15,000t/a high FOG content trade waste from landfill; • Saved energy 5.1mil kWh of natural gas over 330 operation days/a
Partners	• n/a
Sources	Pistacchi, A., Going greener with Palmerston North City Council's biogas to energy project, Waste and water, New Zealand Local Government, June 2010. McCabe, B. K., Schmidt, T., (2018). Integrated biogas systems. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 5, p.21.

Case study 4 – Romerike (R)/ Drammen(D) – Oslo, Norway

<table>
<tr><td>4</td><td colspan="3">Oslo – “biogas powering buses and waste trucks”</td></tr>
<tr><td>Location</td><td>Norway</td><td>Cost</td><td>unavailable</td></tr>
<tr><td>Established</td><td>2012</td><td>Pop’/Capacity</td><td>(R): Capacity 50,000t/a of biological substances;
(D): 6,000t/a of sludge, 16GWh/a</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Input
• solid and liquid organic waste
• sludge, grease and septic</td><td colspan="2">Output
• Raw biogas (60%CH_4 and 40%CO_2),
• Pure CH_4 (99%) – fuel for buses and trucks
• Fertilisers: liquid fertiliser, bioconcentrate, solid organic material
• Knowledge and technology</td></tr>
<tr><td colspan="2">Performance
• 4 mil l diesel fuel (3.3 - 4.4 mil pounds/a) (5.8 – 7.8 mil AUS$)</td><td colspan="2">Technology/Treatment
• Thermal hydrolysis:
• 2 bioreactors (3,200m^3), at 38^{0}C, retention time 24 days
• CH_4 purifier</td></tr>
<tr><td colspan="4">Details – Separate waste collection is maximised and waste is transformed into secondary raw materials engaging citizens, farmers and public transport company. The biogas plants produce raw biogas (60%CH_4 and 40%CO_2), which is further purified to 99% CH_4, cooled to -162^{0}C and stored at 2 bars to be used as fuel for public buses and waste trucks in Oslo. Biogas plants also produce fertilisers: liquid fertilizer, bioconcentrate and solid organic material. The biofertilizers are used by farmers to produce food. Thermal hydrolysis occurs in 2 bioreactors (3,200m^3) at 38^{0}C with a retention time of 24 days followed by CH_4 purification. Cambi technology (steam-based pre-treatment of the feedstock) that is used in these plants has been exported to Korea (See Case Study 7). The method involves heating raw material with pressured steam up to a high temperature (between 130 and 210^{0}C) and then releasing the pressure rapidly. The steam explosion opens up the fibres in the material allowing greater access for the bacteria and enzymes to more easily degrade the input materials.</td></tr>
<tr><td>Drivers</td><td colspan="3">• use of 64% of food waste that is not source separated and remains in the residual waste in Oslo
• power source for buses and waste trucks
• supply of fertilisers for the agricultural land surrounding the plant.
• CO_2 emissions and energy supply security</td></tr>
<tr><td>Environmental Impact</td><td colspan="3">• Plant located in agricultural area removing the need to transport fertiliser to the customers.</td></tr>
<tr><td>Partners</td><td colspan="3">• Cambi</td></tr>
<tr><td>Sources</td><td colspan="3">Full Circle (2017), Cities and the circular economy, Euro Cities, p.24.</td></tr>
</table>

Case study 5 – Zemka, Austria

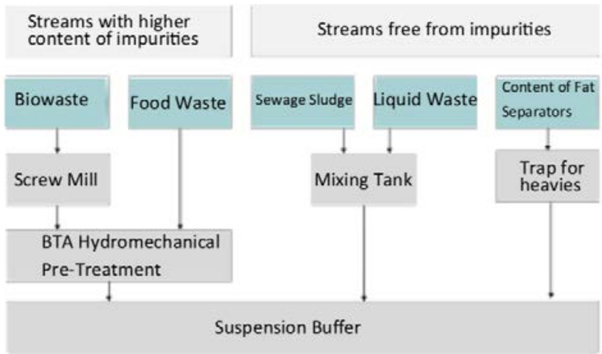
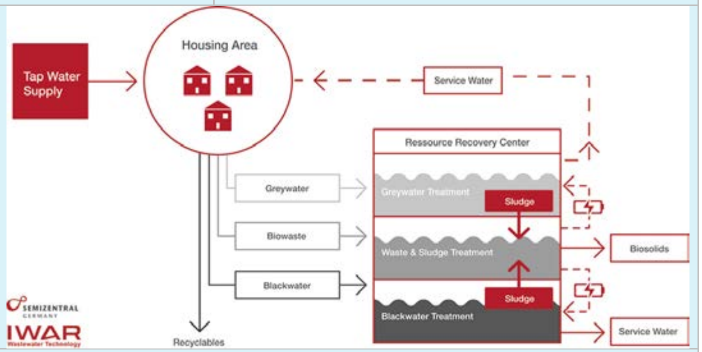
<table>
<tr><td>5</td><td colspan="3">ZEMKA – “Highest substrate flexibility”</td></tr>
<tr><td>Location</td><td>Austria</td><td>Cost</td><td>11.9 mil euro (18.6 mil AUS$)</td></tr>
<tr><td>Established</td><td>2013, new on an old site</td><td>Pop’/Capacity</td><td>18,000 t/a of organic residues (limited by environmental permit);</td></tr>
<tr><td colspan="2">
Fig .1: Aerial View of AD Plant ZEMKA</td><td colspan="2">

Fig. 2: Reception and pre-treatment lines at the AD Plant ZEMKA</td></tr>
<tr><td colspan="2">Input
• biowaste (8,000t/a)
• food waste (2,500t/a)
• sewage sludge (4,500t/a)
• liquid waste (1,000t/a)
• content of fat separators (2,000t/a)</td><td colspan="2">Output
• biogas
• heat</td></tr>
<tr><td colspan="2">Performance
• Energy yield 15 GWh/a</td><td colspan="2">Technology/Treatment
• Wet Anaerobic Digestion (250m^3/h, digestor volume: 4,000m^3)
• BTA® hydro-mechanical pre-treatment,
• treatment of biogas for long distance transport</td></tr>
<tr><td colspan="4">Details – The biogas plant combining high substrate flexibility with intelligent biogas valorisation was constructed on an old MBT plant site for bio-waste and municipal solid waste (MSW). To guarantee maximum flexibility, different reception and pre-treatment lines were designed (Fig.2 above). The streams containing impurities need to be treated before the wet AD step. For the valorisation concept two paths had to be considered, conversion to heat for the thermal bath Tauern SPA (more than 2km distance) and the upgrade of the surplus biogas. Biogas is purified by external biological desulphurisation with oxygen dosing and a three-step condensation cooling gas to -5^{0}C. Raw material composition fluctuates weekly as well as seasonally. Despite strong fluctuations in the amounts of the different streams, the production of CH_4 is stable (+/-9% variability). The plant addresses the value chain at municipal level by strengthening regional infrastructure, safeguarding jobs and securing stable disposal costs for the local population and industry.</td></tr>
<tr><td>Drivers</td><td colspan="3">• transport of sewage and food waste to other Austrian states
• valorisation option for all the regional waste streams</td></tr>
<tr><td>Environmental Impact</td><td colspan="3">• Renewable electricity or heat supply
• Saving on 3,000 t CO_2/a emissions.</td></tr>
<tr><td>Partners/ Cooperation</td><td colspan="3">• Kommunalkredit Public Consulting
• Province of Salzburg.</td></tr>
<tr><td>Sources</td><td colspan="3">European Biogas Association (EBA), Good Practices and Innovation in the Biogas Industry, Success Stories of the Members of the EBA, January 2018, p.16.</td></tr>
</table>

Case study 6 – Semizentral Resource Recovery Centre, China

6	Semizentral RRC – "bringing the technologies together"		
Location	Qingdao, Eastern China	**Cost**	not available
Established	2014, new construction	**Pop'/Capacity**	12,500 people (residential houses, hotels, offices, canteens, guest houses, village of Shi Yuan)
			
Input • food waste • wastewater		**Output** • electricity • heat • soil conditioner • non-potable water • solution model	
Performance • Not available		**Technology/Treatment** • membrane treatment, • sewage sludge AD, • thermal electricity generation, • yield management	
Details – Based on circular economy principles a biorefinery to process urban sewage and food waste was constructed. Within 2 years of operation 100% of generated wastewater was reused, leading to 40% reduction in drinking water demand from the municipal supply (toilet flushing and landscape irrigation). Generated biogas is used for self-sufficient operation and the excess is exported to the grid. The residual digestate is collected by farmers and applied to their crop fields as soil conditioner. Individual technologies used in biorefinery are all well established. The real innovation was bringing the sectors together in one integrated operation. The challenges were also getting buy-in approval across several government ministers and building the operator capacity and skills to manage a wide range of technologies that are not usually combined. While there are advantages in scaling up in optimising capital expenditure and reducing planning costs, the cost of pipeline and heat losses exceed the savings. RRC found that a population of 100,000 is considered optimum. The success of RRC with an integrated approach could be a model for provision of water, energy and waste services in China's cities, where sludge is a rising threat to China's environment.			
Drivers	• increasing production of sludge (e.g. 35 mil. t of sludge in 2015, 16% increase in a year) • untreated sludge disposal into environment • energy required to dry and burn toilet waste as alternative to disposal to landfill • heavy metal contamination of compost		
Environmental Impact	• 100% of the wastewater generated reused leading to 40% reduction in drinking water demand for municipal supply		
Partners/ Cooperation	• Semizentral Germany • Chair of Wastewater Technology of the institute IWAR at Technische Universitat Darmstadt • German industry partners • Scientific partners in Germany and China		
Sources	Ellen Macarthur Foundation, The circular economy opportunity for urban and industrial innovation in China, ARUP, 2018, p.76.		

Case study 7 – Anyang Sewage Treatment Plant, Seoul, Korea

7	Anyang Sewage Treatment Plant – "underground biorefinery"		
Location	Seoul, Korea	**Cost**	Construction project value 321.8 billion won (395 mil. AUS$)
Established	2016, new construction	**Pop'/Capacity**	700,000 people; 84 dry t/day (27,000 t/a organic waste): 300,000 t/d wastewater

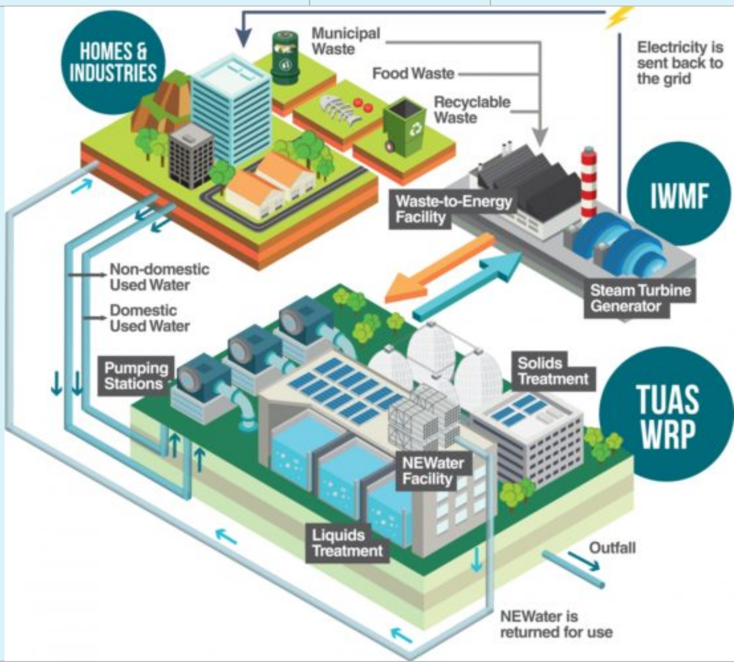
Water and Energy Independent WWTP through PID technique with Recovering Small Water Cycle

Input	**Output**
• sewage (65%) • food waste (35%) • small water cycle balance for climate recovery through decentralised rainwater management	• biogas (electricity and heat, biomass fuel or land application); • renewable biomass fuel for co-firing existing power plants (dry solids dewatered product after digestion blended with millet grass)
Performance • 12,000 MWh/a generated electricity (3,000 households/a)	**Technology/ Treatment** • Thermal Hydrolysis (CambiTHP™)

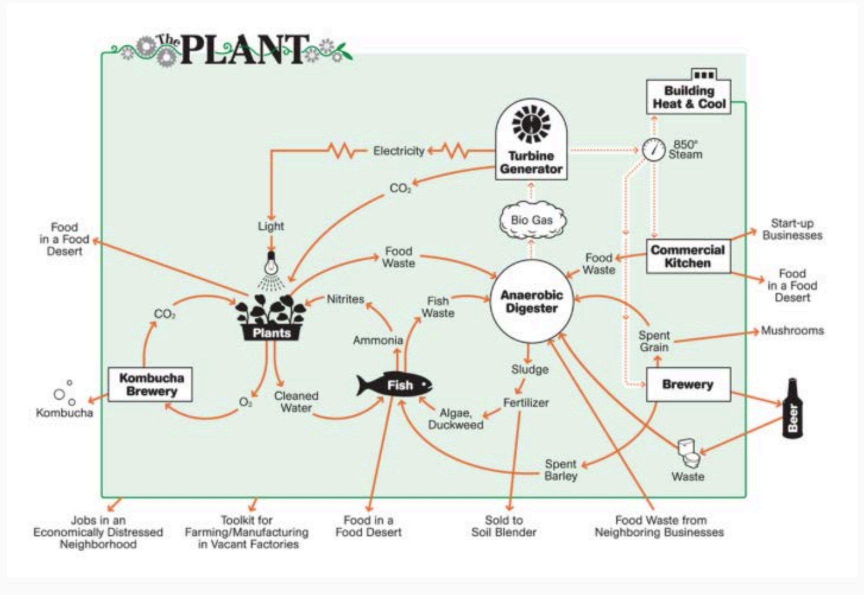
Details – The plant was constructed underground due to strong opposition towards the sewage treatment facilities by nearby residents because of odours. The land covering the facility (180,000m²) was transformed into a park for residents. Chimney used to purify the odour was redesigned into observatory and a range of sporting facilities will be built in the park along grass gardens and urban forests. The new facility requires triple the amount of energy compared to the former plant above the ground due to extra lights, more sophisticated purification and emission processes. However, it is expected that the plant will be self-sufficient through production of biogas and will be generating excess electricity. The solids are pathogen free due to pre-treatment in the CambiTHP™ process and can be applied to land as a back-up to the co-firing solution. The plant was awarded the International Water Association Best Practices on Resource Recovery from Water Award in 2017.

Drivers	• odour from wastewater treatment plant • minimising distance from the collection points
Environmental Impact	• "Positive Impact Development tool" monitoring overall achievement • Reduction of GHG: 19,502 t CO_2/a
Partners/ Cooperation	• CambiTHP™ • POSCO Engineering and Construction, • Korea Environment Corporation (K-eco), • City of Anyang
Sources	http://www.iwa-network.org/news/transforming-sewage-into-valuable-resources-in-korea/ http://english.donga.com/List/3/04/26/862162/1

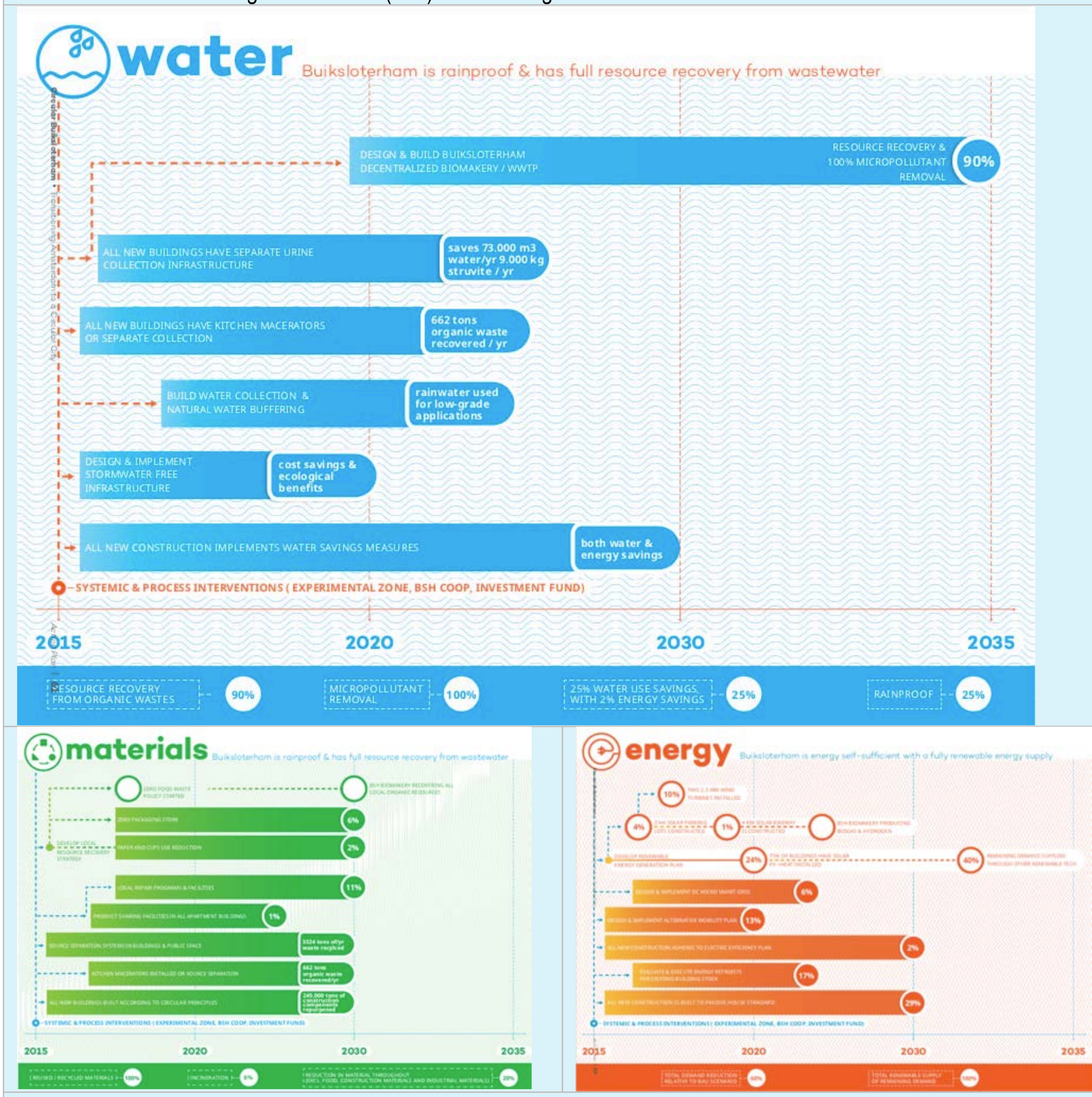
Case study 8 – Ulu Pandan Demonstration Plant, Singapore

8	Ulu Pandan Demonstration Plant – "small steps towards water-energy-waste nexus"		
Location	Tuas Water Reclamation Plant (WRP), Singapore	**Cost**	Not available
Established	2017	**Pop'/Capacity**	12,500 m³/day treatment capacity
			
Input • source-segregated food waste from educational institutions, hospitals and camps • water sludge		**Output** • Biogas for operation of the plant	
Performance • 40 t combined food waste and used water sludge supplying 25% of plant electricity needs		**Technology/Treatment** • MBR (membrane bioreactor) • co-digestion • incineration	
Details – Part of the bigger water-energy-waste nexus to be built in stages. The nexus will be taking food waste, provide power and steam supply and sludge drier condensate from the Integrated Waste Management Facility (IWMF) to the Tuas WRP. It will be supplying dewatered sludge, grit, biogas, water supply and foul exhaust air from Tuas WRP to IWMF as shown in the attached picture. Ulu Pandan won the Water/Wastewater Project of the year award at the 2018 Global water awards in Paris for the novel process that should lower energy use, manpower reliance and land usage. The facility was designed to validate advanced wastewater treatment technologies for the future Tuas WRP. It includes space-efficient tanks, energy-efficient systems and automated controls. The plant will run for 1.5 years and the collected data will be used to design the future Tuas WRP and the National Environment Agency's IWMF, which will be located together when the construction is complete in 2024.			
Drivers	• to develop advanced wastewater treatment facilities for large scale Tuas WRP • only 16% of 788,600 t of food waste is recycled (source separated and recycled to animal feed, composted or digested) • alternative to food waste incineration (majority of the food waste is unseparated and is sent to waste to energy facility for incineration)		
Environmental Impact	• Diversion from food waste incineration		
Partners/ Cooperation	• Black&Veatch • Aecom		
Sources	https://www.straitstimes.com/singapore/environment/new-plant-mixes-food-waste-used-water-to-produce-energy		

Case study 9 – The Plant, Chicago, USA

9	The Plant – "real circular economy precinct"		
Location	Chicago, USA	**Cost**	Not known
Established	2010	**Pop'/Capacity**	At finished full scale AD 10,000 t/a food waste
 Copyright: Matt Bergstrom			
Input • Food waste (from The Plant and neighbouring businesses) • Fish waste • Waste • Spent Grain		**Output** • Biogas • Sludge	
Performance • 85 FTE, 70% leased, anticipated to be fully leased by 2019		**Technology/Treatment** • Miniature AD • Full scale AD in future	
Details – The Plant, 93,500 sq. ft. facility, is a collaborative community of small food businesses, all focused on growing, producing, and/or sourcing a variety of food products. The Plant houses a range of businesses, farms, breweries, bakery, cheese distributor, coffee rosters and other food producers and distributers. Founded on a model of closing waste, resource and energy loops. AD is the key feature of The Plant, utilising waste to produce several valuable outputs. Current projects: • Algae Bioreactor: Processed Waste (nutrients from aquaponics farm) produces Spirulina (algae), which is fed to fish. • Aquaponics Farm: Aquaculture combined with hydroponics (raise fish and grow produce without soil). Fish waste fertilises the plants. Food for fish from spent grains from the brewery on site. • Miniature AD: Input are kitchen scraps, product biogas. Testing scalability of the process. • Bio-briquettes: waste from brewery and coffee turned in combustible fuel source to offset wood fired oven on site. • Textiles from Mycelia: Mycelia (fungus) use in packaging material and textiles. • Sustainable fish feed: cultivation of mealworms and duckweed • Bio-based dishware: coffee chaff and binder like beeswax to make compostable (or edible) alternative to paper plates			
Drivers	• demonstrate what sustainable food production and economic development looks like by growing and producing food inside a repurposed industrial building		
Environmental Impact	• Closed loops, no waste		
Partners/ Cooperation	• Residents of The Plant • Surrounding businesses and community		
Sources	http://plantchicago.org		

Case study 10 – Amsterdam, The Netherlands

10	Amsterdam – "vision of a circular economy city"		
Location	Buiksloterham, Amsterdam, The Netherlands	**Cost**	Not available
Established	2014	**Pop'/Capacity**	252 PE (projected to increase to 6,300 PE)
Input • all wastewater (source separated) • organic waste from kitchen macerators • separated urine • green waste		**Output** • biogas (from blackwater from vacuum toilets and kitchen waste from macerators) • struvite (fertilizer) and heat from greywater • nitrogen, phosphate and drug waste	
Performance • Positive General Progress Indicator (GPI) score for region			
			
Details – The vision of circular, biobased and smart neighbourhood Buikslotherham has been developed based on analysis, modelling and stakeholder consultations who created a vision, defined intervention for transition and Action Plan for transformation. The Action Plan provides a framework for a longer-term transformation strategy, including further research and piloting, and key immediate steps. Buikslotherham can serve as a blueprint and live experiment for formerly peripheral areas worldwide and can be transformed into a motor for change and regeneration in cities. The systematic interventions include designation of the neighbourhood to a Living Lab status, development of inclusive governance and management structure, creation of new incentive structures and financial vehicles, building capacity for urban sensing and			

open data and implementation of a Circular Neighbourhood Action Plan. Technical interventions focus on local renewable energy production, natural water management (free storm-water-sewer through rainwater management and nutrient and resources recovery), soil remediation, smart mobility, and local material cycling (source separation programs and circular building principles). The circular building principles include design and building of flexible infrastructure capacity in buildings and underground with connection options allowing future expansion. It includes sewer lines for different qualities of water: grey, yellow and brown water, allowing natural and above-ground water management techniques. Infrastructure flexibility is expanded for electricity (DC and AC) and heating. Vision of the neighbourhood for 2034 is for a hub for innovation and green industry with zero-emission mobility, circular buildings (materials with digital passport for easy identification, valuation and refurbishment) and zero-waste neighbourhood (closed loops for all material flows – near 100% recycling, minimal packaging, recovery of nutrients from organic waste, building designed for material recovery) that was achieved with utilization of Circular Building Standards and an effective waste management strategy. Instrumental in closing the local material cycle is the biorefinery (recovery of nutrients in locally generated wastewater and organic wastes, that are locally reused in a rooftop-based urban farm).	
Technology/ Treatment	• Sink macerators grind up food waste and other organic material flows created in the kitchen. Organic waste is transported through the regular sewer system to a decentralised biorefinery, enabling circular use of wastewater and organic material at the same time. • Rainwater harvesting • Infrastructure for urine separation and collection enabling capture of 90% nutrients (urine is 1% of wastewater stream but contains 85% of nitrogen, 50% of phosphate in municipal wastewater), reduces energy cost of wastewater treatment and size of aeration tanks • Decentralised biorefinery (production of clean water, nutrients, energy and high value products, e.g. biomonomers for chemicals, coatings, adhesives, foams). • Hydrogen fuel cell powered by urine
Drivers	• Based on urban metabolism scan (flows of water, energy, materials; and stakeholders involved) • Incentive structure (subsidy schemes, tax incentives, incentives for social participation, e.g. students receive free housing in exchange for 40 h/month civil service work with at risk youth) • Circular Economy Business Incubator development • Policy interventions • Opportunity due to post-industrial features (polluted land - 15% in Buiksloterham - and open space) neighbourhoods, an engine for the broader transition of Amsterdam
Environmental Impact	• Reduce the consumption of resources (estimated 25% decrease in overall material demand by 2034) • 100% material recovery in buildings; 99% waste recovered, 1% incinerated • Energy demand reduced by 75%, energy distribution system losses reduced by 30%, energy produced locally • Decrease GHG emissions (self-sufficient energy from 100% RE sources) • 100% recovered water from wastewater, domestic and commercial water, demand reduced by 25%
Partners/ Cooperation	• De Alliantie, a housing corporation active in the area • Waternet, the local water utility • Grond & Ontwikkeling, Development agency of the Municipality of Amsterdam • Active companies in the area (Metabolic, DELVA Landscape Architects, Studioninedots, New Energy Docks, Amsterdam Smart City and Frank Alsema)
Sources	Gladek, E., Van Odijk, S., Theuws, P. and Herder, A., Circular Buiksloterham, Transitioning Amsterdam to a Circular City, Report. 2015.

Discussion

The case study examples provided here include a broad geographical selection of circular economy precincts currently operating around the world. There are many more systems in operation, and with the circular economy rapidly gaining traction, many more in the process of being planned at various scales.

The range of circularity applied in the current transition phase from linear to circular economy varies enormously and so does the starting point of the circular economy base across the sectors. While in a fully developed circular economy precinct, wastewater plants are a default component, some precincts might evolve from a different base.

Such new, not yet operational, precincts will likely encapsulate more advanced forms of circular economy principles as technology advances and new "value chains" emerge such as plastics production and high value chemical extraction[11].

From the examples gathered key driving forces behind the implementation of the case study examples have been policy (i.e. the 1999 European Landfill Directive through to the more recent 2018 Circular Economy Package and its lead up[12]), private business opportunities, ambition to develop green technologies, generation of renewable resources and dealing with consequences of excessive waste released to the environment.

As the selected examples focus on the wastewater treatment component, often the existing wastewater treatment infrastructure has been a starting point, or engine, upon which to build the precincts, as the infrastructure costs for such plants are relatively high.

Virtually all the examples purposely chosen have centred around the combined treatment (using some form of AD) of wastewater/sludge and food waste. From these examples it is clear that such treatment needs to commonly be augmented with: pre-treatment processes (i.e. for removal of contaminants or pre- digestion or maceration), modification of the AD system, and parallel or complimentary systems to treat other materials captured to take full advantage of the input materials and increase the "value chain". Also, the infrastructure is often modified to add value or applicability of the generated product, e.g. purification of biogas for application as a fuel.

Many of the examples have taken advantage of the context of, for example, proximity of industrial/commercial customers or the co-location of businesses, providing immediate savings on transport. What is emerging as a common feature of the examples is that they all focus on local opportunities and provide a tailored specific solution, where the collaboration between communities, public and private sectors has been vital.

The concept of circular economy is complemented by the development goals of biobased and smart cities. Smart cities maximise social and environmental capital in the competitiveness of urban areas using modern infrastructure, highly efficient resource management and active citizen participation. Looking at closing the loops, the more costly it is to move a flow (losses, expense around transport) and the more spatially ubiquitous that flow is (e.g. energy and water in form of sunlight and rain), the higher the priority for that flow locally. The next priority targets local material cycle closure and fast cycling of high-volume material streams like food waste and other local organic wastes from which nutrients can be recovered. The more complex or scarce a material, the less priority there is on closing that material cycle locally.[13] The design approach of circular precincts therefore aims to reduce the volumes of local flows (demand-side management), find local supply synergies (heat cascades, material cascades) and supply of local flows in a renewable fashion. Approaching the transformation requires systematic (process-orientated) and technical interventions.

[11] http://www.ieabioenergy.com/wp-content/uploads/2013/10/Task-42-Biobased-Chemicals-value-added-products-from-biorefineries.pdf (accessed 15/11/18)
[12] http://ec.europa.eu/environment/circular-economy/index_en.htm (accessed 15/11/18)
[13] Gladek, E., Van Odijk, S., Theuws, P. and Herder, A., Circular Buiksloterham, Transitioning Amsterdam to a Circular City, Report. 2015.

There are many potential hurdles and barriers as Sydney looks to potentially planning, designing, implementing and operating a circular economy precinct/s including AD technology[14] from political, environmental, social and technical to regulatory and economic issues. Many lessons can be learned from these existing case studies not encapsulated here as part of this review that will be of value. And there are many lessons to be learnt from the emerging precincts that can take advantage of new technologies and value chains. As food waste is more commonly combined with wastewater processes particular opportunities will emerge such as the increased opportunity to capture phosphorus, cellulose and particular chemicals through to opportunities to be identified.

There is a major shift in federal and NSW waste policy which is moving towards enacting circular economy principles and halving or even banning some forms of food waste or broader organics waste streams to landfill. This will have major ramifications across the waste industry, and specifically in Sydney, which currently has a significant gap in large scale processing capacity of waste streams containing organic materials[15.] With the policy shift and current infrastructure gap there is a significant opportunity to potentially use existing utility and resource recovery facilities assets as the engine for new circular economy precincts. In so doing capturing the vast potential resources available within the Sydney basin including recycled water, biogas to generate green power, as a fuel source, for local heating and/or cooling, production of fertilizers and the creation of new bioproducts such as bioplastics. As the technology advances the extent of organic products that could be made will expand and their application and synergies. For example, in addition to application of recovered nutrients as a fertiliser, they could be used in food production or feedstock for feeding insects that are used as food source. Currently, algae can be used to capture CO_2 to purify the generated biogas and then the algae are used as a feedstock. In future scenarios, there are opportunities for further similar synergies when a problem is addressed with the solution that has a further beneficial application.

[14] https://www.sciencedirect.com/science/article/pii/S1364032117300771 (accessed 15/11/18)
[15] https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wastestrategy/epa-waste-and-resource-recovery-infrastructure-strategy-epa2017p0169.pdf?la=en&hash=58087743D18F89DD199C4CD62EF2373A46436F7C (accessed 14/11/18)