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WASTEWATER – AN UNTAPPED RESOURCE?

A REPORT OF A STUDY BY THE AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES AND ENGINEERING (ATSE)

Funded by and in conjunction with the Australian Water Recycling Centre of Excellence

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Tim Muster (The Commonwealth Scientific and Industrial Research Organisation)
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The report was developed by the Working Group that was led by Dr John Burgess FTSE, and included Professor Damien Batstone, Dr Tim Muster and Mr Francis Pamminger.

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EXECUTIVE SUMMARY

Background and Aims

Population growth, increasing demand for natural resources, rising costs and community expectations place a confluence of pressures to manage natural resources, and on the water industry to develop innovative and more efficient processes.

Phosphorus, nitrogen and energy are necessary for life and continued extraction of non-renewable forms of these resources is ultimately not possible. Notwithstanding these important sustainability issues, this report is focussed on the financial aspects of resource recovery from the point of view of an investor. The analysis only touches briefly on the externalities associated with non-renewable resource depletion and does not attempt to value these externalities. The focus of the analysis is on financial return on investment.

Wastewater contains nutrients, carbon, energy and other inorganic and organic resources. Approximate ultimate quantities and resource values for energy, nitrogen, and phosphorous are shown in Table 1 at different scales, taking only the actual resource quantum into account and not the costs of its extraction.

Key Findings

Case Studies

Analysis has shown that the generation of biogas from sewage and waste and cogeneration of electricity becomes financially viable once a treatment plant reaches typical mid-range size (50ML/d). The major variables impacting the viability are the electricity costs, feed-in tariffs and waste discharge costs at each site. In the case of co-digestion of organic wastes, the fees received for waste disposal are also important for financial viability.

Fertilisers can be produced from both biosolids and side-stream treatment processes. This production of fertilisers is primarily driven by environmental regulations and associated costs to achieve compliance.

The production of magnesium ammonium phosphate fertiliser (struvite) is now an established technology and is growing in its application. Innovative methods of financing the investment and the marketing of the product are effective overseas. These include selling the fertiliser (and enhanced versions of it) as a niche product in retail markets at high prices. The Ostara process installed in 2009 at Durham (Oregon, USA) is one of the first such viable examples.

Investment and management structures that are external to state-owned water corporations are a feature of successful resource recovery businesses.

These structures include:

- Technology Provider Ownership of assets;
- Public-Private Partnerships; and,
- Build, Own and Operate contractual relationships.

In one case in Australia, dried biosolids fertiliser production has been shown to attract private infrastructure investors in a Public-Private Partnership. In this partnership Barwon Water, in Victoria, began making dried and pelletised fertiliser product from 55,000 tonnes/year of sludge in 2012 and the fertiliser is being applied beneficially to broadacre land in blends with conventional inorganic fertilisers.

Regulatory incentives and barriers

Increasing regulation of effluent water nitrogen and phosphorus contents and disposal of biosolids to land involve increasing costs. This generally enhances the economic viability of resource recovery implementation through reduced costs. As such, regulation of discharges has become an important driver of resource recovery investment overseas.

Financial aspects

State-owned wastewater corporations could invest in resource recovery, aiming for a relatively modest return on equity under the capital asset pricing model. A typical return on equity used in the industry is three to four per cent (3-4%). The conservative financial regulatory frameworks in which they operate, coupled with the risk of regulatory change, provide potential barriers to resource recovery investment by these corporations.

Financial analysis in this study has shown that struvite production in Australia, on its own and without considering avoided costs, requires struvite prices in the range $1000 to $2000 per tonne to be economic (two to four times the current commodity price). However, an analysis of six case studies from the Unites States of America shows internal rates of return between six per cent and 21 per cent, mainly due to avoided costs.

This high rate of return is enabled by avoided costs, including reduction of chemical use (for phosphorous removal), reduced sludge disposal costs and reduced maintenance costs around fouling by struvite in piping and equipment. Financially viable struvite production requires either a high market price for the product or high costs for conventional nitrogen and phosphorus removal without struvite recovery.

Net present value-based analysis of nitrogen recovery through ammonia stripping indicates this is highly uneconomic. The production cost is some 10 times higher than the underlying commodity price. Production of nitrogen products from wastewater therefore requires a breakthrough in low-cost technology to be economically viable.

In Australia, there is presently a large difference between the purchase price for electricity and the price that generated electricity can be sold back into the grid by water corporations. The difference is substantial – about $180/MWh versus $80/MWh – depending on the scale of operation. The purchase price is important in dictating avoided costs through energy recovery, while the selling price presents a revenue stream for water corporations.

There is a business opportunity in energy resource recovery for an innovative business model involving electricity trading with third party providers when energy is being saved or generated through the application of new wastewater treatment technologies.

Options for Australia

There are a number of resource recovery options for Australia in the next 20 years. These include:

- Further commercialisation of dried biosolids production for fertiliser;
- Renewable energy generation, including from co-digestion of sewage and other wastes; and,
- Application of new energy-efficient technologies and processes to wastewater treatment, including the production of inorganic fertiliser products.

Conclusion

Probabilistic NPV financial analysis has been carried out as part of the analysis of these energy generation and new energy-efficient options.

The analysis shows that the emerging new energy-efficient process technologies appear to be economically viable for larger scales of operation, nominally above 50 ML/day.

Sensitivity analysis shows that the key controlling parameters in Australia are the capital cost differentials with conventional technologies and the avoided electricity costs associated with the water treatment available through the new technologies.

In some cases, the sales of surplus electricity generated at the plant and the sales of nitrogen and phosphorus resource recovery products also add to the economic viability of the option, as does the revenue stream from the disposal of organic waste in the co-digestion case.

KEY ISSUES AND RECOMMENDATIONS

ISSUE 1

Methods of financial analysis involving costs but not revenues are common across the water sector. This leads to confusion and uncertainty as to whether an investment is actually creating value or not, particularly if avoided costs are not properly assessed. The sector generally has little experience in handling uncertainty in financial analysis.

Recommendation 1: That 'net present value' analyses for resource recovery projects should adopt the approaches outlined in this report. This includes considering revenue streams linked to markets in addition to the capital and operating costs expended to produce the products in determining an NPV. If an investment leads to elimination of operating costs, these should be also taken into account. Financial analysis should also include uncertainties through either sensitivity of probabilistic methodologies. In the latter case, the concept of 'value at risk', or the probability of a return being less than the firm's cost of capital, should be employed. A 'real options approach' to financial analysis should be considered to provide further insights when outcomes are uncertain.

ISSUE 2

Innovative business models have been employed overseas to enable resource recovery. These have involved partnerships between technology developers and water corporations, as well as the innovative development and marketing of products. This area of development is still in its infancy in Australia.

Recommendation 2: The Australian wastewater industry should take the lead in developing value-adding and innovative partnerships with private investment groups to facilitate investment in resource recovery. Upstream, this would mean the active development of Public-Private Partnerships, relationships with technology suppliers and the use of build-own-operate partnerships with private providers to produce resource recovery products. Downstream, it would mean reaching out to energy, agriculture and horticulture users of products to ensure a deep understanding of the associated value propositions.

ISSUE 3

Economic opportunity analysis involving probabilistic outcomes has shown that several of the newer technologies and technology combinations with low energy consumption will in future be economic at larger scales. The main economic barrier is market readiness rather than technical performance. Previous government level research and development funding has been mainly focussed on securing water supplies rather than efficient wastewater treatment.

Recommendation 3: That Australia should remain close to the new wastewater treatment technology developments and participate in international and local research, development and demonstration studies associated with these technologies. This will reap the benefits in terms of renewable energy consumption and increased energy efficiency and will help push the new efficient technologies towards commercialisation

ISSUE 4

It has been shown internationally that resource recovery nutrient products can be marketed with high retail price margins if the market is properly developed and the benefits to customers are demonstrated. Fertilisers from resource recovery are also 'sustainable', and this could also be used as a key market differentiator. The unique value of resource recovery products has not yet been fully developed in Australia (for example, for slow release inorganic fertilisers and fertiliser blends for the retail market).

Recommendation 4: That research and development on the agricultural and horticultural benefits of resource recovery fertiliser products should be increased, especially for niche retail markets. This should include new fertiliser product blends similar to those now being marketed in the United States at high prices. If unique value can be successfully demonstrated, strategic marketing of any produced products should be undertaken to achieve the highest price margins possible in Australia.

ISSUE 5

The regulatory frameworks surrounding water, wastewater processing and waste disposal often present an impediment to investment in resource recovery. This is due to differences in jurisdictions, differences in requirements between 'waste' and 'fertiliser', and the imposition of a time consuming, costly and onerous interface for private investors.

Recommendation 5: Regulatory frameworks for water and waste across state jurisdictions in Australia should aim for commonality and simplicity in order to facilitate investment in resource recovery. Since many resource recovery products are used as fertilisers, they should be treated similarly to fertilisers in terms of trace element contamination regulation. Similarly, energy generation from resource recovery is renewable and should be regulated accordingly, including appropriate levels of feed-in tariff for the electricity generated and renewable energy incentives.

AIMS AND PROJECT SCOPE

Population growth, increasing demand for natural resources, rising costs and community expectations place a confluence of pressures on policy makers to manage natural resources, and on the water industry to develop innovative and more efficient processes. Resource recovery can preserve original natural resources, minimise waste generation and maximise value creation from waste products.

This report examines the potential industry opportunities for wastewater resource recovery in Australia and highlights key learnings from initiatives elsewhere. The report identifies barriers to commercial success, discusses industry opportunities for wastewater resource recovery in Australia and considers ways to realise these opportunities. In doing so, the report analyses the problem from the point of view of an investor interested in creating monetary value through extensions to the existing wastewater management system.

The objectives of the project are:

1. To consider examples of resource recovery initiatives in Australia and worldwide, and analyse 'what worked and why'.
2. To highlight commercial opportunities for resource recovery in Australia, identify regulatory, financial and other barriers to realising the opportunities, and suggest approaches to overcome them.
3. To determine the viability of resource recovery options in Australia by undertaking a high level financial analysis of several potential future resource recovery products and future innovative low energy processes incorporating resource recovery.

The scope of the project was to consider the potential energy and nutrient products from wastewater, but not the water itself. Extraction of metals from wastewater was excluded from this study; however there are techniques that can be employed for the treatment of heavy metal-containing wastewater which may present opportunities into the future. Extensive Australian geographical market analysis of the products was also beyond the scope of the project, but where applicable, the product attributes and their value to customers were evaluated.

Collation of existing examples of resource recovery in Australia, such as biogas recovery from wastewater treatment plants and biosolid reuse for nutrient recovery, was undertaken. The project also considered examples from other countries, including the USA and Europe, where several resource recovery technologies have been commercially deployed. The study analysed what regulatory, financial, policy and social factors contributed to the success of those initiatives.

The report has considered how successful commercial deployment of resource recovery technologies could be replicated in Australia. To achieve this, the project has undertaken several financial analyses to understand the economically viable options for Australia. This financial modelling has sought to assess the economic viability of wastewater resource recovery and to identify related investment opportunities in Australia. The perspective has been from the point of view of an investor seeking a rate of monetary return on the investment. In most cases this has involved analysis of the water treatment costs avoided and revenues generated through capital investment (for example, electrical energy costs, chemicals cost, sludge disposal costs or fertiliser revenues). The analysis has not included pricing of externalities such as future scarcity of raw materials or greenhouse gas costs to the environment. It has also generally not considered the common upstream infrastructure costs for different water processing alternatives (for example, land, receiving pipes and stations, or tertiary water treatment). The analysis has provided the probability of a given business strategy achieving adequate returns for investors. Associated with this approach was an estimation of the required price for some important resource recovery products to achieve financial viability.

Using a case study analysis of international and Australian examples, the project has analysed the market, regulatory, technology, and other barriers to successful commercial deployment of resource recovery technologies in Australia. It has considered factors that influence industry opportunities, such as regulatory framework, market value of products, social perception, financial risk, and technology development and deployment.

The project has maintained a strong dialogue with the industry throughout. This has included the involvement of an industry member on the Working Group of the project, visits to industry facilities, and discussions with a range of potential investors in resource recovery, and international and local industry experts. The project Working Group has been advised by a strong Steering Committee of industry and academic leaders, with a workshop held at the beginning of the project with the Steering Committee and industry participants to define the action plans for the project.

CHAPTER 1: INTRODUCTION

Wastewater is now seen as a valuable resource globally due to advances in technology and processing. The key driver for recovering resources and stimulating innovation in this field are the potential or actual increasing value of products such as energy, nutrients and water. Most wastewater treatment plants (WWTPs) are equipped with the biological treatment processes and solids management processes to do so. Valuable nutrients that could be extracted from wastewater include carbon (C), phosphorus (P) and nitrogen (N).

Resource recovery overseas is currently focussed on energy, biosolids and phosphate-based fertilisers. Regulations in the United States of America (USA) and Europe on the discharge of wastes to land and of effluent waters to rivers and lakes, are strict. The cost of energy and the influence of climate change strategies have also played a part in driving the adoption of resource recovery. This has led to instances of investment in the extraction of nutrients and energy from wastewater. The drivers for resource recovery are nested within a set of regulatory frameworks, with the two being dependent on location and time. Figure 1 illustrates just some of the urban, regional and global drivers for resource recovery and how they interact.

Resource recovery is not a major revenue stream for WWTPs but rather provides a potential mechanism for avoiding increasing costs. Potential avoided costs in wastewater treatment include: electrical energy, chemicals for sludge precipitation, operations and maintenance, and sludge disposal. However, identification of markets for resources alongside implementation of current and developing technologies for more cost-effective recovery processes would significantly benefit the water industry.

Details on the value of the waste in wastewater, expressed in terms of dollars per person per year for different components, are provided in Chapter 2. This Chapter also considers the technologies for resource recovery and the associated available products.

Figure 1 Resource recovery drivers.

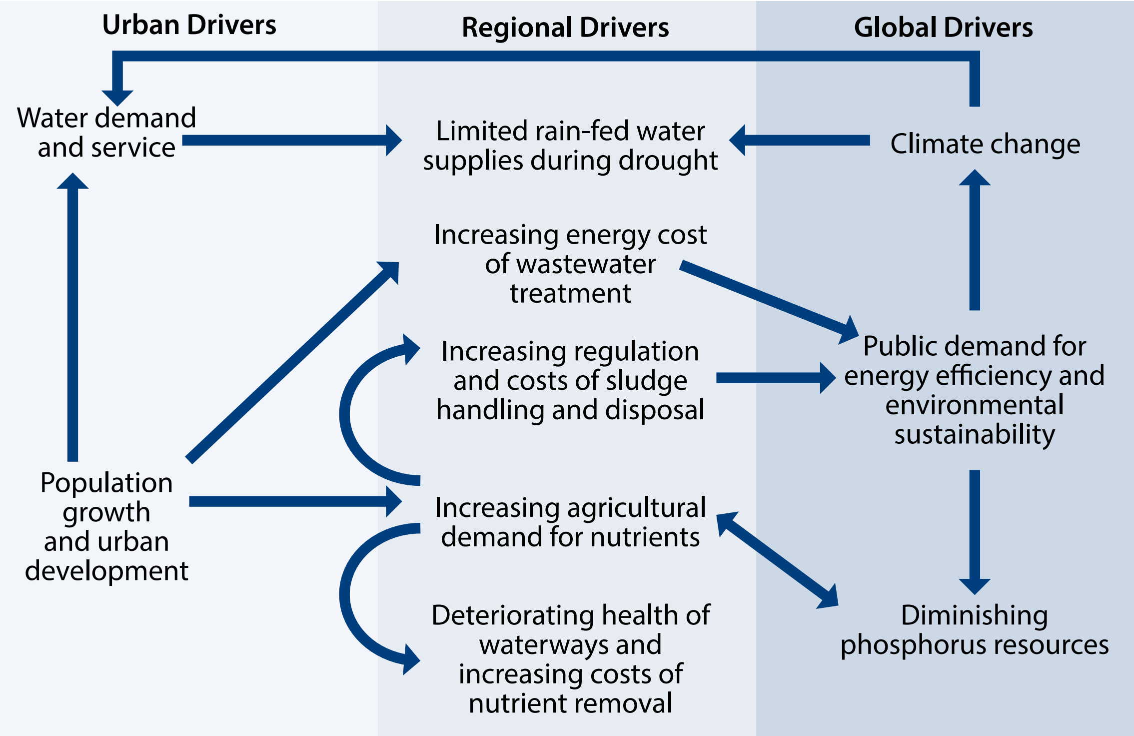
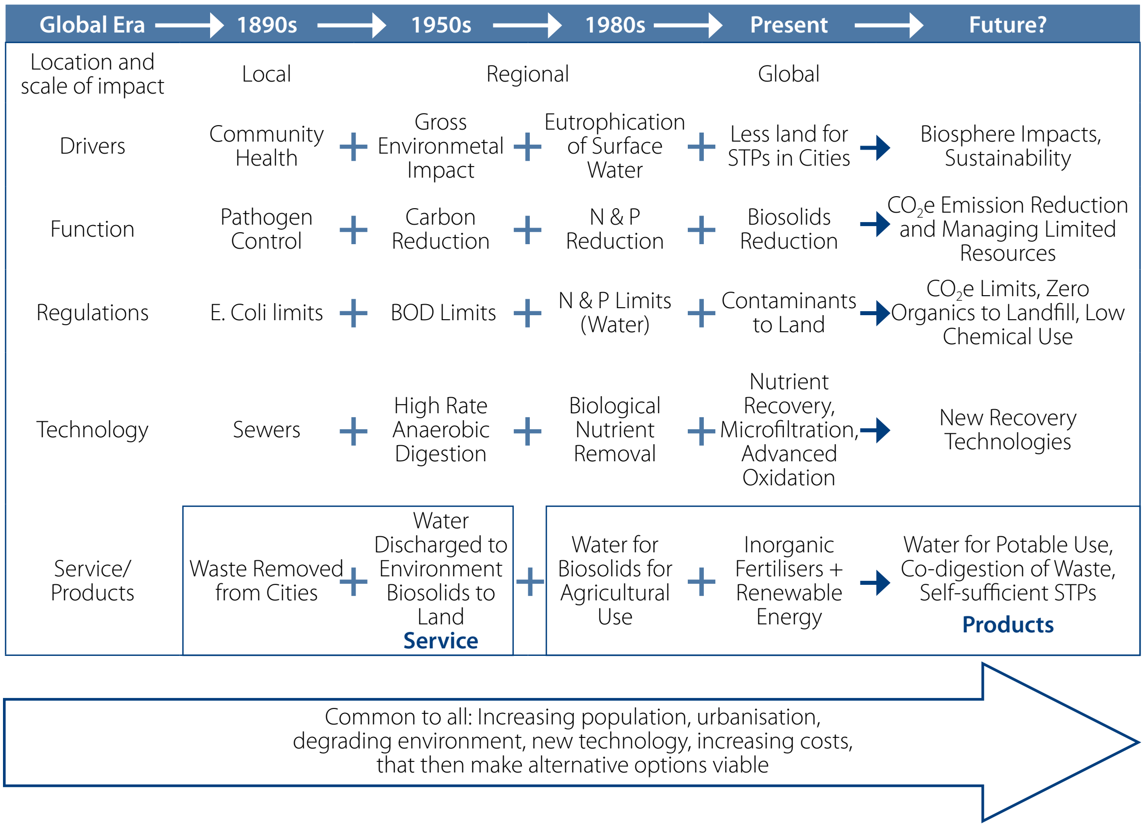


Figure 2 below shows the transition of wastewater treatment over time since the turn of the century. As can be seen, there has been a transition in the drivers for wastewater treatment from 'community health' through 'gross environmental impact' to 'eutrophication of surface waters' to 'biosphere impacts'. This transition has been driven by tightening regulations and has been accompanied by new technology development. Common themes for increasing the level of wastewater treatment have included increasing population pressures, rising standards of living, urbanisation and land availability, biosphere impacts (such as climate change and land degradation), and rising real costs of wastewater treatment, including energy.

Figure 2: Conceptual diagram show transition of wastewater treatment over time



Global Era	1890s	1950s	1980s	Present	Future?
Location and scale of impact	Local	Regional		Global	
Drivers	Community Health	Gross Environmetal Impact	Eutrophication of Surface Water	Less land for STPs in Cities	Biosphere Impacts, Sustainability
Function	Pathogen Control	Carbon Reduction	N & P Reduction	Biosolids Reduction	CO_2e Emission Reduction and Managing Limited Resources
Regulations	E. Coli limits	BOD Limits	N & P Limits (Water)	Contaminants to Land	CO_2e Limits, Zero Organics to Landfill, Low Chemical Use
Technology	Sewers	High Rate Anaerobic Digestion	Biological Nutrient Removal	Nutrient Recovery, Microfiltration, Advanced Oxidation	New Recovery Technologies
Service/ Products	Waste Removed from Cities	Water Discharged to Environment Biosolids to Land **Service**	Water for Biosolids for Agricultural Use	Inorganic Fertilisers + Renewable Energy	Water for Potable Use, Co-digestion of Waste, Self-sufficient STPs **Products**

Common to all: Increasing population, urbanisation, degrading environment, new technology, increasing costs, that then make alternative options viable

Resource recovery – the present Australian situation

A table that highlighted resource value in domestic sewage was presented at 'Ozwater 12' in Sydney by Greenfield[1]. It summarises the amounts and potential values of the inherent components in domestic wastewater in the Australian context. Table 1 shows the components of this resource value.

Table 1 Resource value in domestic sewage

Potential recovery component in wastewater	Component per kL wastewater	Current market prices (nominal, 2012)	Potential value per kL wastewater (A$/kL)	Value estimated by Verstraete *et al.*, 2009 (A$/kL)
Water	1m^3	Zero to A$0.25/kL (non-potable)	Zero to A$0.25	A$0.30
Nitrogen	0.04kg	A$0.76/kg	A$0.03	A$0.015
Methane	0.14m^3	A$0.015 – 0.06 / m^3 methane	A$0.012 – 0.05	A$0.06
Organic fertiliser	0.10kg	NE	NE	A$0.02
Phosphorus	0.01kg	A$2.00/kg	A$0.02	A$0.01
		TOTAL	**A$0.06 – 0.35**	**A$0.40**

In addition to potentially extracting the inherent value outlined in the table above, discussions with representatives from the water industry in Australia have indicated that the predominant business drivers for utility investors are to:

- reduce operating costs, current costs and to hedge against future cost increases;
- improve efficiency, for example through further renewable energy generation and energy efficiency generally;
- adhere to specific regulations governing water and wastewater;
- achieve higher profits and increase revenue through, for example, receiving fees at the gate for processing waste and the sales of new products; and,
- maintain or improve reputation by being publicly perceived to 'do the right thing'. This includes consideration of carbon dioxide equivalent (CO_2e) emissions.

Resource recovery is therefore part of the current business strategy for Australian water corporations, provided it is financially justified.

A detailed tabular summary of the present Australian situation with regard to resource recovery is given in Appendix 4. Several of these resource recovery developments are considered in more detail below.

Water recycling

The technology for water recycling and its adoption is mature. Recycling is undertaken for a number of reasons, including:

- to meet state targets (e.g. Melbourne utilities have a 20% target);
- where the discharge volume is too large or the stream volume is too small, the only alternative is to recycle the water;
- irrigation of land with surplus water (it could be argued this is water disposal rather than re-use, since the water is not sold); and
- non-potable, industrial reuse (enabling production levels to be secured and potentially be expanded through recycling).

Urban reuse of water in Australia commenced in the late 1990s and spread quickly through the 2000s with the millennium drought. Details of the amount of water recycling can be found in the National Performance report for 2012-13: urban water utilities[2]. This data shows that:

- 68 utilities have sewage treatment plants, and there are 535 such plants;
- 52 utilities recycle wastewater, and in 2012-13 there were 138 recycled water treatment plants in Australia; and,
- 19 utilities do not recycle.

Table 2 below shows the six utilities that recycled the largest volume of water in 2012-13.

Table 2 Top six utilities for water recycling in Australia, 2012-13

Rank	Water utility	Water recycled (ML/year)
1	Sydney Water	41,776
2	Melbourne Water	14,379
3	Qld Urban Water Utilities	12,875
4	Western Water (Vic)	7,494
5	Water Corporation Perth	7,356
6	Gold Coast City Council	7,307

Water sold for urban use is sold at a different price to that sold for irrigation. For example, in the 2014 Yarra Valley Water analysis of alternative sewage treatment plants for the Wollert region, it was found that the market price for irrigation water was 1/40 that for urban water.

Energy

Anaerobic digesters are required to generate energy in the form of methane. The biogas from wastewater contains about 60% methane and this biogas can be used for electricity generation. There are many Australian examples of this methane being converted to electricity, usually in reciprocating engines (cogeneration). It is commonplace at large treatment plants in all the major cities, such as the Melbourne Water Eastern Treatment Plant and Sydney Water (multiple sites). The utilities use the cogeneration as combined heat and power, with the heat being used to warm the digesters and the electricity being used to power the pumps and aerators in the wastewater treatment process.

Nutrients

Biosolids

In Australia, biosolids from WWTPs are most commonly applied to land in order to take advantage of the contained carbon and the low levels of nitrogen and phosphorus (7-9% N and 2-4% P), as well as to simply dispose of it. Sixty two percent of Australian water companies reused over 90% of the biosolids that were collected in 2012-13. For example, Sydney Water transports biosolids over the Blue Mountains where they are applied to broad-acre farms in the Central West and South West of New South Wales (NSW). Sydney Water monitors all biosolids they produce to ensure they comply with the requirements of the Environmental Guidelines: Use and Disposal of Biosolids Products[3]. Barwon Water in Victoria has an associated biosolids treatment plant that dries and pelletises biosolids for agricultural use. This is discussed below in further detail as a case study.

Inorganic nutrients

There is no existing example of a product or a sales market for inorganic nitrogen or phosphorus compounds obtained from wastewater in Australia. Queensland Urban Utilities (QUU) installed a struvite recovery plant at Oxley Creek. This facility blended recovered struvite with biosolids (to enhance the nutrient value of biosolids, not to produce struvite as a product) and has only operated intermittently due to difficulties associated with dosing the water with solid magnesium salts[4]. Gold Coast City Council currently incorporates struvite into biosolids at their Coombabah WWTP[5]. Sydney Water and Melbourne Water conducted the feasibility of phosphorus recovery through struvite production, but financial analysis indicated that this is not yet financially viable at projected struvite prices. This is in contrast to Clean Water Services in Oregon where the ongoing cost of removing phosphorus from wastewater was significantly greater than initial investment in a struvite recovery system and struvite production.

CHAPTER 2: RESOURCE RECOVERY TECHNOLOGIES AND PRODUCTS

Technologies

Technologies and research focused on resource recovery have expanded substantially in the last five years towards new products (and opportunities), as well as identifying options for next generation wastewater and waste management processes. There have been a number of recent reviews (e.g. Mehta *et al*., 2015[6] and Latimer *et al*., 2014[7]), which mainly focus on near to market processes and products. It should be noted that market products from resource recovery and the technologies deployed to produce the products are closely linked so a discussion of one necessitates a discussion of the other and are considered together in this review.

Technologies can be considered in terms of their level of development, or in terms of their position along the wastewater processing chain. Latimer *et al*. (2014) adopt the latter approach, and it is also adopted in this project as the products and technologies align well along this timeline. These authors introduce the concepts of **Accumulation, Release** and **Extraction** along the process chain and then characterise the possible technologies in each of these phases as **'Embryonic'**, **'Innovative'** or **'Established'** to describe their level of development. In this context, these terms are defined as:

Established: Commonly applied commercially; mature; current.
Innovative: At demonstration or limited full-scale.
Embryonic: At laboratory or pilot scale.

'Established' technologies

'Established' technologies are mainly focused on low cost nutrient recovery (generally repurposed from nutrient removal). The Water Environment Research Foundation (WERF) Nutrients Phase 1 study[7] focused on the 'established' technologies, and Phase 2 focused on 'emerging' or 'innovative' technologies that are compatible with or that enrich or amend existing processes. Examples include phosphorus and nitrogen recovery (as dedicated product or in-sludge), stripping for ammonia recovery, anaerobic digestion and fermentation for energy and commodity carbon recovery, including the addition of co-feeds, or enhancing anaerobic digestion through pre-treatment (e.g. thermal hydrolysis). These technologies are sometimes termed 'generation 1'. This class of technologies fits well with existing wastewater infrastructure and generally has a well-defined and understood economic proposition. There are multiple (between 5 and 100) providers for each of these technologies. These established technologies are low-risk but with limited scope for expansion beyond current applications. They are generally compatible with existing infrastructure (i.e. form an add-on) and have been applied at full-scale in Australia. Examples include struvite precipitation within sludge streams at Coombabah, thermal hydrolysis in Brisbane for enhanced energy production, mainline energy production in Melbourne through anaerobic treatment, and thermal drying of sludge at Barwon Water.

'Innovative' technologies

'Generation 2' technologies focus on the application of new technologies to allow transformation changes that either generate new products, or allow new larger scale technologies that represent new concepts for wastewater treatment.

An example of the first is electroseparation of ammonia to recover nitrogen, use of adsorption to recover phosphorus from the main wastewater line, or new treatment concepts that enable plant wide energy recovery.
Within the new concept treatment plants, two different proposals have emerged:

- Low energy mainline (LEM) treatment mainly focused on energy recovery through next generation anaerobic processes such as anaerobic membrane bioreactors[8].
- Major and Minor (M&M), which as a first step, separates water (major stream) from organics and nutrients into a concentrated, high-solids, low flow stream (minor stream)[9]. Originally, membrane separation was envisaged, but this has now expanded to the A-stage process (high-rate activated sludge)[10], phototrophic bacteria[11], algae[12] and other fast-growing crops (i.e. duckweed). Nutrients and energy can be recovered from the minor stream by anaerobic digestion in a concentrate stream.

In general, the M&M process now focuses on biological technologies to partition organics and nutrients to the solid phase through a number of biological processes. Most of the partitioning occurs through biological growth (assimilation) and chemical reaction to the solid phase (adsorption). Furthermore, organics and phosphorus (but not nitrogen) can also be biologically partitioned by the formation of specific compounds such as polyhydroxyalkanoates and polyphosphate[13].

This class of innovative technologies includes emerging water treatment technologies that enable resource recovery (e.g. low energy mainline treatment requires nitrogen removal via the anammox process in the mainline water circuit)[14]. It also contains a suite of technologies that are repurposed from existing technologies. None of these technologies is currently market ready, with commercialisation timeframes ranging from 5 years (LEM) to 20 years (phototrophic systems and algae). Further analysis of market readiness is provided in Chapter 8 of this report. All technologies are impacted by legislative barriers and opportunities as identified in Chapter 5.

Embryonic technologies

‘Generation 3’ technologies (‘embryonic’) focus on addressing the requirement for a new resource recovery product approach. Review of these embryonic technologies has been undertaken independently by a number of experts in the field and reviewed partially in Batstone *et al.* (2015)[15]. These technologies include the biorefinery concept[16] which looks at generating a range of non-energy products from wastewater. This platform requires significant market development and has higher uncertainty in terms of technology readiness, capital costs and market acceptance of products. However, it may be the only option that really enables wastewater treatment to be viewed as a profit centre due to generation of increased cash flow through high value added products.

There are also ‘embryonic’ technologies for concentration or recovery of dilute compounds in wastewater. These are focused on key technologies that enable recovery of specific elements and/or compounds, and occasionally classes of compounds from wastewater or specific wastewater streams (e.g. mainly biosolids and sidestream concentrates). These technologies mainly focus on microbial, enzymatic, or chemical oxidation or reduction of chemicals (often in the presence of a counter ion) to induce a phase change. Key examples include:

- microbial oxidation/reduction by specialised microbes to induce precipitation of rare metals, including gold, uranium and cadmium[17];
- oxidative/reductive metals recovery through electrochemical methods, mainly electroplating. This technology is very well established but normally marginally economic from dilute streams owing to

low conductivity[18];

- sulphur recovery from many streams, including gas, salty waters (including seawater), and industrial wastewaters through oxidation-reduction cycling (this may include (bio) electrochemical oxidation reduction and generation of alternatives such as polysulfide[18]); and
- metals recovery mainly from sludge (where it exists as a precipitate) by sequential solubilisation, mainly by acid, but also enzymes and other chemicals (e.g., free nitrous acid). This has the primary goal of removing sludge contaminant and reducing volume and improving sludge dewaterability but also enables metals recovery[19].

There is also a set of embryonic technologies that focus on 'decentralisation' or 'source separation'. This includes technologies that focus on higher strength industrial streams, but also includes the possibility of capturing key nutrients through urine separation and collection. There are cases where small full-scale installations of urine separation have been achieved, including several 'sustainable' housing developments in Germany and Scandinavia. The main issue with this embryonic technology is how to collect and process the urine to recover the valuable components at minimal cost.

Key products

The key products that could be supplied from resource recovery from wastewater can be split into the major groups that are, or could be generated from 'established', 'innovative', or 'embryonic' technologies. A product summary is shown in Table 3. As this qualitatively demonstrates, there is a very broad range of products that can potentially be generated at different time scales into the future. Supporting material for Table 3 and Figure 3 is provided in Appendix 5.

Tables A5.1 and A5.2 in Appendix 5 provide a detailed summary of the various products that could be obtained by resource recovery. The tables summarise the salient features of the products, as well as their production rates per person, value, costs of generation and the range of issues associated with them.

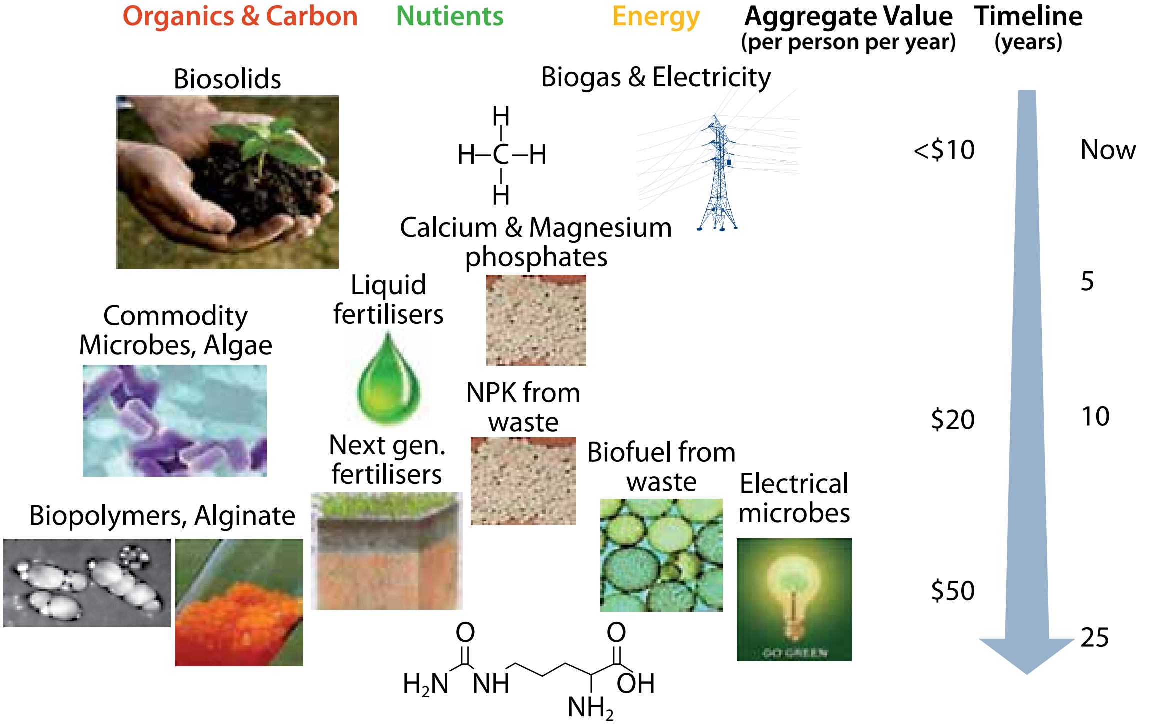
Table 3 Value and potential generation of the various resource recovery products

Established	Product variants	Prod/(EP.D)	Value (A$)	Value/(EP.Y)	Cost of generation	Cost of use	Issues
Biosolids (wet) agricultural	Compost	400g	$10/tonne	$1	NIL	$30-$70/t	Nitrogen limiting application rate. Metal contaminants. Microbial contaminants
Biosolids (dry) agricultural	None	50g	$80/tonne	$1	10 GJ/tonne	$30-$50/t	Nitrogen limiting application rate. Metal contaminants. Dust issues
Energy (biogas from sludge digestion)	Electricity, biomethane (fuel, grid) includes co-digestion or enhanced anaerobic digestion	0.04-0.1+ kWh	$16/kWh	$3	$0.015/kWh	negligible	Feed in contract. Co-digestion or enhanced anaerobic digestion, can double energy output from comparable infrastructure

Energy (biogas from low energy sewage treatment)	Electricity biomethane (fuel, grid)	0.15-0.4 kWh	\$16/kWh	\$9	\$0.015/kWh	negligible	Feed in contract/gas grid compatibility
Phosphate products (recovered from sidestream)	Struvite, $CaPO_4$, $MgPO_4$	0.5g P=5g product	\$3/kg P	\$0.5	\$1/kg P	negligible	Specialised market
Innovative							
Phosphate products (recovered from mainline)	Struvite, $CaPO_4$, $MgPO_4$, H_3PO_4	2g P = 20g product	\$3/kg P	\$2	\$1/kg P	negligible	Limited market
Ammonium products (sidestream and mainline)	Liquid fertilisers NH_4Cl, NH_4SO_4, $(NH_4)_3PO_4$ NH_3	3-10g N	\$0.8/kg N	\$2	\$0-\$1/kg N	negligible - \$0.2/kg N	Concentrates require local market
Embryonic							
Next generation fertilisers	Microbial products, high-nitrogen organics	10gN, 2gP	Increased effect	\$10	medium	low	Needs enabling science to identify products
Commodity inorganic chemicals (H_2O_2, S, Cl_2 etc.)	Peroxide. sulfur, chlorine, metals, caustic	Varies	Varies	-	high	low	Needs extensive downstream processing and new technologies.
Microbial products	Algae, chemotrophs, phototrophs	100g	\$0.2/kg	\$10	medium	unknown	Market needed. May enable manufacture of by-products etc
Biofuels	Algae derived, chemical derived, all fuels	100g+	\$1/kg	\$40	high	medium	Requires algal reactors or biorefinery to generate oils from heterotrophic growth
Commodity organic chemicals	Organic acids, alcohols	100g	\$0.5/kg	\$20	high	low	Extraction/ downstream processing expensive
Biopolymers	Polyhydroxya-lkanoates alginate	20-50g	\$1-\$3/kg	\$20-\$40	high	high	Extraction/ downstream processing expensive
Speciality chemicals	Vitamins, caproate, propandiol, etc.	-	\$10-\$100/kg	-	very high	very high	

EP.Y = Equivalent persons/year
EP.D = Equivalent persons/day

Figure 3 Products and their associated value that could be developed utilising wastewater resources over time.



For this report, the terms 'established', 'innovative' and 'embryonic' have not been extended to resource recovery products. Rather, the products are described in terms of the technologies that produce them.

One key attribute of the possible products from these tables is their value ($/tonne). Figure 4 shows the value of the products on a log scale, varying from $8/tonne for wet biosolids to in excess of $10,000/tonne for specialty chemicals. As shown in Table A4.1 in Appendix 4, the lower value products are from the 'established' technology category, while the higher value products are from the 'embryonic' technology category.

Products from established technologies

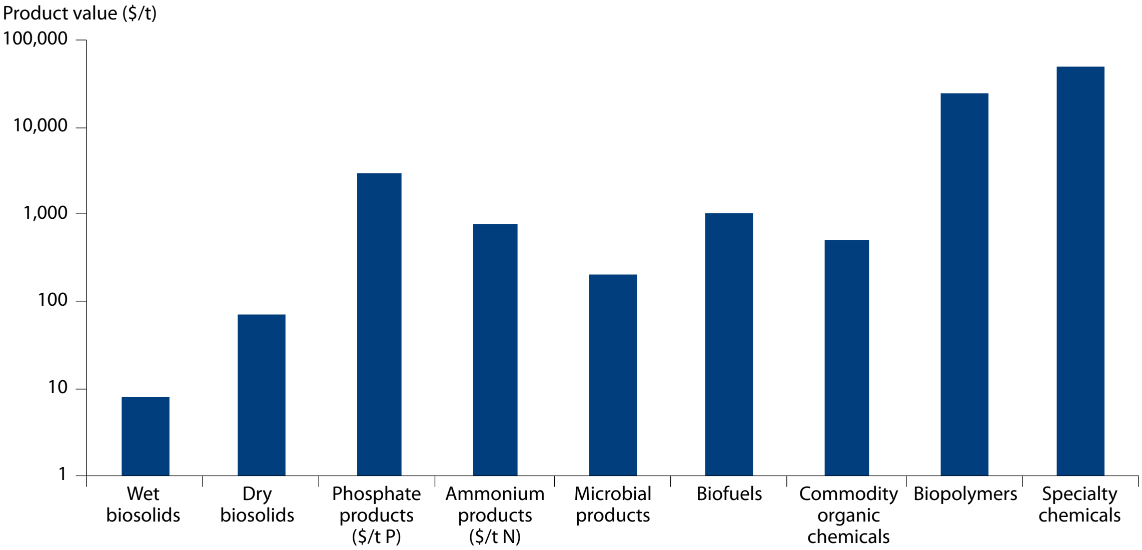
Excluding recycled water, WWTPs generate a number of resource streams, including electrical and heat energy generated from methane, biosolids which are used as an agricultural additive (i.e. nitrogen and phosphorus), and mineral phosphorus concentrates, mainly recovered from sidestream processes. Mineral phosphorus can be recovered in a variety of forms, but is mainly recovered as struvite and calcium phosphates. Ammonia is generally not recovered from the sidestream due to unfavourable economics.

Energy

Energy is generally produced as methane through anaerobic digestion, mainly applied only to sludge (concentrate) streams in existing processes. It is a well-established technology with several technology suppliers. This facilitates nutrient release from the biomass, with nitrogen converting to ammonium (NH_4^+) and the phosphorus converting to soluble forms. Digestion facilitates recovery from the decant water (sidestream) and the sludge (biosolids) to resource recovery products. The biogas contains around 60% methane and can be used directly for power generation in reciprocating engines or small gas turbines at an electrical efficiency of 40%, or upgraded for vehicle and grid use. Waste heat from the engines is also utilised to heat the digesters ('combined heat and power').

The overall production amount of biogas can be improved through the addition of waste foods or organic compounds in the anaerobic digesters ('co-digestion')[20]. In the best cases, this has led to self-sufficiency

Figure 4 Value of resource recovery products.



in energy for WWTPs (see case study on co-digestion). Without co-digestion, self-sufficiency normally requires application of high energy efficiency emerging technologies[21]. There is an increasing trend to utilise co-digestion technology as energy prices increase. The financial case for anaerobic digestion depends on the price of purchased power for the utility and is therefore likely to be improved by the scale of the operation and purchasing power of the utility (negotiated electricity prices are generally confidential). It is also a necessary 'release' precursor to generate products such as struvite.

Innovative technologies such as direct carbon fuel cells which could achieve energy efficiencies approaching 100% could also be employed for power generation in the future. Very embryonic technologies, such as electroactive bacteria (microbial fuel cells) could enable direct electricity recovery from sewage without the methane intermediate[22]. However, the cost of equipment makes this a very marginal proposition unless the cost of materials drops by several orders of magnitude. For this reason, there is now a far greater focus on using electroactive bacteria to generate organic and commodity chemicals such as organic acids, ethanol, hydrogen peroxide, and sodium hydroxide, even at the cost of energy input[2].

Industry representatives have commented that cogeneration has been relatively problematic to date in Australia. The biogas quality is low, and maintenance costs are therefore high. Biogas power generator reciprocating engines are typically large, with viable outcomes in terms of maintenance costs at sizes above 1MW. This situation is improving as design improves.

Twenty years ago, typical small engines were converted diesel stationary engines (e.g. at BerryBank farm near Ballarat). These required new fuel feed mechanisms to run on gas, but the engine block and piston materials were not suited to the potentially corrosive biogas. With current biogas feeds, typically a complete engine overhaul is undertaken every 5 years with comparable costs to a new engine. Sulphides need scrubbing, though new methods such as direct digester air or oxygen injection offer lower costs[23]. Smaller engines are still typically multipurpose – combined biogas/natural gas engines rather than dedicated biogas engines. Opportunities for refinement with smaller-scale micro turbines are becoming available for smaller scale applications and are not subject to sulphide wear. However, turbines are subject to development of siloxanes which will build up on blades and eventually ruin an engine – a particular problem on sewage which has high levels due to cosmetic products. Biogas cleaning for removal of contaminants is improving in both cost and efficiency.

There is increasing interest in co-digestion within Australia, which is the addition of other wastes (food waste, oils, fats, sugars) to the anaerobic digester feed. This interest is driven by the maximisation of biogas production to replace purchased energy. For example, Sydney Water is actively dosing glycerol at one plant and also investigating other feed stocks. Queensland Urban Utilities is investigating using glycerol and other organic waste (i.e. food waste, sugary syrup waste, etc.) to provide energy in peak periods. Melbourne Water is investigating different types of organic waste to generate more biogas in their anaerobic lagoon. Co-digestion with bulk food waste requires pre-treatment prior to digestion (generally maceration or assisted hydrolysis) to improve microbial destruction and rheological consistency).

There are many waste pre-treatment technologies available and working satisfactorily in Europe and the USA. No plants in Australia currently have pre-treatment processes for food waste co-digestion. However, methods for improving wastewater sludge destruction such as thermal hydrolysis are being used at full-scale at Oxley Creek (QLD) and trials have been undertaken using ultrasonics and dual stage digestion in order to gain methane production increases and reduced solids production. Yarra Valley Water is constructing a facility ('Aurora') that will process waste streams in a co-digester and this could be the first facility of this type in Australia. Other methods to increase biogas production that are being considered include pre-treatment of Waste Activated Sludge (WAS) prior to digestion, with thermal hydrolysis generally offering the highest performance[24] (at a relatively high cost).

Biosolids

Biosolids are the carbonaceous microbial material left in the sludge after wastewater treatment. They can be stored, placed on land as a low nutrient fertiliser, or further processed to a retail product (see case studies on Milwaukee Metropolitan Sewerage District's 'Milorganite' and Barwon Water's Bioprill®). The majority of Australian biosolids are currently used for agriculture purposes. Issues relating to biosolids include: odour; pathogen and heavy metal content; and nutrient run-off from land into natural watersheds. Indeed, in Germany, the application of biosolids to land has been banned (it must be incinerated), and in the United States, the land application of biosolids is heavily regulated. For example, it is effectively banned in some counties in California; whereas others only allow the land application of biosolids at certain times of the year. In Wisconsin stringent phosphorus limits have been placed on biosolids used for agriculture. This has proved to be a driver for struvite production from WWTPs in order to lower both the sludge volume and its phosphorus content.

Dosing of wastewater with aluminium or iron-based chemicals, employed to lower phosphorus in the effluent via flocculation, increases sludge biosolids. This process involves relatively low capital cost, but high operating cost. It forms the basis of 'Milorganite', where the bagged fertiliser is marketed as 'high iron that promotes greening' due to its iron dosing. However, chemical dosing increases the salinity of the effluent and increases the sludge volume. Metal concentrations in the sludge are also higher, and the resulting material is agronomically less useful, having lower bioavailability of nutrients.

Thermal hydrolysis

The Working Group discussed thermal treatment of sludge with Sydney Water[25] and has extensive experience with its implementation in Brisbane at Oxley Creek[4]. Thermal hydrolysis of sludge can reduce biosolids volume substantially, and improves dewaterability, which in turn reduces costs for transport of sludge for land application or storage (by up to 80%). Additionally, more biogas can also be produced. Thermal hydrolysis enables Grade A biosolids production, but this has a limited financial impact as capital costs are relatively high and the process requires pressure reaction vessels and production of steam via a boiler. As such, the process overall is generally competitive financially with standard anaerobic digestion[4].

Sidestream nutrients (phosphorus)

There has been extensive work in recent years to enable recovery of struvite (magnesium ammonium phosphate) from sidestreams. Struvite is produced from processing the decant water from anaerobic digestion using magnesium salts (e.g. magnesium chloride) in proprietary reactors provided by equipment suppliers (see Ostara case study). This is now an established technology.

Struvite is a slow release fertiliser with application in turf, specialty horticulture and nursery applications. It has also been blended with other inorganic fertilisers for the retail market. In the case of one technology supplier, Ostara, the struvite product is purchased from the wastewater facility and marketed by Ostara. In this case, the WWTP operator does not need in-house marketing skills to promote the product.

Calcium phosphate is an alternative sidestream product that will generally result in reduced phosphorus capture efficiency, but with a possibly more usable product (calcium phosphate can be more plant available), and with a lower capital cost. Recovery from the sidestream only enables approximately 25 to 30% of the influent phosphorus to be recovered as a mineral precipitate (i.e. 0.5g P per person per day).

Products from innovative technologies

Emerging processes enable improved recovery of energy, nitrogen and phosphorus from both improved partitioning to the sidestream, and possibly direct recovery (e.g. by adsorption) from the mainline. Therefore, they mainly produce larger amounts of the same energy (biogas), and fertiliser chemicals (phosphates and nitrogen compounds), but allow increased recovery. In this way up to four times as much energy and nutrients can be recovered through these emerging processes.

Nitrogen products

- nitrogen can be recovered via the ammonia being separated in its gaseous form via air-stripping or through gas-permeable membranes;
- electrochemical methods to remove ammonium through cation-selective membranes are also embryonic and in the R&D phase; and
- recovery of nitrogen products is currently uneconomic in both mainline and sidestream due to the relatively high costs of ammonia stripping and recovery (see also the analysis of ammonia stripping for ammonium sulphate in Chapter 7)[26].

Mainline phosphorus products

- these can be recovered from 'enhanced sidestream' processes or via adsorption in the mainline[27];
- the resulting products are struvite or calcium phosphate; and
- recovery from the mainline enables up to 2g P per person per day.

Products from embryonic technologies

Emerging technologies that are currently at the laboratory R&D stage can enable the manufacture of value-added products from the raw materials present in wastewater. These may include generation of biofuels and biohydrogen, production of animal feeds from algae and phototrophic bacteria, and the production of bulk speciality chemicals such as bioplastics (PHA), alginate, and chemicals such as hydrogen peroxide or caustic. Gas-permeable membranes to recover ammonia are also embryonic technologies in the R&D phase. This range of technologies enables high-value products, but may require extensive market or process development.

CHAPTER 3: THE ENERGY AND FERTILISER INDUSTRIES

The energy industry

The production and savings of energy represent key options for resource recovery. Co-digestion of organic wastes with sewage can lead to greater than 100% electrical energy self-sufficiency from biogas cogeneration and provide export of renewable electrical energy to the grid. Similarly, low energy treatment of sewage using new technologies and processes will enable increased biogas production in the future, coupled with low electricity consumption. This Chapter briefly examines the global situation, especially in relation to natural gas. This is followed by brief consideration of the current energy supply-demand situation in Australia for both gas and electricity.

Global

Cook *et al.* (2013)[28] considered the global and Australian gas supply situation in a report on unconventional gas prepared by the Australian Council of Learned Academies (ACOLA). The report noted that 21% of the global energy mix is accounted for by natural gas. Moreover, world gas reserves are estimated to meet demand for 230 years at current production rates. One of the principal drivers of gas demand is in the electrical power generation sector, which is expected to grow globally at a rate of 1.6% annually, increasing by 50% by 2035.

Cook *et al.* noted that the largest global consumers of natural gas are the United States (21%), Russia (14%), Iran (4%) and China (3%). Asia accounts for almost 50% of the projected future growth in natural gas consumption, driven mainly by the urbanisation of China. Another key feature of the global gas market is the growth of North American unconventional (or shale) gas. This supply-side development may also involve Australia and China in the future, since these three countries are the three largest holders of unexploited unconventional gas reserves. However, global natural gas production will still continue to be dominated by conventional sources in the Middle East and Eurasia.

The global liquefied natural gas (LNG) trade will have a significant effect on gas availability and prices in Australia. Cook *et al.* noted that Japanese prices of LNG exported to Japan were in the range $US14 to $US16/GJ in 2013. Within 20 years, inter-regional trade in LNG is expected to increase by 80%. Abundant supplies of shale gas in North America have removed the anticipated need to import LNG into the USA which has caused the hub price in the USA to fall from $US12/GJ in 2008 to below $US4/GJ in 2012. Expected gas prices in the USA are expected to remain lower than in Asia in the near-term and therefore there is growing interest in exporting LNG-priced gas from the USA to Asia with a high netback price margin.

Australia – Gas

Coal accounts for 75% of total energy produced in Australia, although natural gas production is growing at a faster rate than coal (see below).Crude oil production has shrunk and is expected to decline further.

Cook *et al.* provided an analysis of the Australian natural gas situation and prospects as well as an economic analysis of unconventional gas production in Australia. It was reported there are 11 trillion m^3 of total identified gas resources in Australia and 788 billion m^3 of proven resources. Gas production in Australia has more than trebled since 1973, and increased by about 50% in the last decade. Once new

LNG projects are in full operation, Australia's LNG export capacity is expected to more than treble to 80 Mt/year. This will make Australia the world's largest exporter of LNG by 2020.

Domestically, over the last decade Australia's gas consumption has increased by 4% per year to a total of about 1,000 PJ/year (1 PJ = 10^{15} J = 10^{6} GJ)[29]. In 2009-10, gas constituted 23% of primary energy consumption and 15% of electricity generation in Australia[30]. By comparison, the ultimate potential biogas production from sewage is estimated to be around 12 PJ/year, a small proportion of overall consumption (see Table 3 in Chapter 2).

From 2014-15, the LNG trains at Gladstone in Queensland have begun to come on stream. When these are at full capacity they are expected to export gas at double the rate of domestic consumption[29]. Low-priced domestic gas contracts in Australia either expired in the last six years or are due to expire in the next three[28]. These existing contracts have a gas price of around $4/GJ in the eastern markets. The fact that the contracts are almost due for renewal and that export-focussed LNG plants are due to commence operation soon will have important ramifications for future domestic gas prices. Wholesale gas prices in the eastern states are expected to converge on export netback price (netback price is equal to the export price in the customer country, less shipping and processing costs) over time. This is projected to give rise to real gas prices of $11 to $12/GJ in Queensland, NSW and Victoria by 2030, with the increase mainly occurring in the early years[30, 31].

The use of natural gas in electricity generation is expected to decrease in the short to medium term as a result of higher gas prices. In the longer term this could reverse as coal fired power stations are retired. This will depend on relative gas prices and capital costs of both gas and coal fired power plants, as well as government policy on CO_2 emissions.

Australia – Electricity

The Energy Supply Association of Australia (ESAA)[29] has noted that overall generation of electricity fell for a fifth consecutive year across Australia in 2013-14, although wind energy recorded an approximately 2,000 GWh increase and solar photovoltaic (PV) also had a noticeable increase. This was balanced by a significant fall in coal-based generation. Although black coal fell by around 5,000 GWh and brown coal fell by around 1,500 GWh, coal maintained its large overall share of total generation in Australia.

ESAA also noted that the Australian electricity market is enduring a challenging period of transformation and uncertainty from multiple factors. In summary, some of the key points driving the uncertainties in the electricity market are:

- steep price increases;
- falling demand and wholesale prices;
- greenhouse gas policy uncertainty;
- high renewables penetration, including solar PV; and
- oversupply.

Retail prices of electricity have increased by between 70% and 100% over the past five years while wholesale prices have fallen since 2009. Wastewater treatment plants pay for electricity closer to the retail price, while export electricity prices from WWTPs are likely to be closer to the wholesale price[32]. The retail price increases have been driven primarily by network costs while the lower wholesale prices have been driven by lower aggregate electricity demand. This has been driven by de-industrialisation of the economy, increased energy efficiency and increases in domestic solar PV installation.

More than 14% (1.3 million) of Australian households have now installed rooftop solar PV systems. In outer suburbs of cities like Brisbane, the penetration is around 40%. Renewable penetration in response to government incentive schemes (mainly wind) has meant parts of the network are starting to see renewable penetration to over 30%, resulting in concerns for transmission system stability and security[29].

Policy uncertainty has been increased by the current Direct Action Scheme replacing a price of $23/t CO_2e under the previous Government. A CO_2e price raises the wholesale and retail prices of electricity therefore it will be an important consideration for investors in resource recovery if it is re-introduced.

Australian electricity consumption rose steadily from 1995 to 2004 to about 9,600 kWh/capita. However, since 2004 consumption has fallen to about 8,400 kWh/capita. Per unit of gross domestic product (GDP), consumption has also fallen steadily since 1995 from an index of 100 to approximately 75 at present (a 25% reduction). The combination of falling demand, penetration of renewables and political uncertainty has resulted in the wholesale electricity market being now oversupplied by around 10GW (or 20% of capacity).

Volume Weighted Average (VWA) electricity prices across the National Energy Market (NEM) dropped 10.7% in 2013-14. In the three year period from 2008 to 2011, prices dropped 9.3%, 22.9% and 11.5% respectively, leading to a wholesale VWA price reduction from $49.39/MWh to $30.57/MWh (38% reduction) over that period[29]. This is in distinct contrast to retail electricity prices, which as mentioned earlier, have risen appreciably over the last five years (70 to 100% increase). Resource recovery projects can involve both the saving and production of energy and the financial outcomes of investments are highly dependent on the prices charged and received for electricity (see Chapter 8). The current transformation and uncertainty of the Australian electricity industry could therefore have an important influence on future resource recovery investments.

Energy generation in the form of either biogas or cogenerated electricity is incentivised by the Federal Government's renewable energy schemes. The Renewable Energy Target (RET) has been the subject of political uncertainty recently, but agreement has now been reached on a target of 33,000 GWh per year of renewable energy by 2030. Market tradable Large-Scale Renewable Generation Certificates (LGCs or RECs) are applicable for renewable energy generated from WWTPs. In 2014-15 these certificates varied in price between $24/MWh (June 2014) to $50.30/MWh (May 2015). Prior to this the LGC price was about $35/MWh. The recent increase in price could be related to greater certainty about recent political agreement on the RET. Despite their volatility, LGCs represent a useful revenue stream for renewable energy generation from resource recovery.

In summary, the energy scene in Australia is highly uncertain for both gas and electricity. It is presently undergoing transformation and outcomes are inherently unclear. An investor in resource recovery of energy will, under these conditions, need to consider a large range of possibilities for revenue streams from the investment and incorporate energy price volatility into their strategic analyses.

The fertiliser industry

The fertiliser industry is a potential customer of, as well as a competitor, to fertiliser products generated from wastewater resource recovery. This brief summary has been prepared and included in this context.

Global perspective

Nutrients, such as nitrogen and phosphorus, are essential for plant growth, food production, and ultimately adequate nutrition for humans. The application of nutrients using fertilisers goes back to ancient civilizations where the Romans were already ploughing in animal manure to enhance the productivity of their crops. However, the commercial production of synthetic fertilisers is a relatively new practice, only increasing significantly after the Second World War.

Since the 1960's, human use of synthetic nitrogen fertilisers has increased nine-fold globally, while phosphorus use has tripled. It is estimated that about half of the world's population now relies on mineral fertilisers for food.

Growth in fertiliser demand is closely linked to world economic growth. The world is likely to grow economically at 4% annually in the medium term, with an average of 2% growth in developed economies and 5% growth in emerging economies. The second largest agricultural crop of all time is in prospect for 2014-15, and this drives the demand for fertilisers. The 800% phosphate price spike in 2008 demonstrated the vulnerability of the global and Australian food system to even a short-term disruption in supply[36]. Significant numbers of farmers suffered, crop yields were compromised and food insecurity increased. In Australia, a Senate Inquiry investigated the potential presence of oligopolies and hoarding that led to short-term phosphate scarcity in this country.

World fertiliser demand rebounded strongly in 2013-14. There was a 3.1% year-on-year growth to give a total of 184 Mt of nutrients[1]. It is expected that demand for these nutrients will climb to 200 Mt/year by 2018-19. On the supply side, the world fertiliser industry is operating at approximately 80% of capacity[37].

Nitrogen: Large plant capacity increases are occurring in East Asia and Africa with 16% growth expected between now and 2018, to 245 Mt/year of NH_3. There is a projected oversupply of 9% compared to demand by this time. This is occurring in countries such as China, Indonesia, Algeria, Egypt, Nigeria, Saudi Arabia, Iran, Bahrain, Venezuela and Brazil. The price of synthetic nitrogenous fertilisers is strongly correlated with the price of natural gas. It is for this reason that production facilities are located close to low cost natural gas supplies.

Phosphorus: Morocco, China and Middle East countries supply 62% of the global raw phosphate rock supply (containing approximately 10% P) with supply expected to grow to 258 Mt/year by 2018[38]. The current (2014) global elemental phosphorous market is 19 Mt P/year. Australia imports 80,000 tonnes per year of phosphorus to replenish naturally phosphorus-deficient soils and support a phosphorus-intensive agricultural and livestock export sector[39]. These sectors are heavily dependent on phosphate fertilisers from both domestic and imported sources and Australia is the world's fifth largest consumer of phosphate fertilisers.

Almost 100% of the phosphorus consumed in food is excreted, meaning that a total of 3 Mt/year of phosphorus is excreted globally[2] (16% of the global P consumption market). By diversifying sources of phosphorus away from imported phosphate rock, Australia can buffer against a range of supply-chain risks and increase resilience in terms of agricultural productivity, food security, ecological integrity of waterways and farmer livelihoods[40]. While Australia exports much of its phosphorus embodied in agricultural exports, phosphorus can be recovered from all pre- and post-farm gate sources, including crop waste, manure, food waste, other green waste, wastewater and excreta. While the quantity of phosphorus available in wastewater is far less than Australia's total phosphorus demand, another opportunity is evident at the urban scale. With 90% of Australians living in coastal cities, cities have become 'phosphorus hotspots'[39]. Indeed, the Sydney Basin has an excess of phosphorus due to wastewater, food waste and poultry manure[41]. This concentration of phosphorus not only creates a pollution risk, but an opportunity for efficient and cost-effective recovery for reuse as renewable fertilisers in and around the Sydney Basin. There is a whole 'toolbox' of technologies and options for phosphorus recovery. It is therefore important to take an approach that considers: (i) the state of existing infrastructure and logistics, (ii) the actual phosphorus flows and fates, (iii) current pressures, and (iv) local opportunities and drivers.

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[1] Components are N = 112 Mt, P2O5 = 42 Mt and K2O = 30 Mt.

[2] The global P market is 19 Mt/year, while the phosphate rock market is approximately ten times this amount since the P content of phosphate rock is approximately 10%.

Recent United States Geological Survey estimates of phosphate rock resources are very large (300,000 M ton)[33], implying that supplies of phosphorus for fertiliser manufacture are unlikely to be affected by lack of raw material in the next 25, or even 100, years.

Geopolitical risks and human rights, however, complicate the availability of phosphorus rock, and a potential investor in resource recovery may wish to take these into account. Geopolitical risks associated with the supply concentrations of phosphate producers, carries perhaps the greatest consequences for the phosphorus supply-chain. Morocco holds the majority of global phosphate reserves, with other major reserves located in Iraq, China, Algeria, Syria, South Africa, the USA and Russia[33]. So few producers of a globally critical resource, many in potentially politically unstable regions, creates a serious risk of disruption to supply and price fluctuations[34].

Further, Morocco's control over the contested territory of Western Sahara, including its significant phosphate reserves, creates not only a supply disruption risk, but also a human-rights risk associated with the exploitation and displacement of the Saharawi people of Western Sahara, and a reputational risk for Australian phosphate companies importing phosphate from the region. This trade means that not only phosphate companies, but also agri-businesses, farmers and food consumers are knowingly or unknowingly supporting a conflict in Western Sahara that is condemned by the United Nations (UN). Many of Scandinavia's largest pension funds and banks have divested from companies, including Australian phosphate companies such as Incitec Pivot Limited, that import phosphate from the conflict region of the Western Sahara[35].

Potassium: Global potassium supply is expected to increase 21% to 51.4 Mt of K_2O in 2018, leading to a significant oversupply of 26%. Potassium-producing countries are Canada, Russia and China.

Sulphur: Global sulphur supply is expected to increase 31% to 73 Mt/year of sulphur in 2018. Sulphur is mainly supplied by the oil and gas sectors, and is expected to be in near supply-demand equilibrium by 2018.

European perspective

High-cost natural gas is an ongoing challenge for Europe, with high feedstock costs continuing to have a major impact on producer profitability. Gas is a source of energy for production, but also serves as raw material to produce nitrogen-based fertilisers.

In Europe, there has been a 50% reduction in phosphorus discharge from WWTPs between 1995 and 2010, partially due to the European Union Urban Waste Water Treatment Directive (UWWTD) and the Water Framework Directive that limits the amount of phosphorus that water companies are allowed to discharge to the environment. There has also been a widespread ban on phosphorus in detergents implemented in Europe between the 1980s and around 2000, and this has typically reduced the wastewater P load to around 50% of previous levels. This reduction is not unique to Europe and many WWTPs worldwide have reduced the level of phosphorus they discharge. About 20% of the imported phosphorus in Europe ends up in wastewater, and it is believed to be both productive and sustainable to recover this phosphorus from the wastewater.

In the European Union (EU), regulation is a strong driver for nutrient recovery. For example, The Netherlands are at the forefront of policy and regulatory reform to drive greater recovery, and there is cooperation between industry, science and policymakers in the Dutch Nutrient Platform (established 2008). Revisions to the EU Fertiliser Regulation 2003/2003 are under discussion. To facilitate placing considerably more organic products containing recycled nutrients and inorganic recovered phosphate products on the Internal Market for transport and sale across the EU, quality and safety compliance regarding component requirements is essential. There was a proposal to widen the EU Fertiliser Regulation that was welcomed by stakeholders at a meeting organised by The European Sustainable Phosphorus Platform (ESPP) and Fertilisers Europe in 2014[42].

Current fossil phosphorus sources contain a significant amount of the toxic heavy metal cadmium (Cd) that accumulates in soil and enters the food chain. In some countries that extensively use phosphorus fertilisers, Cd levels are now reaching hazardous levels, and it is difficult and expensive to remove. The Fertilisers Europe's Decadmiation Workshop was held in Brussels in 2013 to provide insight to the latest scientific data on Cd levels in European agricultural soils and available 'de-cadmiation' technologies[43]. However, obtaining phosphorus from recycling systems from wastewater generally includes low levels of such contaminants.

There are no financial incentives in the United Kingdom to encourage water companies to recover the phosphate in a form that the agriculture sector can use. However, in other European countries, legislative and regulatory support encourages collaboration between those involved in phosphate removal from waste streams and its recycling to land. ICL Fertilisers in The Netherlands and Germany are using some of the excess phosphate that is currently a problem. The Amsterdam fertiliser plant has made a legal covenant with the Dutch government to use 15% recycled phosphate in the manufacture of fertilisers by 2015 and will aim to use 100% by 2025[44].

In Europe, a recent Consultative Communication published in July 2014 asked EU Member States and the public how best to manage phosphate resources. Currently, any phosphate management is focused on reducing environmental emissions of phosphate rather than recycling. Within Europe, awareness of the need to tackle phosphate problems in a number of ways is being raised by the ESPP[42]. ESPP is working to engage all relevant parties, including mining companies located in Northern Africa.

Recently, in Europe, attention has moved towards "closing the fertiliser loop" through more effective use of on-farm waste and nutrient recycling strategies. These primarily involve recycling crop waste through composting, anaerobic digestion of manure for energy or fuel, and its more efficient use within the overall fertilisation strategy.

An Australian industry perspective – Incitec Pivot Fertilisers

An interview was held with the Technical and Development Manager of Incitec Pivot Fertilisers[45] to understand the potential value of resource recovery products to this major fertiliser producer in Australia.

Incitec Pivot supplies 36% of the fertiliser market in Australia. Although phosphorus is the primary target for fertiliser products from wastewater resource recovery at this point in time, nitrogen has the largest fertiliser demand in Australia. Australia has a relatively low demand for potash-based fertilisers. Overall, demand for fertilisers in Australia slowed in the years after the Global Financial Crisis (GFC), but has recently increased to year 2000 levels.

Phosphorus – MAP, DAP and Superphosphate

Australia uses about 400,000 tonnes of elemental phosphorus per year for fertiliser. This is made up of mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP) and superphosphate. Compositions of these fertilisers are given in Appendix 5.

Superphosphate is made by reacting sulphuric acid with mined phosphate, mainly sourced from Christmas Island, Nauru, Vietnam and Morocco for production in Australia. There are four superphosphate plants in Australia.

Roughly 55 to 60% of phosphate fertilisers are used in Australia for broad-acre cropping (wheat, barley, legumes and cotton). Twenty to 25% is used in pastures (beef, sheep and dairy), around 10% is used for sugar cane, while 15% is used for horticulture (trees and vines, vegetables and flowers). The application of phosphorus is seasonal, and most is consumed for winter cropping (April to June) during the sowing period. A smaller amount is used for summer crops (September to November) such as cotton and sorghum. In some years, 60% of the crops are 'dry sown' before rain.

Incitec Pivot export Australian manufactured MAP and DAP from August to December. This is to maintain production and to prevent quality deterioration, avoid storage problems and to minimise working capital associated with storage of fertilisers. They also import these phosphate fertilisers in sowing season to meet supply. There are a number of key product criteria for MAP and DAP fertilisers:

Sizing: The size distribution of the fertiliser must be consistent to enable sowing by the farmer using mechanised equipment. A 'size guide number' is used to specify sizing, with a desirable value for this parameter being between 3.2 to 3.8mm.

Hardness: The fertiliser must meet a 'crush strength test' in order to survive the worm drives and rollers in the farmer's equipment. The crush strength must be greater than 5kgf/m^2 ('5 kg').

Moisture absorption: The fertiliser must have a parameter termed 'critical relative humidity (CRH)', which is a measure of the way that the fertiliser takes on water and becomes 'gummy'. MAP and DAP have values of 70 and 60 respectively for this parameter, which are high on the scale. Blending with urea for example, can change the CRH.

The above specifications are relevant to an investor considering investment in the production of a bulk fertiliser product from wastewater.

Nitrogen – urea

Eighty percent of nitrogen in Australia is supplied through urea ($CO(NH_2)_2$). This amounts to 1.4 Mt/year elemental N or 2.5 Mt/year urea. It is manufactured in the Brisbane Incitec Pivot facility where 300 kt/year of ammonia, 280 kt/year of urea and 200 kt/year of ammonium sulphate are produced. The balance of Australia's requirement of urea is imported (2.2 Mt/year). Urea is used in all farming - cropping, sugar cane, dairy and horticultural. The fertilisers that are higher in nitrogen are applied close to planting and then used as top dressings while the crop is growing. For pastures (e.g. for dairy cows), the fertilisers may be applied every month. Urea is relatively low cost and any nitrogen-based resource recovery products would need to compete with this product.

Potassium

Potash, in the form of muriate of potash or sulphate of potash, is applied as needed. This may be through standard programs or governed by soil and plant tissue testing. It is usually applied to pastures, horticulture and for sugar cane, and is more applicable to sandy soils such as those in Western Australia.

Resource Recovery Products

Comments were sought from Incitec Pivot on potential resource recovery products, especially struvite. General principles required for fertilisers are:

- Good plant availability of nutrients.
    - related to good fertiliser solubility.
- High nitrogen, potassium and phosphorus analysis.
    - the highest- possible nutrient content delivered to the farmer is required. This is especially

  relevant to Australia where large distances lead to high transportation costs.
- Sizing and hardness.
  - important for farmer fertiliser delivery mechanisms, with no dust formation.

In the context of the above points, the following comments were made about struvite:

- Struvite is a slow rate release fertiliser, requiring an acid soil that is incompatible with the majority of Australian soils. It is also currently very low volume, and marketed in the United States as a high-priced product ($7.50/kg P) to the horticultural market. This would be the most advantageous market in Australia also, with a market size of 50,000-100,000 t/year. The magnesium content has limited value, possibly in citrus, dairy, and sugar cane.
- Struvite is not seen by Incitec Pivot as a product they would blend with their commercial products for farming in Australia; it does not fit with their large-scale, fast-release fertiliser business model.
- As in the United States, struvite may find application in Australia in consumer markets as a sustainable product sold through retail networks at a high price margin.

Regulatory issues

The fertiliser industry is not strongly regulated in Australia. However, there is generally a disconnect between 'waste' and 'fertilisers' in regard to regulation. In Victoria, for example, waste materials and their disposal are regulated by the Environmental Protection Agency (EPA), whereas fertilisers are regulated by the Department of Primary Industry[46,47]. The metal content of a fertiliser is important and some metals are valuable as trace elements in fertilisers, while others can be toxic if applied in excess. The entire metal content of waste materials is of concern to the EPA. Contaminants may also exist in fertiliser imports from other countries (such as China). All these aspects would need to be clarified in the event that fertiliser products were made by a WWTP.

Fertiliser prices

The price of fertilisers (in real terms) has been relatively constant over several decades, except for two spikes in the prices associated with global economic instability. The most recent spike was associated with the beginning of the global financial crisis (GFC) that distorted global supply and demand factors for fertiliser[48].

It was noted that fertiliser prices will follow energy prices. This is because fertiliser manufacture is very energy dependent, especially on natural gas. Analysis of future energy prices in Australia is very complex and related to export parity pricing of LNG from Queensland and Western Australia.

New fertiliser plants in Australia also have to face higher construction costs relative to international locations. Incitec Pivot noted that capital costs of new fertiliser plants in Australia could be up to double that of countries like China or even the United States. The regulatory approval costs of Environmental Impact Statements and the like in Australia also significantly contribute to costs. The same arguments would apply to new resource recovery facilities at WWTPs in Australia.

CHAPTER 4: CASE STUDIES OF RESOURCE RECOVERY

A number of international and Australian case studies were undertaken to reveal any key emergent themes that show 'what works and why' for resource recovery. The case studies encompass different countries, different scales of operation and discuss a number of factors that influence the viability of resource recovery, including regulatory requirements and financial aspects. A summary of the key learnings from the case studies is provided at the end of this Chapter.

Case Study 1 – Milwaukee Metropolitan Sewerage District, USA

Milwaukee Metropolitan Sewerage District (MMSD)[49] is a regional government agency providing wastewater treatment and flood mitigation services for 28 municipalities in Wisconsin, USA. It serves 1.1 million people over a 411 square mile (1064 square km) area. MMSD has two major treatment plants in Milwaukee: the Jones Island plant and the South Shore plant.

The MMSD Jones Island Plant processes 333 MGD (1,262 ML/d) of wastewater. It was among the first sewage treatment plants in the United States to succeed in using the activated sludge treatment process and was the first treatment facility to economically dispose of the recovered sludge by producing an organic fertiliser. At this site, 98% of all the sludge produced and imported (all digested sludge from the South Shore plant is sent to the Jones Island plant) is processed to make a biosolids fertiliser, called Milorganite. Milorganite is sold all over the United States as a specialty product. The 1925 plant has been designated as a Historic Civil Engineering Landmark by the American Society of Civil Engineers. The manufacture and sale of a biosolids fertiliser product has therefore been carried out by MMSD for a significant period of time[50].

MMSD sustainability focus

The 2012 sustainability report[51] by MMSD illustrates its focus on the Milwaukee region, its water supplies, and environmental and social responsibility. The 2035 vision of MMSD has two key components: 'Integrated Watershed Management', and 'Climate Change Mitigation'.

MMSD financials

MMSD is not especially profitable (in fact it has made a loss in the last two years). In 2012-13, MMSD had a total revenue of $US195.9M, where $US7.7M came from the sale of Milorganite. Overall, MMSD had a loss of $US 1.4M for that period. Although it is the largest manufacturer of a fertiliser product in the industry, it is not necessarily a pathway to commercial viability. It is also noteworthy that large-scale fertiliser sales are only approximately 10% of MMSD's operating revenue, and less than 4% of its total revenue.

MMSD have contracted out the daily operations of both the Jones Island and the South Shore facilities to a large international French water corporation, Veolia Water, rather than operating the facilities themselves. Veolia Water is charged with achieving operational efficiencies at the two plants, and the contract was for 10 years until 2018.

South Shore Plant

The South Shore plant processes 1,137 ML/d and has 8 anaerobic digesters. These take 2.27 ML/d of input sludge from primary sludge treatment and produce 25,560 m^3/d of digester gas. This is fed to electrical generators that produce 2 MW of power, which is roughly 50% of the power requirements of the South Shore plant.

The South Shore plant has a plan to increase co-digestion. A trial utilising glycol (from airport de-icing) increased power generation by 8% from the digester/generator combination. South Shore has also now added food waste to the digesters and increased power generation by another 5-12%. The cogeneration system is to be upgraded to 56,800 m^3/d gas production to give a power generation of 5.5MW by 2018, enough to power the South Shore site in all weathers and rainfalls.

Emission limits

MMSD has low emission limits on effluent released into Lake Michigan from both its plants.

Jones Island:	Phosphorus < 1.0 mg/L (monthly average), 0.6 mg/L (6 monthly average). BOD < 30mg/L.
South Shore:	Phosphorus < 1.0 mg/L (monthly average). BOD <30 mg/L.

There are also stringent emission limits to river systems at their Nine Springs WWTP at Madison, the lowest in the USA (0.03mg P/L). To assist with reaching such low levels and to reduce costs on chemicals associated with phosphorus removal, the MMSD plant has recently invested in an Ostara Pearl struvite recovery system. The phosphorus removal capability of the Ostara system is around 80 – 90%.

MMSD is under pressure from the communities that they operate in to lower the nutrient content of the water and sludge that it discharges. MMSD appears to be responding to these pressures through its actions and public documents.

Figure 5 Milorganite
($US12.78 for 36 lbs. at 'The Home Depot').

Milorganite product

MMSD makes a processed biosolids product called Milorganite (**MIL**waukee's **ORGA**nic **NIT**rogen)[52]. Milorganite (Figure 5) is made at the Jones Island facility by taking its own sludge, sludge from the secondary classifiers and sludge from the South Shore plant, drying and dewatering it with belt filters and then granulising it in kiln dryers operating at 450°C to 650°C for 40 minutes. The resulting product granules have 5% moisture content. The 2013 MMSD Annual Report states that the price received for this product was $US21.74/ton and about 45,000 tons (40,800 tonnes) was produced during that year. Approximately 4M tonnes of Milorganite has been produced since 1926.

The Milorganite MSDS shows the following composition[53]:

Biosolids (dried microbes)	86.8 – 90.8%
Iron Chloride	1 – 3% Fe
Iron Sulphate	1 – 3% Fe
Water	4 – 8%
Calcium Carbonate	1.2%
Trace Metals and Organics	<1%

Meets US EPA 40 CFR Part 503 Class A Exceptional Quality Biosolid requirements.

Milorganite is a 5-2-0 fertiliser, containing 5% N, 2% P_2O_5 and zero potassium. Milorganite is heavily marketed by MMSD to the retail trade. Milorganite is marketed as an 'eco-friendly' product and appears to be mainly bagged for small boutique, retail and turf markets, and is available globally online.

Case Study 2 – Ostara and its Partners in Canada, USA and UK

Ostara is a clean-technology company that has developed a water fluidized bed process to produce millimetre scale solid prills of struvite (magnesium ammonium phosphate) from decant water following anaerobic digestion of wastewater sludge. The process removes phosphorus and nitrogen from the wastewater circuit in treatment plants and produces a slow release fertiliser for sale as a revenue stream. The fluidized bed reactor is called 'Pearl®' and product struvite is termed 'Crystal Green®'.

In 2014, Ostara was named in the 'Global Cleantech 100' for the 6th year in a row.

History

The Ostara process was developed in British Columbia (BC), Canada. It was driven by British Columbia Hydro, who requested that the University of British Columbia (UBC) Environmental Studies Department develop a fertiliser to rehabilitate areas around hydroelectric dams. At this time, the Department of Fisheries and Oceans in BC were buying fertiliser to add to rivers to repair salmon habitats. The slowly release of nutrients in the fertilisers mimicked the nutrients available to salmon fry from the decomposition of dead adult salmon after breeding. The UBC Department of Civil Engineering developed the fluidized reactor pilot plant to manufacture struvite for this purpose. Positive results were found for the young salmon ingesting the slow release struvite in the rivers.

An initial market analysis for struvite was conducted under a grant provided by the National Research Council of Canada Industrial Research Assistance Program (NRC-IRAP). In 2007 a full-scale demonstration plant was constructed in Edmonton's WWTP based on the core technology from UBC, but scaled up by a factor of 100. Ostara benefited from seven NRC-IRAP grants and around $C2 million in seed financing as the initial investment. Ostara has grown 50-100% per year since 2009 and employs 34 people. It has four separate patent applications.

Ostara has been supported by private equity. Equity investments in Ostara have been made by Frog Capital, a UK-based clean tech venture capital firm, and Vantage Point Venture Partners. Frog Capital has a portfolio of €100M, and is growing its portfolio at 40% per annum. Vantage Point Capital Partners has $ US4B in capital and seeks disruptive companies and technologies for investment. It has a focus on clean technology.

Ostara has provided struvite recovery systems in Edmonton, Canada, and Oregon, Virginia, Pennsylvania, and Wisconsin in the United States.

Clean Water Services, Oregon, USA

Clean Water Services (CWS) was the first utility in the USA to invest in a commercial scale Pearl® reactor from Ostara and place it at its Durham WWTP in Oregon. Ostara has a private-public partnership (PPP) with CWS. Through this agreement, Ostara receives an agreed annual payment for its services. Ostara offers two methods for an investment in its technology, where the buyer can either make the capital investment itself, or can negotiate a service payment deal to Ostara on a monthly basis over 20 years. Figures 6 and 7 show photographs of the Ostara crystalliser and the struvite product at the CWS Oregon facility.

Figure 6 Ostara Pearl® crystalliser at Clean Water Services, Oregon USA together with packaged 'Crystal Green' product.

Figure 7 Struvite product from the Clean Water Services Plant in Oregon, USA.

Clean Water Services operates four WWTPs in Oregon treating a total of 60 MGD (227 ML/d). It also has cogeneration facilities using WWTP sludge and grease collected from local food services to provide 70% self-sufficiency in energy. CWS manages flow in the Tualatin River Watershed above Portland and it has flood mitigation and water quality projects to protect the river and its water resources. It is a separately managed and financed public utility. CWS has 550,000 customers and a vision to "enhance the environment and quality of life in the Tualatin River Watershed through visionary and collaborative management of water resources in partnership with others".

The 20 MGD (76 ML/d) Durham facility of CWS was the first facility in the United States to recover struvite fertiliser from a WWTP. The facility previously used biological phosphorus removal plus aluminium sulphate (alum) at 'significant expense'. It spent $2.5 million on the Ostara struvite recovery system to recover 250 ton/year. This was primarily to satisfy the stringent water effluent discharge requirements for the Tualatin River of <0.1 mg/L phosphorus. Ninety percent of the phosphorus in the decant stream from its digesters is removed and this has resulted in a 23% reduction in alum use. The nitrogen content of the centrate is also reduced by 15%. Other benefits stated by CWS/Ostara for the investment are:

- pollution reduction;
- reduced chemical use;
- revenue from struvite sales;
- reduced operational and maintenance costs;
- reduced sludge volume and phosphorus content (by 12%); and
- reduced greenhouse gas emissions.

Financial payback for the facility, taking all the above into account, is stated by CWS as five years.

The struvite product is dried and bagged at the CWS Durham facility. Ostara markets the struvite as 'Crystal Green®' to nurseries throughout Oregon and the Pacific Northwest. It is marketed for turf (golf courses), container nurseries and specialty agriculture. Furthermore, CWS has developed its own new fertiliser called 'Clean Water Grow®', targeted at the retail market for flowers, shrubs, fruits and vegetables. It is a slow release mixture of struvite, polymer coated urea and potassium chloride, with 'non-hazardous ingredients' making up the balance. 'Clean Water Grow®' retails at a price of approximately $10,000/tonne at nurseries in Oregon and is sold in 1.3 kg bags.

Thames Valley Water, United Kingdom

Thames Valley Water (TVW) has invested £2M in capital to put in place an Ostara struvite recovery system to produce up to 150 t/year of struvite. The investment was completed in 2013 and the facility will save £200,000 per year in chemical dosing costs. Ostara has a public/private partnership with TVW, where Ostara designs, builds and finances the facility, and TVW pays a monthly service fee to Ostara.

Metropolitan Water Reclamation District, Chicago, USA

An Ostara struvite recovery unit will be installed by the Metropolitan Water Reclamation District (MWRD) in Chicago, Illinois. This is the world's largest nutrient recovery facility and will be located at the Stickley Water Treatment Plant in Cicero, IL. This plant serves 2.4 million people with a 673 km^2 service area including Central Chicago. The plant processes 4,548 ML/d of wastewater. The 'Pearl 10,000®' struvite recovery unit will produce 10,000 to 15,000 tons (US) per year of struvite. Ostara plans to buy the struvite at $US400/ton and this is stated to provide enough revenue to 'offset the (cash) costs of the operation'. The investment will total $US30 - $US35 million, with a payback of 3 to 5 years through the saving of $US8-9 million avoided costs of chemicals and avoided operating and maintenance costs. One of the main drivers for this investment is MWRD's voluntary imposition of a phosphorus limit of 1.0 mg/L to river systems that enter the Gulf of Mexico through the Mississippi River. This is to help prevent the creation of hypoxic zones on the Louisiana and Texas coasts of the Gulf of Mexico.

Case Study 3 – Barwon Water, Australia

A dried and granulated biosolid fertiliser product is made at Barwon Water's Black Rock Water Reclamation Plant. The product, which is safe to handle, is sold as a fertiliser additive for broadacre application in Victoria.

Barwon Water is Victoria's largest regional urban water corporation, with the service area centred around Geelong. It bounds Little River in the east, to Apollo Bay in the west and encompasses 8,100 sq. km. Barwon Water operates $2.3B in assets, including nine water treatment plants and eleven water reclamation plants. The Black Rock WWTP treats 60 ML/d of sewage from the region and is sited located near Barwon Heads.

The Black Rock Water Reclamation Plant wastewater treatment process uses an activated sludge process with decanting. The water effluent, that is not otherwise recycled, is discharged into Bass Strait via a 1.2km long deep ocean outfall. The effluent water from the plant contains about 4 mg/L phosphorus. Sludge is treated with belt filter presses to bring the solids content up to around 13%. Barwon Water produces approximately 55,000 tonnes/year of sludge which is then transferred to a separate biosolids management plant to make a dried, pelletised fertiliser product. The sludge from all of Barwon Water's Water Reclamation plants is delivered to the biosolids plant. The production rate of the dried biosolids product is approximately 10,000 tonnes/year. The biosolids treatment facility commenced operations in September 2012.

The Barwon Water biosolids treatment facility is a PPP with Plenary Group under the *Partnerships Victoria* framework.

Under this arrangement, Plenary Environment built, financed and now operates the plant using a contractor, Trility (formerly Water Infrastructure Group). The net present cost of the plant is stated as $77.6M. Debt was provided by Bank of Tokyo – Mitsubishi UFJ while equity was provided by Plenary Group under a project financing arrangement.

The small footprint, fully enclosed thermal drying facility is the first of its kind in Australia and the largest of its type in the Southern Hemisphere.

Figure 8 Bioprill® product from the Barwon Water plant.

Figure 9 Vertical drier reactor for the Barwon Water Bioprill® plant.

PHOTOS: COURTESY OF PLENARY ENVIRONMENT AND REPRODUCED WITH PERMISSION FROM BARWON WATER

Plenary Group states that:
"The facility provides a model for Australia of a sustainable solution for managing urban biosolids on a large, regional scale to address the environmental issues associated with biosolids stockpiling, disposal and reuse".

The facility has received independent recognition for its contribution to sustainability, taking out the prize for Environmental Protection at the recent 2014 Victorian Premier's Sustainability Awards.

On inspection, the facility is a serious piece of engineering and a significant technology investment. Figure 8 shows the nature of the dried product, called 'Bioprill®' produced from the plant, while Figure 9 shows the vertical arrangement of the drier. The biosolids pellets appeared to be strong and resilient on inspection.

The plant treats the biosolids using indirect heating, with gas-heated hot oil as the transfer medium. The biosolids are raked over hollow plates, through which the hot thermal oil is pumped, termed a 'pearling process'. In addition to the materials handling and safe processing of the biosolids, measures have been implemented to minimise the local environmental impact of the plant, such that water, odour and the vapour from the drying process are captured and treated.

Barwon Water previously trucked approximately 55,000 t/year of wet biosolids to Melbourne Water's Western Treatment Plant. Avoided costs associated with this transport and CO_2e emission savings are cited as assisting in financial justification for the investment, along with the desire of Barwon Water to achieve environmental sustainability.

The facility has resulted in a 30% reduction in greenhouse gas emissions and has cut heavy truck movements by 1,000 a year compared to the previous practice of transporting wet biosolids to Werribee to be stored and air dried over many months.

In Chapter 5, it was noted that environmental waste regulations are different to fertiliser regulations. In this case the more stringent regulations imposed by the EPA (Guidelines for land application of Biosolids) apply to the Bioprill® product, particularly in terms of its heavy metal content which originates in sewers from household pipework (Cu, Zn, Se). These trace elements restrict the use of the biosolids products and require farmers to have an Environmental Improvement Plan (EIP), an alternative to an application in accordance with the guidelines, to reduce these trace elements to a level at which the product becomes unrestricted and in line with Victorian EPA Guidelines. The product is blended with commercial urea, MAP and DAP in a typical one third Bioprill®/two thirds synthetic fertiliser ratio before being sold to farmers for broadacre application. At these levels Cu, Zn and Se are not problematic to farmers. Bioprill® contains approximately 6.5% N, 2% P and 38% C. Extensive negotiations were held with the EPA regarding the regulation of the dried biosolids for agricultural use. Plenary Group confirmed that the differences between regulations for 'waste' and 'fertiliser' made these negotiations a lengthy process. This reinforces the project risk associated with the timing and issue of approvals from regulators in these types of projects.

Biosolids are designated according to both 'treatment' and 'contaminant'. Thus an EPA grading of 'T1C1' means that it is 'best treatment' and 'best acceptable contaminant level'. The Bioprill® product is initially T1C2 and then blended to make T1C1. Both these qualities of the biosolids products are sold to farmers, with 'T1C1' unrestricted and 'T1C2' requiring farmers to have an EIP[54].

The initial 'Beneficial Use Provider' for Bioprill® was Biolife Australia, who blended the product and on-sold it to farmers. The Chief Executive Officer of this company is Mr Mike McCosker, a farmer from Inverell, NSW. Mr McCosker was consulted with during this project and made the following relevant points about Bioprill®:

- The value proposition to farmers of Bioprill® is the 'biologically active carbon' it contains. This leads to a 'bloom of biology' in the soil and stabilises the nutrient content. It has a lower analysis in terms of N and P, but gives better results in terms of plant yield when compared with straight synthetic fertilisers. Bioprill® gives better availability of N and P from the blended fertilisers to the plants.
- The price for the one-third Bioprill® blended fertiliser was similar to or slightly lower than MAP and DAP, giving a reasonable margin to Biolife Australia who purchased the Bioprill® and blended it with the synthetic fertilisers.
- It is important to get the physical specification correct for any fertiliser product and Bioprill® is no exception. This is because of constraints associated with farming equipment.
- Negotiations with the regulator, especially in relation to trace element content of the biosolids, were long and arduous.
- Biolife Australia is no longer involved with Bioprill®.

Mr McCosker also made the following comments about slow release fertilisers, such as struvite:

- Most farming country in Australia is high in magnesium, so there would be no value to farmers for the Mg content of struvite.

Hamburg Wasser, Germany

The Hamburg Wasser sewage treatment plant (STP) has a capacity of 1040 ML/d. It has a biological centrate treatment plant, with sludge treatment stages consisting of thickening, digestion, dewatering, drying and incineration. Additional organic waste is added to their digesters to utilise their full capacity. The residuals from the treatment processes are used in agriculture. Gate fees for organic waste vary between €5/t for liquid waste with low organic content, up to almost €40/t for problematic industrial wastes. The Hamburg Wasser site generates 88.9 GWh of heat, 79.2 GWh of electricity and 19.5 GWh of biogas from their STP.

There are a number of drivers that have led to this result. From Hamburg Wasser's perspective, the desire to reduce their operational costs has been a major driver. This comes against regulatory conditions that do not permit organics to be disposed of to landfill. Germany also has a greenhouse gas reduction target of 40% by 2020 (compared to 1990 levels), increasing to 80% by 2050. Against this background, Hamburg Wasser has set a company target to be energy self-sufficient by 2018.

Germany does have a feed-in tariff for renewable energy; however this is not a major financial driver. Hamburg Wasser gets their greatest benefit when they use the energy produced on-site, rather than selling it into the grid. Purchasing electricity from the grid costs Hamburg Wasser in the order of €0.21/KWh, whereas they only receive about €0.09/KWh for feeding power into the grid.

Scottish Water, United Kingdom

Scottish Water Horizons is a commercially stand-alone business of Scottish Water. Scottish Water has many assets; including treatment works, reservoirs and tens of thousands of kilometres of water and wastewater pipes throughout Scotland. Scottish Water Horizons was set up to capture the commercial opportunities these assets provide Scottish Water. It is a non-regulated part of the business, which allows Scottish Water to choose what it does with its revenue, which they have directed to keeping their customer bills low.

Co-digestion at WWTPs has proven to be a revenue-raising proposition in Scotland. The viability has been aided by a favourable feed-in tariff, a landfill tax of $136/tonne, an impending European Landfill Directive that will ban some landfill, waste regulations requiring a separate pick up for food waste over 5kg (previously 50kg), and the removal of exposure to future electricity price increases.

- Farmers in Australia are very price sensitive to the cost of fertilisers, unless the crop is of high value (e.g. strawberries). Broadacre farmers are looking for the simplest and lowest cost system.
- The main interest to farmers around fertilisers is biological activity promotion and release of nutrients to the beneficial use by plants.

Case Study 4 – East Bay Municipal Utility District (EBMUD) – USA

East Bay Municipal Utility District (EBMUD) serves 650,000 people in a 228 km^2 area along the east shore of San Francisco Bay. It treats 222 ML/d of wastewater, with a capacity to treat 635 ML/d. The facility commenced co-digestion in 2002 and became self-sufficient in energy in 2012. The anaerobic digestion volumetric capacity is 83ML.

The US EPA has studied and reported on six water resource recovery facilities in the USA[20] and EBMUD is included as the largest facility. The US EPA notes that in 2013, 1,238 US WWTPs processed wastewater solids with anaerobic digestion and 85% of these beneficially used the biogas. Around 270 facilities (roughly 22%) generate electricity with the produced biogas.

Increased use of supplementary organic matter in digesters is being driven by rising energy prices and tighter regulations. Enhancing biogas production by adding fats, oils and greases (FOG) is now standard practice. Less widespread is adding food waste, including the by-products of food processing facilities and agricultural production.

Since 1985, EBMUD has been operating a cogeneration facility at one of their WWTPs to recover energy from wastewater. Increasing power demands and higher energy costs were the primary incentives at that time. Three separate 2.15 MW internal combustion reciprocating engine power generators were constructed at this first site.

California experienced an energy crisis in 2000-2001 that resulted in a number of rolling blackouts and electricity wholesale costs increased significantly following that crisis. At this time, digester capacity became available as the number of industries in the region reduced, and consequently the industrial waste load reduced. EBMUD chose to accept high-strength industrial and commercial wastes to increase their ability to generate onsite power. Since doing this, they have been able to increase the power demand at the WWTP from their own power generation from approximately 40 to 80%.

This success led EBMUD to explore further alternative energy extraction technologies. California's adoption of policy targets to achieve 20% of the state's energy from renewable energy by 2010, and 33% by 2020 further supported this decision. EBMUD chose to convert food scraps into energy using anaerobic digestion at their main WWTP, becoming the first WWTP in the United States to do so. Food scraps are collected from local restaurants and markets and transported to the treatment plant. The plant is now a net producer of renewable energy and can generate more than 55,000 MWh annually.

Co-digestion wastes for EBMUD digesters now include FOG, winery and animal processing wastes, as well as post-consumer commercial waste. Each day 100 truckloads containing liquid and solid wastes from 20 to 30 industrial processors, plus 18 to 36 tonnes of post-consumer food waste are transported to EBMUD.

Co-digestion has led to a doubling of biogas production at EBMUD. The company now produces approximately 70 M m^3/day of biogas and the company would like to use more co-digestion feed. A full-time business development manager is employed to identify and recruit potential suppliers.

Figure 10 EBMUD's gas turbine cogeneration facility[32].

EBMUD currently generates 129% of its energy requirements, or 52,561 MWh/year. To generate the electricity, three internal combustion reciprocating engines are used (2 to 2.5MW rating) and EBMUD has recently installed a new 4.5MW gas turbine. The total installed capacity is 11MW, which represents 200% of facility requirements.

The company established a Power Purchase Agreement with the Port of Oakland to sell the excess power. EBMUD also participates in the California Renewable Auction Mechanism program for renewable energy generation. Under this market-based mechanism, power generation utilities may purchase up to 1,299 MW at 6 monthly auctions. Bids in these auctions are selected on a least cost-price first basis.

EBMUD generates millions of dollars each year in revenue from tipping fees and energy savings and sales. Tipping fees range from $US0.11 per litre for organic liquid material to $US60/tonne for solid organic material. In 2012, EBMUD received $US8M in tipping fees and $US3 million in energy savings and electricity sales. The investment to achieve these revenues was $US36.3 million, associated with a new waste receiving station, interconnection costs and a new gas turbine. No new anaerobic digesters were required since the facility had excess digestion capacity.

The EPA estimated a simple payback period for the EBMUD co-digestion investment to be 3.2 years. Calculations done for this report show that this is equivalent to an after-tax internal rate of return (IRR) of approximately 24%. From the point of view of an investor, this is an excellent return on investment. However, the investment would not be so attractive in other situations if further capital expenditure is required to build new digesters as well as the associated infrastructure to produce the biogas.

Summary of case studies: 'what works and why'

The case studies in this report are varied in their location and business environment, but several drivers are common. Table 4 summarises the key business strategies that promoted and drove resource recovery from the case studies.

Table 4 Factors that contribute to the success of resource recovery from wastewater, and why

'What works'	'Why it works'
■ Socially and environmentally supportive boards and senior management. ■ Numerical sustainability targets in business plans.	■ Promotes a clear social and environmental outcome culture within the company, driven by high level leadership.
■ Investment in new technologies that lower operating costs and increase revenue, including supportive arrangements for the purchase and sales of renewable electricity.	■ Lowers avoided operating costs and improves the NPV of the investment.
■ State regulatory controls that limit nutrient emissions to the environment, especially for phosphorus.	■ Stringent emissions imposed by the state regulators drive nutrient reduction strategies and investments at the lowest cost.
■ Active product marketing to retail fertiliser sales markets, with wide product distribution networks. ■ Articulation of a product value proposition for customers that creates value for them.	■ Retail fertiliser markets have higher margins than bulk fertilisers. ■ Superior marketing and distribution of the products ensures higher turnover and prices. ■ Understanding the customer's business model and requirements assists in increasing sales revenue.
■ Innovative fertiliser product development and marketing.	■ Achieves high retail prices and margins for the product.
■ Innovative business models for external technology development and marketing of products.	■ Assists water utilities in their capital investment strategies and removes the need to have their own product marketing team in place.
■ Involvement of external private companies in the provision of finance and business management expertise, e.g. PPP	■ Provides capital (debt and equity) for a resource recovery development separate from the water utility's own capital allocation.
■ Build, own, and operate business structures developed and controlled by private investors.	■ Simplifies water utility management structures and enables greater focus on other key strategic issues associated with their business.

CHAPTER 5: REGULATORY BARRIERS AND DRIVERS FOR RESOURCE RECOVERY

Regulations are important for their role in achieving and encouraging desirable environmental and health outcomes for the entire population. They also provide the necessary framework to enable effective planning, installation, operation and monitoring of wastewater management systems. They are particularly important in the water industry, as clean water is one of the fundamentals of life. In some cases, over-regulation can cause barriers to innovation and development. On the other hand, under-regulation can cause valuable nutrients to be discharged into the ecosystem with attendant potential environmental consequences and loss of value. Regulations therefore play a large role in the implementation of wastewater resource recovery and in the governance of water corporations and their co-investors.

Investor view

Consultations with a range of investors as part of the study have revealed that government regulations provide "quite significant barriers to investment" in Australia. The regulations are complex, vary between States and, in the context of this report, vary between 'waste' and 'fertiliser'. This adds to the risk of a potential investment in resource recovery. Comments received from investors and entrepreneurs include the following points:

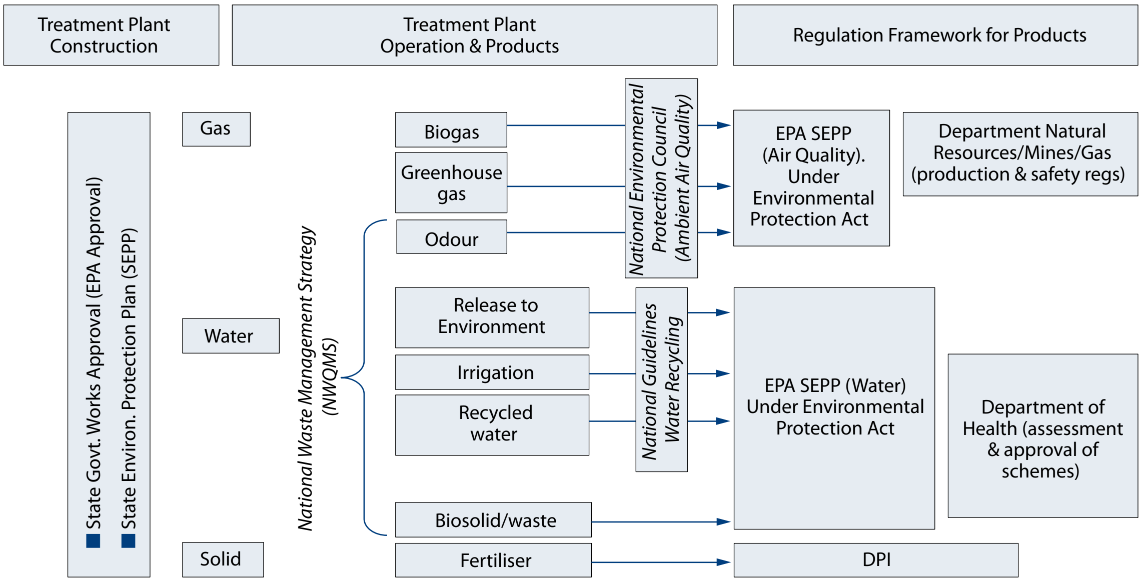
- "The water industry is slow and conservative. Warranties can be voided, even when a relatively small piece of equipment is added to a wastewater processing facility".
- "The level of regulation can be cost prohibitive and differs across states and their departments in Australia".
- "Dealing with the regulations and the departments who administer them is time consuming and difficult".
- "Extensive negotiations are often required with the various EPAs, especially where a wastewater product is desired to be used as a fertiliser through land application".
- "Extensive legal costs are often encountered through the judicial processes required to obtain permission to proceed (e.g. for works approval)".

In addition to the environmental, health and safety regulations outlined in the report, there are financial regulations governing water corporations and these may affect the investment criteria in financial strategic planning and the investment itself. These types of regulations are considered further in Chapter 7.

Australian regulations

A number of national guidelines have been established to support good practice in wastewater treatment, treated effluent reuse (including recycled water) and solids reuse within Australia[55, 56, 57, 58]. However, state and territory environmental agencies (EPAs) are responsible for enforcing local operational requirements for the construction and operation of WWTPs, as well as the use of products generated from these (Figure 11). Wastewater contains significant microbiota, and therefore, products generated from wastewater treatment plants that are likely to come in contact with humans are regulated through state Departments of Health. Departments of Primary Industry (or similar) within Australian states

Figure 11 Schematic summary of National Guidelines and regulating state bodies for wastewater treatment and products derived from wastewater.



*Note: EPA and DPI represent States' Environmental Protection Agencies and Departments of Primary Industry, respectively.

and territories have Acts and Regulations which assist in deciding whether a recovered material meets the specifications of a fertiliser. Where biogas is produced there are additional regulations around the safe production and handling of biogas. The following sections provide a brief summary of the National frameworks in which State and Territory Regulations are implemented.

State Environmental Protection Policies (SEPP)

State and territory environmental agencies in Australia develop environmental protection policies to set the statutory framework for the protection of fresh and marine water environments and air quality[59]. This framework enables the states to create objectives and indicators for the protection of the environment, such as the protection of water bodies against point source effluent discharges. The ongoing assessment of environmental and biodiversity indicators provides evidence-based guidance for the enforcement of nutrient (and toxicant/sediment) loading limits. Limits for the discharge of waste and wastewater are generally made as a licence agreement with the State environmental agency with national guidelines assisting by setting levels for minimum performance. The terms of the licence specify environmental performance conditions and outcomes that must be met.

One major factor influencing the viability of phosphorus recovery is the licence agreement for nutrient discharge. Nutrient discharge limits vary considerably depending on whether discharge is to land, inland rivers, bays, shorelines or deep-oceans, which influences the level of nutrient removal that is required to protect the environment. For instance, Melbourne Water (Western Treatment Plant) discharging to Port Phillip Bay has a limit of 90th percentile less than 15 mg/L phosphorus, and Sydney Water (Deep Ocean Outfalls) have no phosphorus limits. Sydney Water manages nutrient loadings based upon environmental monitoring programs[60]. Some examples from NSW and Victoria of specific licences for nutrient levels are recorded in Table 5. Similar situations exist in Queensland, South Australia and Western Australia.

Table 5 General limits enforced as minimum discharge standards within Australia[61]

Discharge type	Guideline level	Minimum treatment	Comment
Land application of water	■ For effluent applied to land, total N < 5 mg/L (VIC 2002)	Secondary treatment & disinfection	■ Where there is risk of run-off total nitrogen must be reduced to < 5 mg/L
	■ Irrigation loadings should not exceed 100 kg/ha/y (TAS 2002)	Secondary treatment & disinfection	■ Class B recycled water.
Coastal discharge	■ Melbourne Water discharge to Boags Rocks, Victoria. ■ Mean daily flow <540ML/d. ■ Annual median limit for Ammonia < 0.5 mg/L. ■ Phosphorus is limited to < 15 mg/L (90th percentile).	Advanced Tertiary Treatment	■ Total N is not specified. ■ Recorded values 2013-14: Discharge = 381 ML/d. Ammonia (median) = 0.1 mg/L Total P (90th percentile) = 8.2 mg/L
	■ Sydney Water Deep Ocean Discharges, 2-4 km offshore. ■ Malabar, North Head and Bondi together managing >80% of all Sydney effluent and release ~1140 ML/d with no set N or P limits.	Primary treatment	
	■ Sydney Water Cronulla discharge 64 ML/D to the shoreline. ■ Avg. mean limits: Ammonia = 45.7 mg/L. No phosphorus limit.	Tertiary & disinfection	■ Actual mean ammonia = 1.3 mg/L.
Bay discharge	■ Melbourne Water discharge to Port Philip Bay, Victoria. ■ Mean daily flow <700ML/d. ■ Annual median limits: Ammonia < 10 mg/L. No Phosphorus limit.	Secondary treatment	■ Total N and P are not specified. ■ Recorded values 2013-04: Discharge = 398 ML/d. Ammonia (median) = 9.0 mg/L Total P (90th percentile) = 10.8 mg/L.
Discharge to inland waters	■ Sydney Water – Quakers Hill (11, 153 ML/y), Riverstone (771 ML/y) and St Mary's (10,315 ML/y) discharge to Breakfast Creek, Eastern Creek and South Creek. ■ They have a specified nutrient load equivalent to: N = 10 mg/L, P = 0.1 mg/L	Tertiary & disinfection	■ Quakers Hill, Riverstone and St Marys plants operate to meet the 'Bubble Limit' for total nitrogen of 222 tonnes/year and total phosphorus of 2.3 tonnes/year. ■ These plants performed within their Bubble (shared) Limit during 2011-12. The majority of Sydney's growth in the future will occur in areas served by inland plants, providing opportunities for nutrient removal within the Sydney Basin.
	■ ACTEW Lower Molonglo ■ Total N < 2100 kg/D, 1.6-7.4 mg/L ammonia depending on season. P = 0.4 mg/L	Tertiary filtration & disinfection	■ Mean P achieved = 0.15 mg/L
	■ Sydney Water – Picton. Total flow approx. 670 ML/year. Re-used for on-site irrigation. ■ N = 6 mg/L (50th percentile), 10 mg/L. P = 0.02 mg/L (50th percentile), 0.4 mg/L.	Tertiary & disinfection	■ Actual 2011-12: N < 2.8 mg/L, P < 0.06 mg/L.
	■ Yarra Valley Water - Brushy Creek (15ML/d) and Lilydale (12ML/d) have 0.3 mg/L		

As can be seen from the table, there are very large differences in the regulatory environment for effluent water discharge between ocean and riverine discharges. Also, the water corporations are meeting the targets based on measured outcomes. Notwithstanding this, large quantities of nutrients, especially phosphorus, are being discharged from WWTPs into the oceans around Australia.

The objectives and indicators set by state and territory environmental agencies are generally based upon scientific and intelligence-based environmental data and evidence, but are also influenced by historic activities, government departments, co-regulators, businesses and members of the public. This regulatory model therefore opens itself up to a range of scenarios whereby objectives, indicators and licences can be greatly influenced by:

- social pressure to improve the environment, which can lead to water utility upgrading facilities, and providing a driving force to invest in recovery technologies;
- direct social or political pressure to recover energy, water or phosphorus to achieve wider productivity and resource gains. This could create direct incentives for investment into recovery of these products[62];
- social or political pressure to lower water bills, resulting in lower spending on upgrades for environmental gain or resource recovery; and
- Departments of Health seeking tighter measures on products created from wastewater.

In most cases the environmental agencies will endeavour to develop clear guidelines, seeking external inputs where necessary (i.e. national guidelines), which enables decisions and enforcement to be made efficiently and with clarity. However, in many instances, particularly when businesses are looking to expand into new opportunities, fixed frameworks may not be able to assess the risks adequately or in a timely manner, thus creating complications and difficulties for both the regulator and business.

Construction of a wastewater treatment plant

Works approvals are required for industrial and waste management activities that have the potential for significant environmental impact. Typically, this may be restricted to a WWTP exceeding a critical volume (e.g. 3-5 ML/d). The approvals permit the construction of a plant, the installation of equipment or modification of processes (i.e. EPA Victoria under the Environment Protection Act 1970). A works approval application needs to demonstrate:

- consistency with the relevant environmental policies (i.e. SEPP);
- that it will not cause pollution or cause an environmental hazard by delivering an Environment Management Plan;
- will not endanger public health; and
- complies with the relevant land use planning scheme.

When applying for a works approval, the applicant needs to demonstrate environmental best practice design considerations[63]. This implies that the establishment of new infrastructure and processes to treat wastewater face a higher level of scrutiny and is expected to deliver improved environmental outcomes compared to existing treatment facilities. Improved outcomes may result in lower discharge limits being set for nutrients or gaseous emissions for the site in question. Biosolids regulations are typically set at state level and will not vary at individual sites.

Work permit permissions may be delayed or even legally challenged by social unrest in the local area or beyond. In one case discussed with investors this legal challenge went to the Supreme Court before resolution.

Regulation of nutrients in effluent

Nutrients in effluent such as nitrogen, phosphorus, potassium, magnesium, sulphur, calcium and zinc are generally beneficial to plant growth. In closing the nutrient cycle, it is therefore advantageous to capture the nutrients from wastewater and return them to agricultural production. This can be achieve in three ways: (i) nutrients contained in treated effluent; (ii) biosolids; or (iii) as a fertiliser.

There are Australian guidelines for land application of treated effluent and solids. These are enforced by the individual states and territories, and are written in such a way that demonstrates that the receiving land can effectively use such nutrients in both the short and long term, and nutrients are not required to be removed from the treated effluent/waste[64].

The basic principles for land application in Australia are summarised within the National Water Quality Management Strategy (NWQMS)[55] as being dependent upon:

- the build-up of any substance in the soil should not preclude sustainable use of the land in the long term;
- the effluent is not detrimental to the vegetative cover;
- any change to the soil structure should not preclude the use of the land in the long term;
- any run-off to surface waters or percolation to groundwater should not compromise the agreed environmental values; and
- no gaseous emissions cause nuisance odour.

Within the NWQMS, the re-use of treated effluent is managed against the guidelines for "Use of reclaimed water"[56] and the National Guidelines for Water Recycling[58]. Similarly, biosolids are managed against the guidelines for "Biosolids management" [57].

Aside from nutrient considerations, there are key health-based requirements that are legislated for the use of treated effluent and biosolids. These health-based objectives ensure that effluent and solids are treated to a minimum level to avoid the risk of human exposure to pathogenic microorganisms. These objectives are set through guidance from Departments of Health. For instance, secondary treatment with disinfection is a typical prerequisite prior to using treated effluent for any irrigation purposes[55] but depending on use, may need to be treated to a higher level to make it safer to use. Generally, the level of nutrients contained within the wastewater will be lowered during the treatment processes undertaken to meet more stringent health-based targets. For solids, health-based criteria are enforced through demonstrated lowering of pathogen levels and alongside contaminant levels (see Table A7.1 and Table A7.2 of Appendix 7) which control how biosolids can be used. The amount of solids that can be applied to soil is controlled through state controlled management plans that assess safe soil loading limits of nutrients, contaminants and residues[57].

State and territory-based enforcement of recycled water usage is consistent with National Guidelines in that each considers nitrogen and phosphorus environmental overloading risks. The risks that are considered include: plant nutrient imbalance during irrigation (the oversupply of nutrients can result in plant deficiencies and toxicities); increased plant pest and disease incidence; eutrophication of surface waters; and contamination of groundwater[65].

At the state and territory level, local understanding of agriculture and crop demands are used to develop sustainable water re-use plans where nutrient contents limit application. Details on nutrient demand levels for various crops may be found in Appendix 7.

In most cases, verification may be sought from the regulating agency (i.e. EPA) that nutrient applications are not leading to environmental complications. Sampling and monitoring programs are therefore needed to determine whether: (i) predicted effluent quality is being achieved; (ii) level of impact or change caused by the management system is as predicted; and (iii) that the agreed environmental values are met[55]. This would involve the establishment of background levels prior to irrigation, and an ongoing monitoring program where specific points are sampled at predetermined reporting frequencies, and the evidence is provided to demonstrate that land applications are carried out using best practice (e.g. to avoid pooling). Due to there often being a chance that irrigation water may run off the land and into surrounding waterways, or that WWTPs discharge treated effluent directly into receiving water bodies, regulating bodies may set more stringent nutrient limits for the treatment facility.

Fertiliser regulation

In contrast to the regulation of treated effluent and biosolids, fertiliser usage in Australia is less regulated. The description, sale and use of fertilisers in Australia are governed by Acts and Regulations within state jurisdictions[66, 67]. There is a national code of practice for fertiliser description and labelling, which provides maximum permissible concentrations (MPCs) for cadmium, lead, mercury and fluorine. Details of these concentrations may be found in Appendix 7, which demonstrates that regulations on waste products are significantly stricter than for fertilisers. For instance, Grade C1 biosolids need to achieve 1 mg/kg for Cd and Hg; 300 mg/kg for Pb, plus meet limits for As, Cr, Ni, Se, Cu, Zn, DDT and derivatives, organochlorine pesticides and PCBs. In comparison, fertilisers in Australia are only required to contain down to 10 mg Cd/kg, 5 mg Hg/kg, and 300 mg Pb/kg (for product containing >25% organic matter).

It has been demonstrated that some materials can be recovered from wastewater in a highly pure form. For example, struvite crystallises and has a purity of at least an order of magnitude more pure than commercial fertilisers[26]. It is not clear, given the current guidelines, how a material such as struvite would be regulated within Australia. Departments of Primary Industries (and similar) typically have responsibility for the definition of a fertiliser. For example, the NSW Fertiliser Act specifically excludes uncomposted manure and any biosolids products from being classed as a fertiliser[68]. The term 'biosolid' usually refers to any treated solid or slurry product that is derived from sewage sludge[69]. For unrestricted biosolids use, which includes home lawns and gardens, both the contaminant grade and stabilisation need to meet Grade A. Strictly speaking, struvite produced from a WWTP would need to meet Grade A stabilisation before it could be used without restriction, unless deemed to be a fertiliser by Primary Industries. Under the Commonwealth Mutual Recognition Act (1992)[70], if a material is classed as a fertiliser in the state of manufacture and complies with regulations, then it can be sold Australia-wide.

Where nutrient loads to receiving environments are demonstrated to cause environmental impact, state legislation may limit the amount of fertiliser applied to agricultural land. As an example, the Great Barrier Reef Protection Amendment Act 2009[71] has led to the direct regulation of the water quality impacts of cattle grazing and sugarcane farming in the Burdekin, Mackay and Whitsunday regions. This legislation requires that farmers/growers calculate and apply no more than the optimum amount of fertiliser to prevent nutrient run-off to the Great Barrier Reef.

Biogas and electricity regulation

The installation and operation of equipment for biogas generation is regulated through state departments pertaining to natural resources and mines, with approvals and inspections being carried out through petroleum and gas regulatory bodies within the state jurisdiction. This extends to the equipment used in the conversion of biogas to other forms of energy (heat and/or electricity).

In most cases, generated electricity will feed into the National Electricity Market (NEM); however, state-level feed-in tariffs have provided incentives for stimulating the uptake of renewables in markets. Western Australia and the Northern Territory are not connected to the NEM and have their own electricity systems and separate regulatory arrangements.

In some jurisdictions anti-competition laws may inhibit publicly funded water utilities from competing in the electricity generation market.

International regulations and initiatives

The regulation of wastewater treatment operations varies globally. The USA and Canada tend to match effluent characteristics to the receiving waterbody, using a total maximum daily load (TMDL) to set limits and may be seasonally dependent[72]. The EU takes a consistent approach to nutrient discharge limits, which are met by showing a net percentage reduction (80%) in total nitrogen and phosphorus, or meeting the enforced nutrient limits based upon the size of the treatment facility. Australia at present is more aligned with the USA and Canadian model in that operational limits are set on the basis of risk.

Western European countries (e.g. The Netherlands and Germany) have regulations banning land application of biosolids and promote incineration technologies. These have largely arisen due to negative public opinion on the safe use of biosolids, and on the back of this, there are several phosphorus recovery technologies relating to the use of ash or recovery of phosphorus from ash.

There are numerous global phosphorus initiatives lobbying for incentives to recover and use phosphorus more effectively due to uncertainty in its future availability (Global Phosphorus Network, Global TraPs, Japanese Phosphorus Recycling Promotion Council, National Nutrient Platforms in Netherlands/Flanders, Centre European d'Etudes des Polyphosphates). In response to global uncertainties in phosphorus supply, the Swedish Environmental Protection Agency (SEPA) announced in 2002, a long-term objective to recycle 60% of phosphorus from sewage by 2015[73]. Additionally, the German Federal Government offered significant funding to universities to develop phosphorus recovery technologies.

Direct legislation has been made internationally to provide incentives for renewable energy production as a result of energy security concerns. Germany offered considerable renewable credits that facilitated the construction of anaerobic digesters for treating organic waste streams. These credits have since decreased in value, thus making new investment into similar technologies less attractive.

CHAPTER 6: SOCIAL LICENCE TO OPERATE

The following Chapter briefly considers public acceptance of resource recovery from wastewater and provides some guidance to a potential investor as to the social risks that may be encountered. It also outlines the simple steps that should be adopted to manage the risk. Although the section is brief, the importance of these social licence risks to a business should not be underestimated.

There are many aspects of resource recovery from wastewater that could influence the industry's 'social licence to operate'. For example, there is public interest and willingness to pay for recycled water. There are other positive aspects in the public mind, such as the production of renewable energy and the production of sustainable products. The public is also interested in a clean environment and could actively support a regulatory environment that moves towards an obligation for zero discharge of wastes. There is the potential for a social media campaign around, for example, persistent organic compounds or endocrine disrupters in the aquatic environment. There are therefore significant social risks and opportunities for the industry in the resource recovery space.

Australia is the fifth largest importer of phosphorus raw materials globally and the current supply chain is driven economically. Other drivers could potentially exist, including a drive from the public towards material efficiency or concerns about sovereign risk associated with the countries that provide phosphorus. Underpinning this, the ethics associated with the Brundtland Statement on what we leave behind for future generations is also relevant.

For an investor, there are a number of risks associated with public perception of resource recovery products from wastewater. The potentially negative perceptions could lead to a withdrawal of a 'social licence to operate', and any investor needs to be aware of these and to put in place processes to manage this risk. Some of the positive and potentially negative social aspects of resource recovery from wastewater relating to a 'social licence to operate' are given below.

Positive social aspects

- sustainable production of renewable energy.
- sustainable production of both nutrient and non-nutrient products.
- fertilisers are produced with decreased levels of toxic metals.
- provision of high quality recycled water for a drought-prone continent.
  less nutrient run-off from agricultural land to pristine natural environments.
- opposition to the use of finite world resources through unsustainable mining.
- without resource recovery, outrage at the pollution of ocean, estuary and watershed environments with excess nutrients and other contaminants.

Potentially negative social aspects

- fear/dread of recycled water made from sewage.
- fear/dread of retail fertiliser products made from sewage.
- outrage at the high or escalating price of water supplied to the home.
- fear/dread of edible products irrigated with waste or recycled water, or fertilised with waste products.

For an investor, it is important to note that people are not outraged by the scientific 'hazard', but the very fear-inducing intuitive idea. This is not solved by scientists presenting people with the 'facts'. Indeed, research has shown that people distrust government agencies and scientists as well as corporations, although there are considerable differences in the level of public trust in these entities.

A 'social licence to operate' is granted informally by people to the organisation concerned. If society believes that the organisation has violated their trust, then the 'social licence to operate' is withdrawn. For resources projects public opposition can come from many sources:

- numerous media stories;
- internet; YouTube videos; social media;
- resistance; e.g the 'Lock The Gate' campaign against coal seam gas;
- direct action by protesters;
- political lobbying; and
- alliances; e.g. non-governmental organization and farmers.

By using social media (Facebook, Twitter, YouTube, blogs), a message can be communicated very quickly and effectively.

Professor David Brereton noted in the ACOLA report '*Engineering Energy: Unconventional Gas Production A study of shale gas in Australia*'[28] that the consequences of not obtaining a 'social licence to operate' can be severe. It can also lead to disruption and delays, reputational damage, more onerous regulatory requirements and even bans on certain business activities.

> *'Successful resource developments require not only formal approval by government, but the broad acceptance of communities and other key stakeholders'*
>
> — PROF. DAVID BRERETON, UQ

Securing a 'social licence to operate' requires active management like any other business inputs such as costs or marketing. Brereton[28] notes that the following three approaches are essential:

1. Provide a reasonable level of assurance that the activity can be undertaken without causing any environmental, health or social harm.
2. Ensure that communities are receptive to the message.
3. Provide assurance that concerns will be recognised and addressed in a timely way.

Community engagement is a critical mechanism for obtaining a 'social licence to operate'. This engagement must adopt the following approaches:

- community communication must be a two-way activity;
- communities must have an informed understanding of technologies, hazards, risks, impacts, and potential benefits;
- proponents and regulators must have an informed understanding and show respect for concerns and perspectives of various community stakeholders; and
- different parties must engage in constructive dialog with each other and work towards agreed outcomes.

The International Association for Public Participation (IAP2) has provided a guide to different levels of social engagement for different types of outcomes, the 'Spectrum of Public Participation'. The Spectrum was developed to help groups define the public's role in any public participation process. The Spectrum

(Table 6) was included to assist future investors in resource recovery to gain and maintain a 'social licence to operate'.

Table 6 IAP2's Spectrum of Public Participation

Increasing impact on the decision

	Inform	Consult	Involve	Collaborate	Empower
Public participation goal	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision making in the hands of the public
Promise to the public	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision. We will seek your feedback on drafts and proposals.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will work together with you to formulate solutions and incorporate your advise and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

CHAPTER 7: FINANCIAL ASPECTS OF RESOURCE RECOVERY INVESTMENT

This Chapter considers several aspects of investment in new resource recovery projects. Firstly, the strategies and views of different types of potential investors in resource recovery are discussed which are based on individual consultations. Secondly, the influence of regulation on the water sector is outlined, and the implications of this for investment in resource recovery are considered. Thirdly, a summary of the methods employed in this study to financially analyse investments is reviewed. Finally, some preliminary financial analyses aimed at answering some resource recovery investment questions are presented. These include preliminary analyses of the prices of fertiliser products required to provide a return on the capital employed to produce them from wastewater.

Chapter 8, 'Options for Australia', takes the financial analysis a step further to include a preliminary probabilistic analysis of NPV for several process choices available at different time and process scales. A discussion of probabilistic financial modelling is included for reference.

Investors

Potential investors for wastewater resource recovery include equity venture capital firms, equity investors, banks for debt financing and government. As part of this study, interviews were held with venture capital firms and equity investors. The purpose of these interviews was to establish the ideal characteristics of a project required for an investment to proceed.

Prospective new technologies or new product market developments require funding in order to progress to commercialisation. There are several stages of funding as the idea progresses from the laboratory to full-scale market deployment. These stages can be characterised as:

1. The desktop development of a concept or idea.
2. Embryonic studies to investigate and validate the science of the idea and demonstrate the concept at laboratory scale, usually funded by government.
3. The first technology studies, taking the development out of the laboratory to pilot or demonstration scale, often funded by venture capital suppliers.
4. 'First-of-a-kind' full-scale plant operating commercially, often funded by commercial banks in partnership with equity participants, equipment manufacturers and potentially governments.

Venture capital

The Working Group discussed the philosophy of this financing trajectory with Mr Jan Dekker, Managing Director of venture capital firm Cleantech Ventures Pty. Ltd.[3] Cleantech Ventures is a specialist venture capital fund manager focused on investments in companies commercialising clean technologies. Cleantech Ventures has in the past invested in several water sector-focussed companies.

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[3] For more information, please visit: http://www.cleantechventures.com.au/

Mr Dekker (speaking in a personal capacity) confirmed that a technology proponent desiring funding from any venture capital firm must submit a detailed business plan or information memorandum that includes (but is not limited to):

- management team skills and experience for the venture;
- technology development and commercialisation plan;
- intellectual property status and plan;
- target markets and channels;
- customer engagement strategy;
- investment amount sought and proposed use of funds;
- cash flow and profit and loss forecasts; and
- proposed exit strategy for investors.

Generally, venture capital firms seek to invest in companies with a new technology with growth prospects, and where they can realise an exit from the investment in approximately 3-5 years, ultimately generating a return on investment of 5-10 times the funds invested. This is a high rate return that is designed to compensate (in a portfolio sense) for the risks associated with each investment, noting that a significant number of such investments will ultimately not succeed.

Key negative issues relating to venture capital investments in the water sector relate to high capital intensity, conservative channels of technology adoption (i.e. water companies) and a highly regulated water sector into which the investee companies need to penetrate/comply.

Equity investment

The Working Group interviewed the Plenary Group (the sponsor, developer and investor in the Barwon Water Biosolids project). Plenary Group is an international long-term investor and operator of public infrastructure. This includes finance, planning, design and construction, asset management and operations. The firm has 11 PPPs in the tourism, health, defence and water areas in Australia. It has 34 projects valued at $21B and 60 directly engaged specialist personnel in Australia and North America.

Plenary Group invests in projects like the Barwon Water PPP using a Project Finance type structure. This type of structure uses non-recourse financing from banks with their asset as the only security, and require both technology and market risk to be minimised before the investment, to reflect the credit metrics, technical risk analysis and the investment return. These structures are highly leveraged (80-85% debt) and the risks are transferred by the State or government agency to the private sector. A credit-worthy sub-contractor, Trility, (formerly Water Infrastructure Group), is used to design, construct and operate the facility.

According to the Plenary Group, there is massive appetite for infrastructure projects among investors, provided the risk and returns are balanced. Partnerships with State governments with steady cash flows will find investors. Greenfield projects present higher risk so higher returns are required, whereas established project partnerships could stand a lower equity return[4].

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[4] For more information, please visit: http://www.cleantechventures.com.au/

Strategic investment analysis by water corporations

State-owned water corporations and PPPs are expected to use the capital asset pricing model (CAPM)[74].

The CAPM calculates a weighted average cost of capital (WACC) from the cost of debt and cost of equity. In order to calculate their cost of equity (kE), most state corporations are required to assume the historic 'share market risk premium' of 6%, and then apply the CAPM equation:

$$k_E = R_F + \beta(R_M – R_F) \qquad (1)$$

where: k_E is the cost of equity.
β is the appropriate 'beta factor' for risk of the firm or project compared to the share market.
R_M is the share market risk premium (6%)[75].
R_F is the risk-free rate (10 year government bond rate for the last 6 months)[76].

In other words, in their financial analysis of strategic investments (such as resource recovery facilities), the state-owned corporations are expected to assume they have similar risk to privately owned corporations and to deliver a return on equity to the government appropriate to the risk.

The 'beta factor β' is a measure of risk relative to the share market as a whole. If β=1.0, then the company concerned has the same risk as the share market, while if β<1.0, then the company has a risk lower than that of the share market. For water infrastructure, the value assigned to β by governments is 0.5[74]. This means that the risk, and hence the required return on equity, is similar to the low risk end for public companies on the share market.

The after tax weighted average cost of capital (WACC) for a water utility is then calculated from:

$$k_C = \text{WACC} = (D(k_D)(1\text{-tax}) + E(k_E))/(D + E) \qquad (2)$$

where: k_C is the weighted average cost of capital (WACC).
D is the relative interest-bearing amount of debt of the organisation.
E is the relative amount of equity of the organisation.
k_D is the cost of debt (interest rate paid) of the corporation.

Typically for an Australian water corporation at the present time, the nominal WACC is given by combining equations (1) and (2) above with typical levels of debt (55%) and equity (45%), cost of debt (6%) and cost of equity using the CAPM equation (1) with β = 0.5, RM=6% and RF = 3%:

$$\text{WACC} = k_C = (55\%)(6\%)(1\text{-}30\%)+(3\%+0.5(6\%\text{-}3\%))(45\%) = 4.3\%$$

where D = 55% and E = 45%[77]

A new investment in resource recovery is likely to have more risk than existing business operations for a water utility. In the case of resource recovery this could include technology risk and market risk for new products. Therefore, it is likely that the β value will be higher for a new resource recovery project. This in turn implies a higher required return on equity and hence WACC. A higher level of WACC implies greater discounting of future cash flows to determine the NPV. Discussions have been held with water companies as part of the present project and this is indeed the case. In some cases, discount rates in the range 8 to 11% have been cited as the hurdle rates for new projects. The implication of this is that there is greater emphasis on the importance of capital than on operating costs and revenue streams with a higher discount rate. This is appropriate if the risk is indeed higher.

Definition of net present value

The Project Lead of this report has noticed in many publications from the water sector, that the sector tends to use the term 'net present value' or 'NPV' as representative of 'net present costs'. In other words, the water sector 'NPV'[78] is calculated from a sum of capital costs and discounted operating costs without including all revenue streams. Strictly speaking, this is an inappropriate use of the term NPV, although it is commonly used to evaluate project proposals in the sector (e.g. Yarra Valley Water).

Higgins, in the book 'Analysis for financial management' provides a rigorous methodology for the calculation of true NPV. It involves the following sequence of calculations for every year of an investment life:

EBITDA[5] = revenue – costs

EBIT[6] = EBITDA – depreciation

Free Cash Flow = EBIT (1 – tax rate) + depreciation – capital investments

NPV = sum of (all annual free cash flows discounted using the WACC)

In this way the true NPV gives an indication of whether or not value is being created for the firm or entity concerned. It also avoids undue confusion. If the true NPV is positive, then value is being created for the firm. If negative, then value is being destroyed. If NPV = 0, then the firm is just earning the cost of capital, so the investment is marginal.

A higher discount rate than WACC may be used to discount the free cash flows (FCF). Higher risks in an investment are consistent with the use of a higher discount rate to provide a hurdle rate for the investment.

It is important that the correct cost of capital is used in the analysis of an investment proposal. If the FCFs are nominal (i.e. include an adjustment for the annual inflation rate), then the cost of capital (or WACC) should be based on nominal interest rates and cost of equity. On the other hand, if the free cash flows in the NPV calculation are real (with no inflation adjustment) then the interest rates and cost of equity must also be real. Interest rates are normally quoted as nominal, so the inflation rate must be deducted from these to obtain the real cost of debt and cost of equity in the NPV calculation outlined above.

Value at risk in an investment

Rather than increase the discount rate for higher risk in an investment, an alternative approach is to use probabilistic methods to produce a probability distribution for NPV. For example, probability distributions for expected capital costs, prices of product and operating costs could be proposed. The NPV could then

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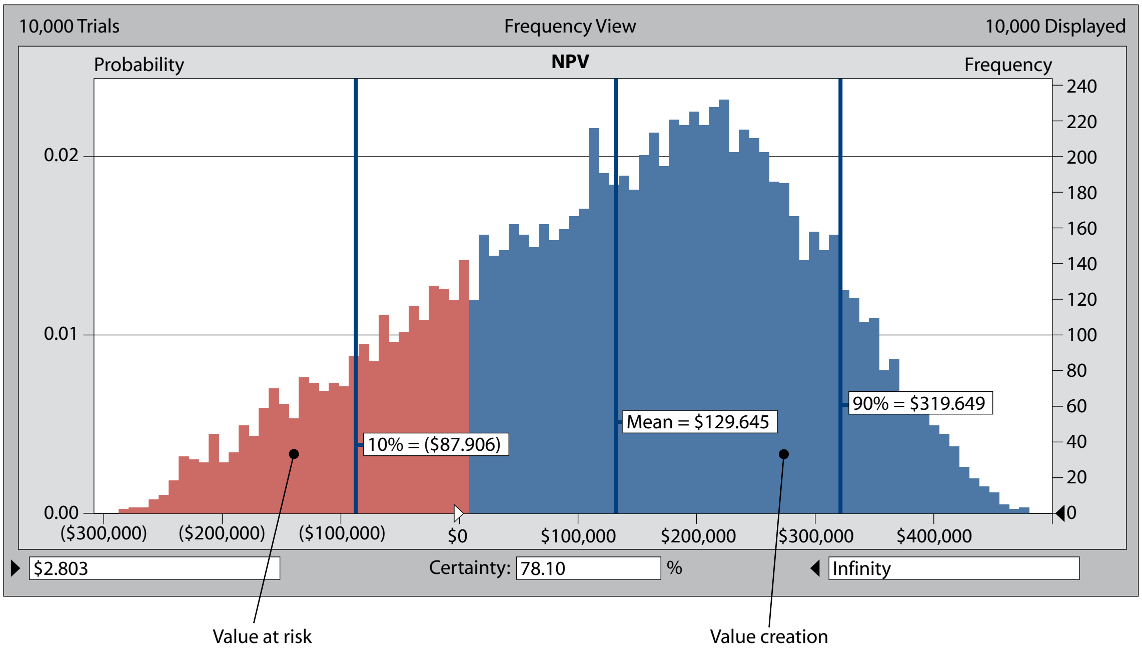
[5] EBITDA: Earnings Before Interest, Taxation, Depreciation and Amortisation
[6] EBIT: Earnings Before Interest and Taxation

be calculated (using the above methodologies) to produce an output probability distribution of NPV. For a given WACC, the proportion of NPV values less than zero can then be determined: this is termed the 'value at risk'. Since value is being destroyed at values of NPV less than zero, only a small probability of this occurring is desired. Figure 12 shows a hypothetical NPV probability distribution calculated in this way. In this illustrative example, the probability of NPV<0 is 22%, as can be seen from the 'Certainty' parameter below the graph (in this case 78% 'certainty' that the NPV is positive).

Figure 12 NPV probability distribution showing 'value at risk' (red section where NPV<0).



In Chapter 8, a probabilistic NPV approach has been adopted in order to analyse some of the future technology and resource recovery options.

Financial regulation of water utilities

State governments in Australia regulate the rates of return required from the water corporations they own. This is achieved through state government Treasuries and the application of the CAPM, described above.

Water prices are generally regulated by state-appointed independent pricing regulators. There are two models for price regulation: (i) price monitoring (e.g. South-East Queensland); and (ii) building blocks cost-based regulation (e.g. Victoria and NSW metropolitan). The 'building block' methodology involves the following steps:

1. determination of the regulatory period (e.g. five years);
2. assessment of service outcomes for each of the regulated services that the water utility proposes to deliver in order to validate that they reflect government (including regulator) obligations or demonstrated customer needs; and
3. establishment of the following 'building blocks' in accordance with the governing criteria, to:
    - establish an efficient level of operating expenditure;
    - establish an efficient level of capital expenditure;
    - calculate the regulatory asset base;
    - apply a rate of return to the regulatory asset base; and
    - establish the tax allowance.

These 'building blocks' determine the forecast required revenue for the water utility to deliver on its service outcomes and obligations. Prices are then set to achieve the required revenue, taking into account forecasted demands.

In Victoria and other jurisdictions, incentives are built into the pricing framework. For example, where a water utility's actual operating costs during the regulatory period exceeds the benchmarks used to set prices because of inefficiency or additional expenditure on other activities, the water utility is required to manage this rather than increase prices to customers. When a water utility identifies additional ways to improve the efficiency of its operations during the regulatory period (which reduces its operating costs) it allows the water utility scope to either improve services to its customers or to reduce prices below the approved maximum.

In Victoria, the services to be regulated by the independent economic regulator, the Essential Services Commission (ESC), are prescribed in the Water Industry Regulatory Order 2012[79].

In Victoria, energy and nutrient recovery are typically seen as 'non-regulated' services which compete in competitive markets with other products. The ESC has no role in regulating prices for non-regulated services but it needs to be satisfied that these services have been correctly classified as not related to regulated services, and that the costs of these services are accurately identified and excluded from the regulated cost base. A water utility must demonstrate in its price submission that the costs of non-regulated services have been excluded from its expenditure and price calculations. Whether or not a water utility would 'ring-fence' a resource recovery business from a WWTP and/or outsource it to others is an open question. However, there is at least one example in Victoria (Barwon Water Biosolids Management project) where this has been permitted. This price regulation of state-owned water utilities, does, however, complicate strategic financial decision-making within utilities.

Financial modelling

A number of financial models have been developed as part of this study. All are based on the basic NPV calculation on discounted free cash flows using the method outlined above. Further details on this financial modelling are given in Appendix 6.

The financial models developed have been applied to:

1. Struvite recovery in the USA for a group of water utilities using struvite recovery to lower operating costs through avoided chemicals and operations and maintenance costs.
2. Possible struvite recovery in Australia using data from Yarra Valley Water and Jacobs Consultancy. Also included in this analysis for comparison purposes is struvite recovery in Australia using data from the *Affordable and Sustainable Water Recycling through Optimal Technology Integration (ASWROTI)* study currently underway and using capital cost data from the consultant firm GHD.
3. Recovery of ammonium sulphate in liquid form in the United States using data from Tsuchihashi *et al*. (2011)[80] analysing this opportunity for the District of Columbia Water and Sewer Authority.

Further analyses using probabilistic NPV techniques for newer technologies are also presented in Chapter 8.

Struvite resource recovery business proposal case studies in the United States of America

Business case studies on Water Resource Reclamation Facilities (WRRFs) in the United States and Canada have been reported by Latimer *et al*., (2014)[7]. Of the 20 water treatment facilities studied, six have implemented (or are about to implement) a nutrient recovery process, seven have performed desktop evaluations and seven have performed initial evaluations. The following were the main conclusions from the Latimer *et al*. report:

1. Of the six facilities that had implemented (or were about to implement) a struvite recovery process, four installed an Ostara process and two installed a Multiform Harvest process. Reported sidestream phosphorus removals ranged between 80-90% and ammonia removals ranged between 7-19%.
2. The drivers for the investment in a struvite recovery system were mainly:
   a. existing or forthcoming stringent phosphorus removal limits for effluent waters (< 1 mg/L);
   b. high operating costs associated with the addition of ferric or alum chemicals to lower the phosphorus;
   c. high costs associated with sludge disposal, and forthcoming limits on sludge disposal to land; and
   d. nuisance struvite formation in equipment and pipelines in the facilities and associated high maintenance costs.

The revenue stream from the sales of struvite as a fertiliser was seen in the WERF report as a useful but not dominating driver for the installation of a struvite production facility.

Financial calculations were undertaken in the present study to further understand these WERF case studies. In essence, the analysis calculated the internal rate of return (IRR) for the six cases. The financial calculations included in the WERF report were apparently undertaken by the water companies themselves, and were presented in terms of 'present cost'. It is not clear from the reports whether the actual or proposed investments are really value-creating and the methodologies for financial calculation are essentially unknown. For this reason, it was decided in the present study to re-analyse the WERF data (where it was available) using the above standardised and rigorous method to calculate the NPV for the case study investments listed.

The discount rate in the discounted free cash flow calculations was varied to determine IRR of the investment in struvite recovery in the various WERF business case studies, where it was possible to do so. This parameter, which represents the rate of return on the investment when the NPV is zero, was not calculated in the WERF study by Latimer *et al.*[7]

The investment revenue from struvite sales as a fertiliser in the market may not be sufficient to meet both the operating costs and pay back the capital at an acceptable return to the investor. However, in the context of the drivers mentioned above, the costs avoided as a consequence of investment in the struvite facility are valid as negative costs in the financial analysis contributing to increasing earnings as Earnings Before Interest, Taxation, Depreciation and Amortisation (EBITDA). If operating costs can be avoided, then EBITDA increases. This then flows through to increased free cash flows and hence NPV through the relationships above (also see Appendix 6).

The Free Cash Flows (FCF) determined in this way from the WERF data (including extra costs associated with the struvite facilities and the cost savings) were discounted at a nominal cost of capital of 5% (the same as in the WERF study), and these were then summed over 25 years to get the NPV. To calculate the IRR, the discount rate was adjusted until the NPV ~ = 0.

Table 7 shows the calculated IRR values for several of the actual and proposed investments in struvite recovery in Canada and the United States, taking into account the avoided costs in the WERF report by Latimer *et al.*[7] Also included in the table are the drivers in each case study that enabled the business case for struvite production.

The case studies in the WERF report had IRRs between 5.9% and 21% (with a mean value of 12.1%). There was a wide range of IRR values depending on the circumstances of the costs avoided through the struvite investment. Nevertheless, the investments are all NPV positive and have good rates of return.

Table 7 Calculated Internal Rate of Return (IRR) for recent struvite production case studies in the USA and Canada

WERF case study number	Calculated IRR (%)	Drivers for struvite production investment
1	8.8%	**Virginia USA.** 30 MGD. P: 2 mg/L down to 1 mg/L, N: 8 mg/L to 5 mg/L *Drivers:* Nutrient limits (regulations); nuisance struvite formation, unstable bio-P performance; sludge disposal savings; oxygen savings; methanol savings.
5	7.8%	**Georgia USA.** 50 MGD. *Drivers:* Undisclosed stringent P limits (regulations); additional P loads; nuisance struvite; future increased P loads on facility – investment needed; Ferric chloride, alum and $Mg(OH)_2$ savings.
10, 11	21.0%	**Alberta, Canada.** (Two WWTPs, desktop study, planning a Ostara struvite recovery system in 2016), 96 MGD and 20 MGD. *Drivers:* Emerging stringent P limit (0.5 mg/L); Alum addition to biosolids reduces bio-available P; nuisance struvite formation; increased capex and O&M; Large sludge disposal costs ($2.9 M/year); avoidance of chemical usage ($1.1 M/year); struvite fertiliser revenue $304 k/year.
12	5.9%	**Florida USA.** 143 MGD. Current NH_3-N 21.6 mg/L, TP 1.2 mg/L. *Drivers:* Ocean outfall future stringent requirements (< 3 mg N/L, <1 mg P/L); nuisance struvite in anaerobic digesters and centrate pipelines; savings in ferric chloride (~$0.5 M/y); savings in new ferric feed facility (capex and opex); sales of struvite. Struvite capex $4,900,000.
13A 13B	7.8% 9.8%	**Florida USA.** 100 MGD. Current TP 1.97 mg/L, NH_3-N 19 mg/L. *Drivers:* 60% of effluent must be re-used (regulations - varies depending on the final concentrations); nuisance struvite formation in digesters and pipelines; future stringent effluent limits; savings on ferric sulphate, capital costs of chemical facilities, operations and maintenance costs.

In Table 7, all the IRR values are above the cost of capital assumed in the WERF study (WACC=5%, nominal, after tax). This means that they are not only financially viable but are good investments. In some cases the IRR is appreciably above the cost of capital. This means that investment in struvite recovery is value-creating for the firm concerned, taking into account the 'avoided costs' at the facility associated with trying to reach the low phosphorus and nitrogen limits through chemical addition or associated with high maintenance or sludge disposal costs. The value creation in some cases is of the order of millions of dollars.

Also, as seen from Table 7, there is clearly a wide range of IRR values depending on the local circumstances. This is because each case study is different, with different regulatory and cost drivers. The 'costs avoided' vary significantly from case to case. The regulatory framework and requirements are important in driving these financial outcomes. Therefore, each nutrient recovery investment strategy needs to be considered on its merits in order to take the individual circumstances of the water treatment company and its assets, as well as regulatory requirements, into account.

Financial analysis of struvite recovery in Australia

Potential struvite recovery from digester sidestreams has been financially analysed in this study using two Australian data sets. The data correspond to high-level cost estimation only. The analysis presented here is aimed at understanding the price of struvite that is needed to cover the operating costs and capital costs of investing in struvite recovery, without avoided costs.

The first data set was from a study by Yarra Valley Water for a new 45 ML/d Kalkallo WWTP North East of Melbourne. The capital and operating costs for this facility were estimated by Jacobs Consultancy for Yarra Valley Water and were made available to the present study. Details may be found in Appendix 6.

The second set of data was from the ASWROTI study[81]. The struvite facility in this case was part of a broader study of several new technology options. The capital cost data was estimated by GHD. The cost contingencies of the National Energy Technology Laboratory (NETL) of the United States Department of Energy were applied to the bare erection costs to obtain the total cost. Details can be found in Appendix 6.

In each case, the sensitivity of the NPV of the investment to the price of struvite was determined using the discounted FCF method outlined above. The discount rate was the real after tax cost of capital of 2.5% for both cases.

The capital and operating cost estimates for the two cases were not the same. The costs for the two cases are shown in Table 8 below, along with the calculated struvite price to breakeven (i.e. NPV = 0).

Table 8 Capital and operating cost estimates for potential struvite recovery from digester sidestreams in Australia

Cost item	Kalkallo WWTP (45 ML/d)	ASWROTI data (100 ML/d)
Total capital cost	$2,960,000	$1,561,000
Operating cost (per year)	$524,000	$882,000
Production rate	1,008 kg/d	2,416 kg/d
Struvite price required for NPV = 0 ($/tonne)	**$1,150**	**$2,000**

The two different sets of data from separate sources show that the struvite price required to just earn the cost of capital for a firm investing in struvite recovery is in the approximate range of $1,150-$2,000 per tonne. Unlike the case studies from the USA above, no 'avoided costs' have been taken into consideration in this analysis.

This is because the avoided costs due to the struvite production alone were unavailable for these generic cases. The price of struvite required is calculated to be significantly higher than bulk synthetic fertilisers (up to 3 times higher, or more), and this shows that an investment in struvite recovery that relies solely on the selling price of struvite to provide revenue is likely to be uneconomic in Australia. To make struvite recovery economic either: (i) boutique marketing would be required to raise the struvite price; or (ii) extra operating costs aimed at lowering phosphorus levels are present and these can be avoided through the alternative investment in struvite recovery.

The result from this analysis is different in terms of financial viability compared with the US study above. This is because in every case in the US study there were significant avoided costs associated with methods to reduce phosphorus levels in effluent waters. These included the costs of chemicals (alum and ferric additions), maintenance and sludge disposal. If these avoided costs were taken into account in the struvite price analysis for the Australian cases here, the struvite price required for breakeven would fall and the investment could be financially viable, depending on the level of the avoided costs. In individual WWTP cases, the avoided costs need to be individually evaluated and included in order to make the financial case for or against struvite production. These costs will be specific to each case and will depend, for example, on the regulatory limits on phosphorus in effluent water and the treatment processes employed to meet them.

Financial analysis of ammonia stripping for ammonium sulphate

The simplest technology for removing ammonia from a wastewater sidestream is to raise the water pH and then use blown air to strip the ammonia from the liquid. The resulting ammonia–air mixture is then contacted with an acid to make an ammonium salt in solution. The acid could be either nitric or sulphuric to make ammonium nitrate or ammonium sulphate respectively. The contact of the air with water and then with the acid is typically carried out in two packed towers in series.

Tsuchihashi *et al.* (2011) have analysed the production of ammonium sulphate in solution by this method as part of a study by the District of Columbia Water and Sewer Authority (DC Water) together with the engineering consultancy firm, AECOM.
They determined that there was a sufficient market for a liquid ammonium sulphate product in the Mid-Atlantic region of the USA. They found that the market price at the plant for the aqueous ammonium sulphate was $US22/ton after adjustment for freight charges.

The Tsuchihashi *et al.* study was undertaken using two chemicals to raise the water pH: (i) sodium hydroxide (NaOH) or, (ii) the less expensive lime. A financial analysis was conducted by the authors for ammonium sulphate production, where capital costs were assigned as $US12.77M and the operating costs were $US7M per year for NaOH and $US3.6M per year for lime. The authors calculated the '20 year net present worth' of these two alternatives as $US141.2M and $US121.8M, respectively. As highlighted elsewhere in this report, these numbers do not give an indication of whether value is being created or not by this investment. They are actually of the wrong sign (they should be negative since they are costs) and do not give any indication of the price of the product required to actually create value. For this reason, the true NPV has been calculated in the present study and the price of ammonium sulphate product required to just earn the cost of capital (i.e. NPV=0 at 5% WACC) has been determined.

The true NPVs for the two alternatives at a product price of $US22/ton are approximately negative $US82M and negative $US33M (NaOH and lime additions respectively). The required ammonium sulphate product price increases to achieve NPV = 0 are approximately 7 times for NaOH and 4 times for lime chemical addition. This represents a very uneconomic business case, driven by the high operating cost of chemicals.

The situation in Australia for this type of process and market is probably worse than in the United States. For instance, the capital cost of the facilities is likely to be 50 to 100% higher. Also, the transportation costs in this country for a liquid product would probably be prohibitive and chemical costs could be higher. The product could be crystallised, but the capital costs for this additional facility (perhaps over $A10M according to Tsuchihashi *et al.*) would add further to the required product price and position it well above the market price that farmers would be prepared to pay.

There are alternative, newer technologies to manufacture nitrogen fertilisers from wastewater. The economic analysis of these technologies has not been possible in this report because of a lack of financial data. If capital and operating costs could be reduced in extracting the nitrogen compounds in next generation processes then the economics of nitrogen resource recovery could become more favourable than it appears at present.

CHAPTER 8: RESOURCE RECOVERY OPTIONS FOR AUSTRALIA

Australia is characterised by urban concentration, has substantial markets for energy, potential markets for nutrient products, and relatively large and centralised treatment plants. It is also undergoing fairly strong levels of urban development, offering the opportunity to build new treatment processes, both to replace and expand existing sites as greenfield sites. This Chapter applies near term analysis (0-15 years) to identify comparative opportunities for emerging technologies in the 'established' and 'innovative' classes to identify overall opportunities.

As noted in the Technology and Markets section of Chapter 2, bare resource loads in terms of energy, nitrogen, and phosphorus can be expressed on a per person (per annum) basis. On an annual basis, each person generates 70 m^3 of wastewater, containing 0.5 GJ of energy (the analysis in this chapter assumes that any renewables financial incentives, such as Renewable Energy Certificates (RECs), apply until 2030, i.e. when the RET scheme expires), 3.5 kg nitrogen, and 0.7 kg phosphorus. These resources have an aggregate value of approximately $15 per person per year, which potentially allows revenue of up to $1.5M for a mid-sized 100,000 person plant. This represents the upper revenue limit for 'established' and 'innovative' technologies, and hence represents the scope limit for this analysis. It should also be noted that the effluent water itself can be considered a very valuable resource, with typical potable water having a value of $2.50/$m^3$ or around $175M per year, with 'Class A' recycled water having a slightly lower value than this of around $2/$m^3$. In the context of this report, however, recycled water was excluded from the scope of the study and is not considered further in the financial analysis given in this Chapter.

As noted throughout this report, releasing energy from wastewater is technically straightforward, with anaerobic digestion applicable in both direct wastewater treatment (low energy mainline), and to organic concentrates (sludge digestion). This is through existing technologies. However, these processes are not able to remove or recover nutrients, and hence enabling technologies such as mainline phosphorus recovery (adsorptive), mainline nitrogen removal through anammox, and dissolved methane recovery are the key to future efficiency improvements. These integrated and new approaches are considered here.

The main technology timeframes include:

Now to less than 5 years: Mainline anaerobic digestion, A-stage (high rate aerobic) wastewater treatment (described below), sidestream phosphorus concentrates recovery, sidestream anammox nitrogen oxidation, and mainline phosphorus recovery. Also included in this category is anaerobic digestion with cogeneration and co-digestion, leading to 100% energy self-sufficiency for WWTPs.

5-15 year timeframe: Mainline anammox, sidestream nitrogen recovery, and photo-assimilative recovery (algae, phototrophic bacteria).

25 year timeframe: Biorefineries, engineered microbial products, next generation fertilisers, bioelectrical processes, etc. At this stage these technologies are at the R&D and 'embryonic' stage and are beyond the scope of this study.

Focussing on the first two technology classes (0-5 and 5-15 year timeframes – 'existing-innovative' technologies), a number of potential future treatment options can be identified that form the basis for economic opportunity analysis. The analysis undertaken in this work, extends the analysis of the Australian Water Recycling Centre of Excellence on future treatment options considered by the *"Affordable and Sustainable Water Recycling through Optimal Technology Integration (ASWROTI)"* project[81]. The present study undertakes probabilistic financial analysis, and adds a photo-membrane recovery process to the suite of technologies considered by ASWROTI. Analysis undertaken by Yarra Valley Water on co-digestion and electrical energy self-sufficiency is also included in this financial analysis as an established technology. The five treatment processes considered are:

1. Conventional activated sludge process, utilising biological nutrient removal as a base case (timeline: available now).
2. Biological nutrient removal plus anaerobic digestion together with power cogeneration and co-digestion for energy self-sufficiency (timeline: available now).
3. The near market process of A-stage biological accumulation (high rate aerobic treatment), coupled with sidestream digestion, removal of residual nitrogen through nitrification and denitrification, and anammox treatment (timeline: available now to 5 years).
4. The near market process of anaerobic membrane wastewater treatment, coupled with the innovative (5-10 year) mainline anammox process for nitrogen removal (Low Energy Mainline) (timeline: available 5 to 10 years).
5. The developing process of phototrophic removal (in this case, through photo-anaerobic membrane bioreactors using purple phototrophic bacteria), with sidestream anaerobic treatment and nutrient recovery (timeline: available 15 years+), applying the model provided in Batstone *et al.*[13].

Economic opportunity analysis

For all these cases, relevant financial data have been gathered in order to undertake the financial analyses. This includes capital costs (including contingencies), operating costs, power requirements, electrical power generated, sludge disposal costs, and renewable energy certificates. These costs were provided by Yarra Valley Water/Jacobs (1 and 2 above) and ASWROTI/ GHD (1, 3, 4 and 5 above)[39]. In essence, each of the options above was compared with its base case, and the financial analysis was undertaken using the differences between the base case and the various options. The methodology from the previous section on financial analysis was employed to calculate NPV based on these differences. The data and the analysis are relatively complex and are detailed in Appendix 6 for all cases.

Capital costs for a WWTP vary depending on the technology option selected. In the analysis here, four options were selected for financial analysis. In the first case, (anaerobic digestion plus cogeneration with co-digestion of organic wastes) the 45 ML/d plant was compared with a conventional activated sludge WWTP base case with no digestion, cogeneration or co-digestion at the same scale. In the three new technology cases, 10 ML/day and 100 ML/day plants were compared with a conventional activated sludge WWTP of the same scales. The capital cost data for these cases is shown in Table 9 below. Further details, including capital costs and contingencies of individual process items, are given in Appendix 6.

The capital cost differences shown in Table 9 were used as the extra investment required for commercialisation the option in question. Revenues to repay this capital for the extra investment in the option included:

- sales of struvite and nitrogen products (where applicable);
- sales of electricity (where applicable);
- savings in electricity purchases;
- revenue from Renewable Energy Certificates (RECs);
- savings on sludge disposal cost; and
- waste tipping fees (where applicable).

Operating cost differences offset against revenue in the cash flow calculation included:

- general operating cost increases associated with higher capital costs; and
- use of extra chemicals as part of the new process.

Details of these operating cost differences for each option are given in Appendix 6.

Table 9 Capital costs of the WWTP options examined

Item	Base case	Co-digestion (45 ML/d)	A-stage (100 ML/d)	LEM (100 ML/d)	Photo-bioreactor (100 ML/d)
Total capital	$100M	$129.6M			
Difference to base case	-	$29.6M			
			A-stage (100 ML/d)	**LEM (100 ML/d)**	**Photo-bioreactor (100 Ml/d)**
Total capital	$148.5M		$166.2M	$173.1M	$197.6M
Difference to base case	-		$17.7M	$24.6M	$49.1M
			A-stage (10 ML/d)	**LEM (10 ML/d)**	**Photo-bioreactor (10 Ml/d)**
Total capital	$33.7M		$42.3M	$44.4M	$54.6M
Difference to base Case			$8.6M	$10.7M	$20.9M

Common facilities such as land, inlet works, tertiary treatment and decommissioning excluded. The difference in capital for the two base cases are a result of different scales of operation, exclusions and erection cost assumptions in the two cases (Appendix 6).

In addition to the base calculation of mean NPV, a probabilistic calculation of the range in NPV values was also conducted. Estimates on the range in capital costs, operating costs and electricity prices into the future were input to the analysis. Higher uncertainties for capital cost components were assumed for the more uncertain technologies (i.e. Low Energy Mainline and phototrophic). For the ASWROTI cases, two scales of operation were considered: 10 ML/d and 100 ML/d, whereas the co-digestion case considered a scale of 45 ML/d. In all cases, electricity prices were assumed to increase at 1.5% per year, together with a probabilistic range and appropriate starting electricity price now as a function of scale of operation. Details of these probabilistic calculations are given in Appendix 6.

In all the cases below the analysis is 'high level', using relatively uncertain costs and revenues, as well as contingencies. The analysis should not be relied upon for investment decisions. Any potential investor should undertake their own investment analysis using more refined data and assumptions before considering investment in any of the options discussed. As shown later, the assumptions made can significantly change the financial outcomes, so any assumptions made by an investor should be carefully considered.

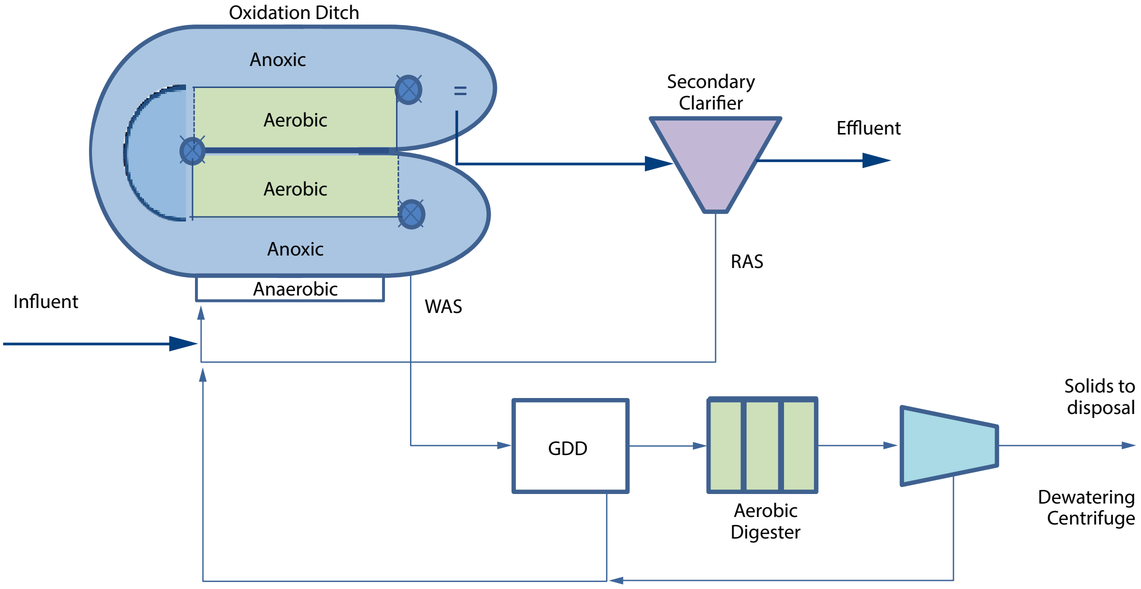
Conventional biological nutrient removal

The flowchart for the base case, conventional biological nutrient removal, is shown in Figure 13. This provides the base case for the economic opportunity analyses that follow.

The base case consists of a carousel biological nutrient removal process, medium-long mean biomass retention time (sludge age – 20 day nominal). This represents the majority of small-medium (less than 100,000 person) processes. All nitrogen is removed by conventional nitrification-denitrification. Most of the larger nutrient removal plants in Australia are also similar to this process (e.g., Oxley Creek in Brisbane is a carousel process), but may replace the carousel or ditch process with a compartmentalised bioreactor with internal recycle streams (e.g., Bardenpho, UCT), reduce the sludge age to reduce energy consumption, and possibly replace the aerobic digester with anaerobic digestion. No energy generating processes with the base-case design are used.

In fact, a larger scale, short-moderate sludge age (12d) activated sludge biological nutrient removal (BNR) process with anaerobic sludge digestion, and possibly primary sludge digestion (e.g., Luggage Point Brisbane) is probably the most efficient form of conventional process. This was assessed as the base option in Batstone[13], and as quantified in this paper (and elsewhere in this report), allows 24% of the plant energy consumption to be recovered from anaerobic digestion of primary and activated sludge. In addition, energy consumption related to operation of the aerobic digester is offset by energy generated by the anaerobic digestion for a net increase in energy efficiency of approximately 34% versus the base case utilised here[81] and shown in Figure 13. This option also enables struvite recovery from the anaerobic digestate reject. This demonstrates the energy efficiency gains enabled by careful selection of conventional technologies. Capital cost, particularly at the 100ML/d scale is likely to be the same or slightly higher[6], but anaerobic digestion is more marginal at smaller scale (e.g., 10 ML/d), due to a number of reasons, including longer sludge ages, lack of gas capture and utilisation equipment, and cost scaling of this capital item[89]. For this analysis, we have restricted the base case to that in Figure 13, as being ubiquitious, and generally scalable across the range of plant sizes, while noting that more efficient options are available, and have been quantified in the literature.

Figure 13 Conventional biological nutrient removal.

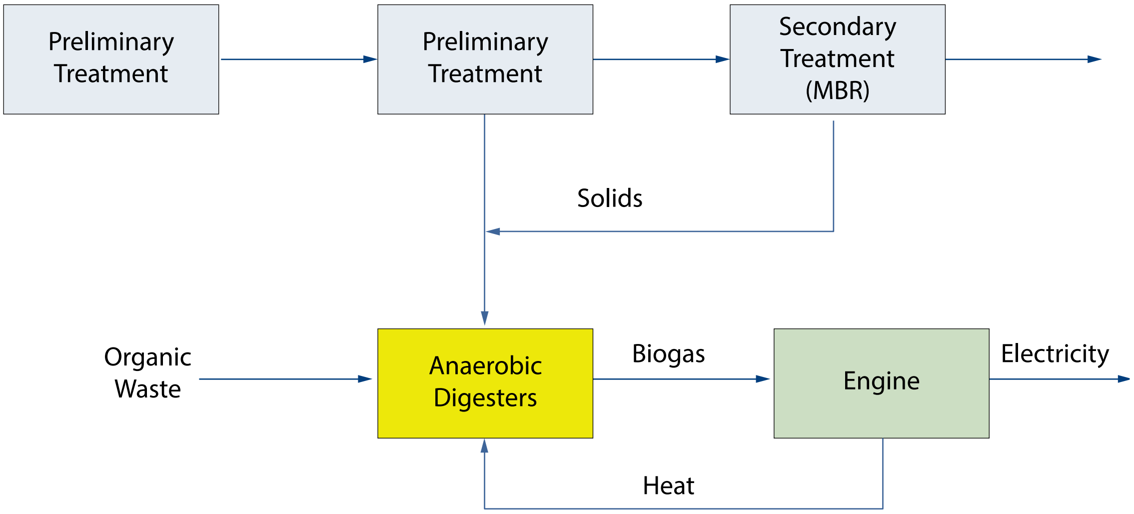


(From[81], used with permission)

Anaerobic digestion plus cogeneration and co-digestion

Figure 14 shows the flowchart for this existing technology. It was compared with a base case of a WWTP with no digestion, but with similar sludge handling facilities at a scale of 45 ML/d. It was assumed that sufficient co-digestion is occurring for the co-digestion case to provide 100% of the electrical power requirements for the plant, whereas the base case had no power generation. The objective of the analysis was to examine whether investment in anaerobic digestion and co-digestion for electrical energy production is financially viable in its own right at a relatively high purchased price of electricity ($200/MWh). It should be noted here that the price of electricity purchased by water corporations is generally confidential and the price chosen here is at the higher end of the range. The prices vary considerably (from about $120/MWh to $200/MWh) depending on the electricity retailer and individual purchase contracts. Electricity prices are also difficult to predict into the future especially for large consumers such

Figure 14 Flowchart for anaerobic digestion plus cogeneration and co-digestion.

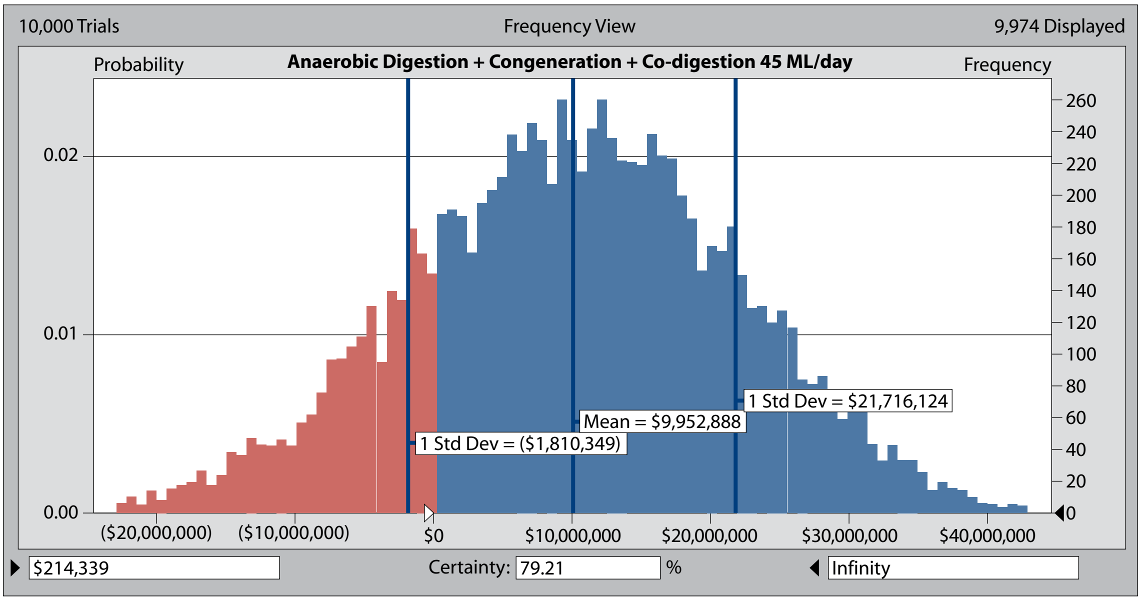


In the case evaluated here 'Engine' refers to a reciprocating internal combustion engine driving an alternator to generate electricity. A gas turbine could also be employed for this duty. MBR: Membrane Biological Reactor.

as water utilities as these are individually negotiated contracts. A sensitivity analysis on this parameter has been undertaken and is described later in the Chapter to show the impact of this assumption.

The probabilistic NPV distribution from this analysis is shown in Figure 15. As can be seen, there is wide variation in predicted NPV, depending on the capital and operating cost, revenue and electricity price uncertainties. The 'value at risk' in this case for the assumptions listed is about 21% (red area on the distribution). This means that the investment has a positive NPV and there is only a moderate risk that the investment will not create value. This could be for cases where (say) the purchased electricity price is not as high as expected, or the capital costs are higher than anticipated in the probabilistic analysis. Another important parameter in this case is the revenue stream from imported organic waste. As shown later, this benefit is relatively important in the financial outcomes. A further parameter that could be considered in this analysis is the optimum size of the anaerobic digester. Digester size is a function of the amount and characteristics of the co-digested organic waste and further analysis (not undertaken here) could determine the sensitivity of digester size to the financial outcomes.

Figure 15 Probabilistic NPV for the anaerobic digestion plus co-digestion case.

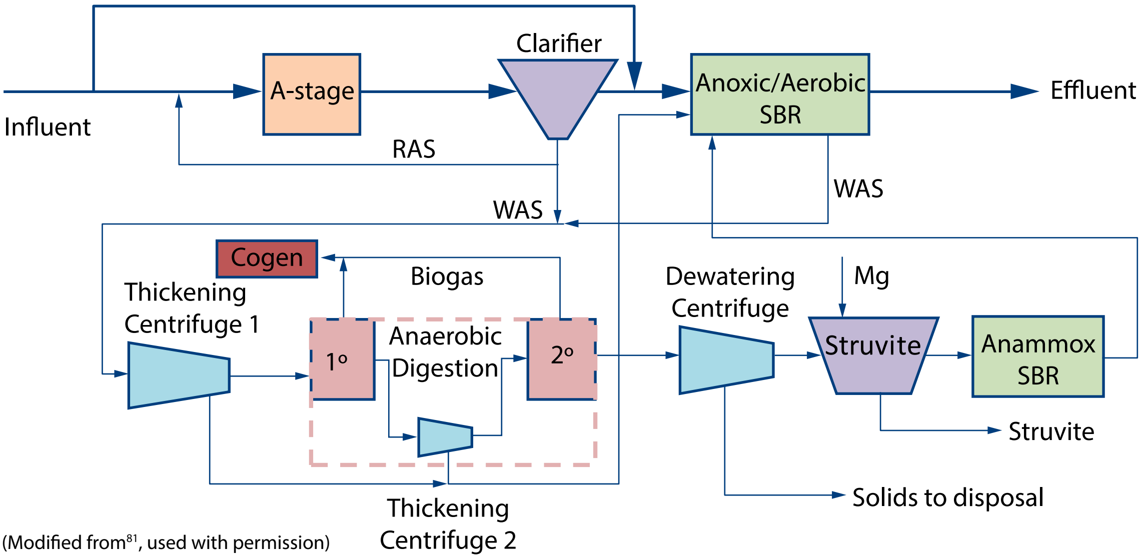


$214,339 Certainty: 79.21 % Infinity

A-stage (high rate aerobic) plus nutrient removal

In order to have a successful mainstream de-ammonification process, it is important to reduce the carbon (BOD) load prior to the mainstream de-ammonification process (a necessary condition for partial nitritation and anammox). The A-stage process is one high efficiency way to achieve this. In the A-stage case, a very short sludge retention time (0.5-3d) and hydraulic retention time (0.25-1h) A-stage reactor[10] is used to assimilate and adsorb organics, nitrogen and phosphorus from the liquid phase. The term 'high-rate activated sludge' has also been used, and is more technically correct, but less commonly used in comparison with 'A-stage'. Approximately 30% nitrogen removal is modelled to occur in this stage, which is conservative against actual performance achieved (for example in Rotterdam)[82]. Because nitrogen removal is incomplete, further nitrogen removal is achieved in a sequencing batch reactor (SBR). Sludge (WAS) is concentrated and digested in a two-stage thermophilic process, with organics recovered from the intermediate process to drive nitrification-denitrification (if required). Struvite is recovered from the dewatering centrate. Sidestream nitrogen removal is achieved by partial nitritation and anammox, which is well established in this context[83.] A summary of the A-stage plus nutrient removal process is shown in Figure 16.

Figure 16 A-stage plus nutrient removal flowchart.

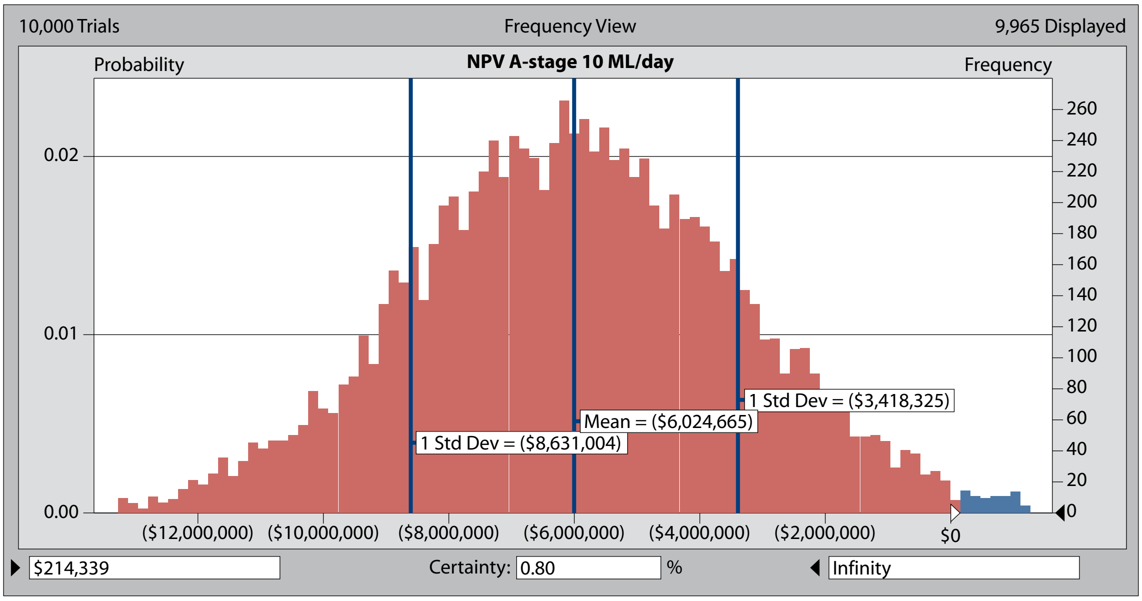


(Modified from[81], used with permission)

Probabilistic financial analysis of the NPV of this process configuration has been carried out for two scales: 10 ML/d and 100 ML/d. In each case, the differences between the base case (Figure 13) and the A-stage process were used as the investment criteria. The main avoided cost in these cases is the electrical power used and generated (Appendix 6) as well as other operating cost differences such as chemicals usage. For the 100 ML/d new technology cases following (A-stage, LEM and photo-bioreactor) the purchased price of electricity has been assumed as $160/MWh, while for the smaller 10 ML/d plants, a price of $200/MWh has been assumed. The 10 ML/d case has relatively higher capital costs per unit of water flow than the 100 ML/d case and this difference significantly affects the NPV. To illustrate this, Figure 17 shows the NPV distribution for the 10 ML/d case and Figure 18 shows the NPV distribution for the 100 ML/d case.

The 10 ML/d case is clearly uneconomic, with 100% of the value of the investment at risk. On the other hand, the 100 ML/d case has positive NPV for almost all situations, meaning that at this scale, the A-stage technology investment is excellent relative to the return required to just meet the cost of capital. This is because the capital costs at the larger scale are relatively lower than the smaller scale. For example,

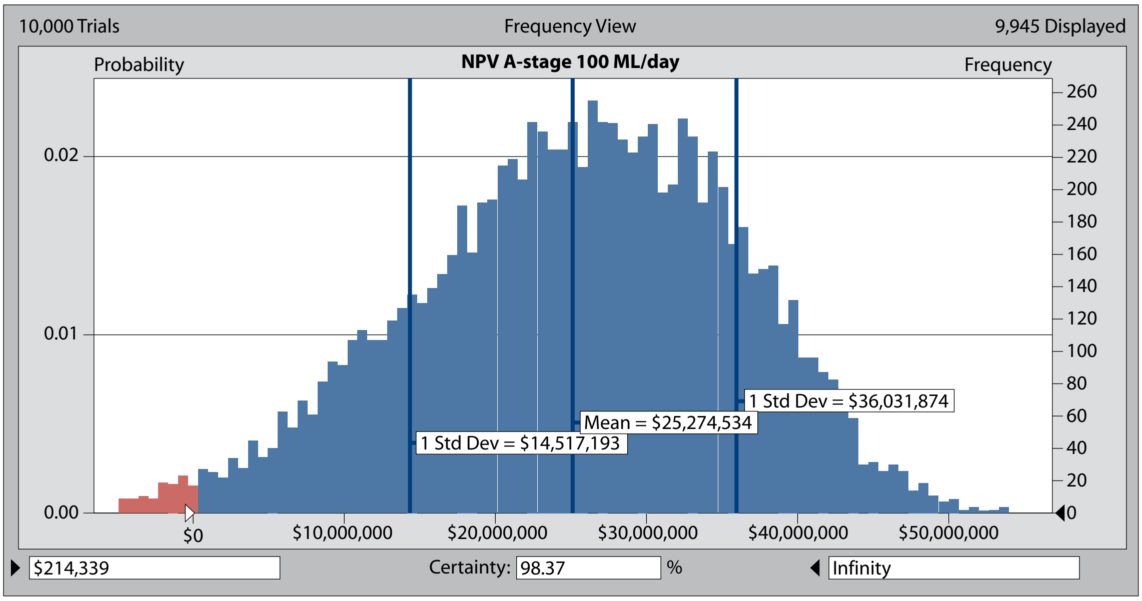
Figure 17 Probabilistic NPV distribution for the A-stage case for 10 ML/d flow.



$214,339 Certainty: 0.80 % Infinity

the capital intensity of the 10 ML/day case for the above A-stage configuration is $0.86M per ML/day, whereas for the 100 ML/day case the capital intensity is $0.18M per ML/day (for the extra capital compared to the base case). Since the revenue and operating cost differences are the same per unit of water flow, the extra capital required gives rise to a negative NPV at the 10 ML/day scale. Process complexity is also important here, since only large-scale complex processes can justify some of the additional elements like struvite production and anammox (because the capital costs per unit of water flow are lower as size increases). As shown above, at smaller scales the capital costs are proportionately higher when compared with the operating costs and this lowers the financial attractiveness. In this case, some of the more optional process steps may need to be excluded in the smaller-scale implementations of the new technologies in order to reduce the capital costs. One opportunity may be to allow process configuration flexibility depending on scale of operation and discharge regulations. As an example, a simpler process that focuses on decreased nitrogen removal (or possibly nitrification only) could be applied at smaller scale with single stage anaerobic digestion, and chemical phosphorous removal through sludge, rather than struvite precipitation.

Figure 18 Probabilistic NPV distribution for the A-stage case for 100 ML/d flow.



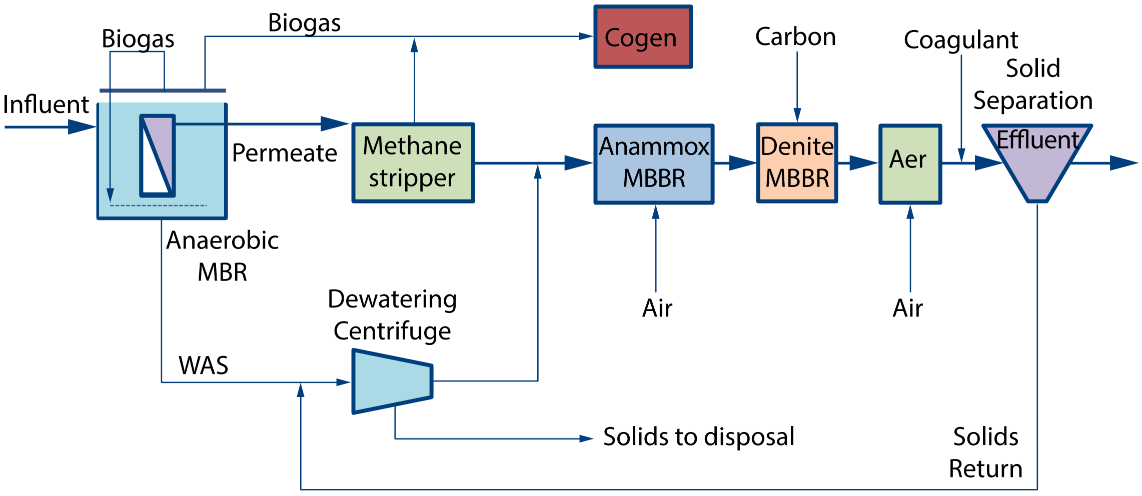
$214,339 Certainty: 98.37 % Infinity

Based on this analysis and its assumptions (Appendix 6), the A-stage (high rate aerobic) with a sidestream anammox process appears to have an attractive financial prospectivity at larger scales of operation. This is primarily due to its small incremental capital cost, high energy efficiency and attendant significant power savings, lower sludge disposal avoided costs and a revenue contribution from struvite production, the sum of which outweigh the extra costs for chemicals. Since the scale effect seems to be significant, further economic opportunity analysis of this option should include different scales of operation.

Low Energy Mainline (LEM) – anaerobic membrane bioreactor

Figure 19 shows the flowchart for this process. The low energy mainline process is further described in Batstone *et al.*[13] and consists of low energy treatment options, including an anaerobic membrane bioreactor (AnMBR), nitrogen removal via mainline anammox[7, 8], and phosphorus removal through either coagulation with iron, or adsorption[9]. As further documented in the source reference[13], a moderate AnMBR energy consumption of 0.25 kWh kL^{-1} has been chosen, rather than the ultra-low energy non-aerated AnMBR processes[10], or upflow anaerobic sludge blanket, which is very low energy, but does not produce effluent suitable for nitrogen removal via anammox. All of the processes utilised in Figure 20 are well established at pilot or full-scale except stand-alone mainline anammox, which has a number of technical barriers, including biomass retention, achieving the partial nitritation required, and achieving the required discharge limits. Because anammox results in residual nitrates, conventional denitrification is used in a moving bed bioreactor process to achieve complete removal.

Figure 19 Low Energy Mainline – anaerobic membrane bioreactor flowchart.

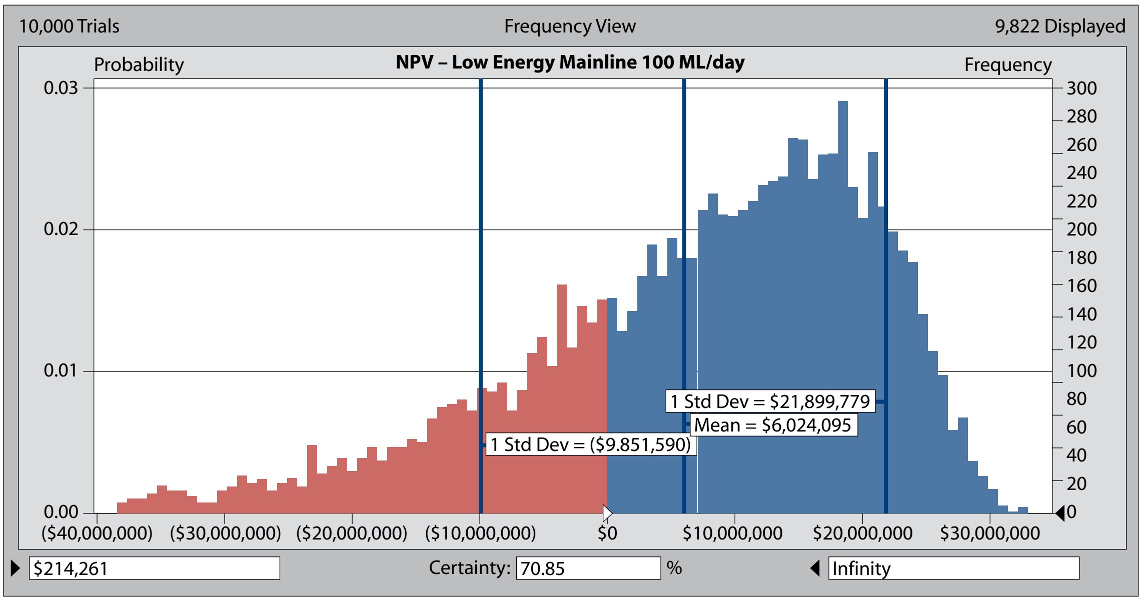


(Modified from[81], used with permission)

Probabilistic financial analysis of the NPV of this LEM process configuration has again been carried out for two scales: 10 ML/d and 100 ML/d. In each case the differences between the base case (Figure 13) and the LEM process (Figure 19) were used as the investment criteria. The main avoided cost in these cases is the electrical power used and generated (Appendix 6) as well as other operating cost differences such as chemicals usage. The 10 ML/d case has higher capital costs per unit of water flow relative to those of the 100 ML/d case and again this difference makes the smaller scale uneconomic. LEM has a higher capital cost difference relative to the base case than A-stage and the REC revenue benefit only lasts for 5 years from 2025 to 2030. This is because it is assumed that this LEM new technology will only be commercially available post-2025 and the RET scheme expires in 2030. The REC revenue stream is thus generally a relatively small proportion of the overall revenue and avoided cost streams for the investments in these technologies that are longer to commercialisation (Appendix 6).

The more uncertain technology components in the process flowsheet also have a higher standard deviation on capital costs than A-stage. All these effects change the NPV distribution relative to the

Figure 20 Probabilistic NPV distribution for the LEM case for 100 ML/d flow.



$214,261 Certainty: 70.85 % Infinity

A-stage case above. Figure 20 shows the NPV distribution for the larger scale 100 ML/d LEM case.

The LEM case at large scale under the assumptions employed has an NPV distribution that has a long tail towards negative NPVs. This is a manifestation of the assumption that there is some probability of capital costs being higher because of the earlier technology development stage of LEM. Nevertheless, the 'value at risk' is predicted to be moderate (~30%) and LEM is predicted to be economic for the average NPV. This is mainly because of large power production and power reduction savings, the REC benefit early in the life of a LEM plant built in 2025, and sludge disposal savings. These factors more than outweigh the increased chemicals used with LEM. Again, the scale up effect is predicted to be significant, since the 10 ML/d case has been predicted to be uneconomic in a similar way to the A-stage case as part of the present study (not shown here).

Photo-membrane bioreactor

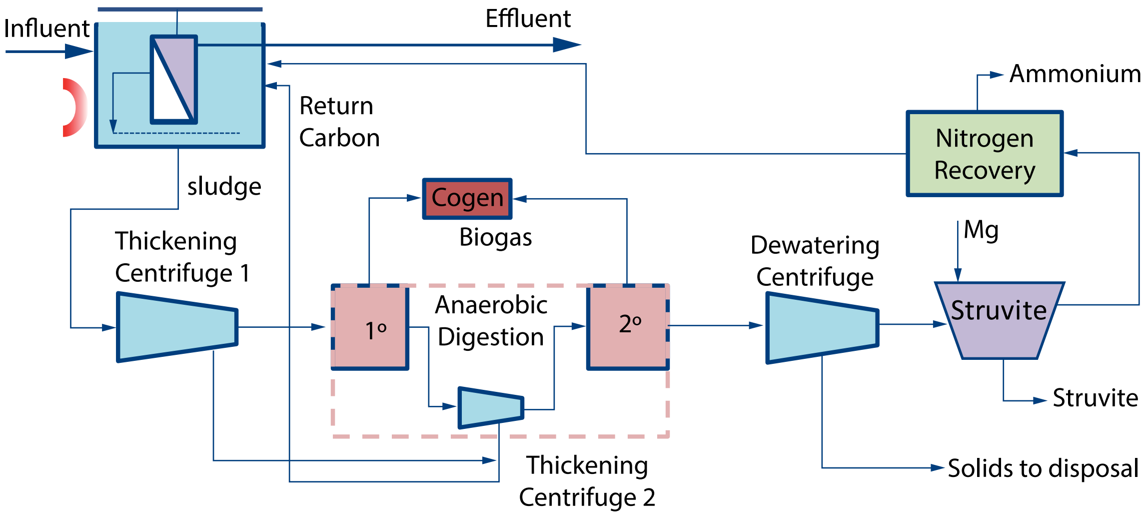
Figure 21 shows the flowchart for this process. The photo-membrane process is further described by Batstone *et al*[13] It is comparable to the A-stage process except that use of infrared light enables growth of phototrophic bacteria that enable discharge nutrient limits to be reached without further treatment[11]. Nitrogen removal is via electrodialytic recovery rather than anammox[13].

Probabilistic financial analysis of the NPV of the photo-membrane bioreactor process configuration has also been carried out for two scales: 10 ML/d and 100 ML/d. As previously, in each case the differences between the base case (Figure 13) and the photo-bioreactor process (Figure 21) were used as the investment criteria. The main avoided cost in these cases is the reduction in electrical power used and increase in generated power (Appendix 6) as well as other operating cost differences such as chemicals usage. A revenue stream is also provided by struvite production. The photo-bioreactor cases have significantly higher capital costs than either the A-stage or LEM processes. The REC revenue benefit does not apply to the photo-bioreactor case, since it is currently embryonic and will not be ready before 2030.

The more uncertain technologies also have an even higher standard deviation on capital costs than A-stage or LEM. All these effects change the NPV distribution relative to the cases above. Figure 22 shows the NPV distribution for the larger scale 100 ML/d photo-bioreactor case.

The photo-bioreactor case at large scale has an NPV distribution that has an even longer tail towards

Figure 21 Photo membrane bioreactor flowchart.

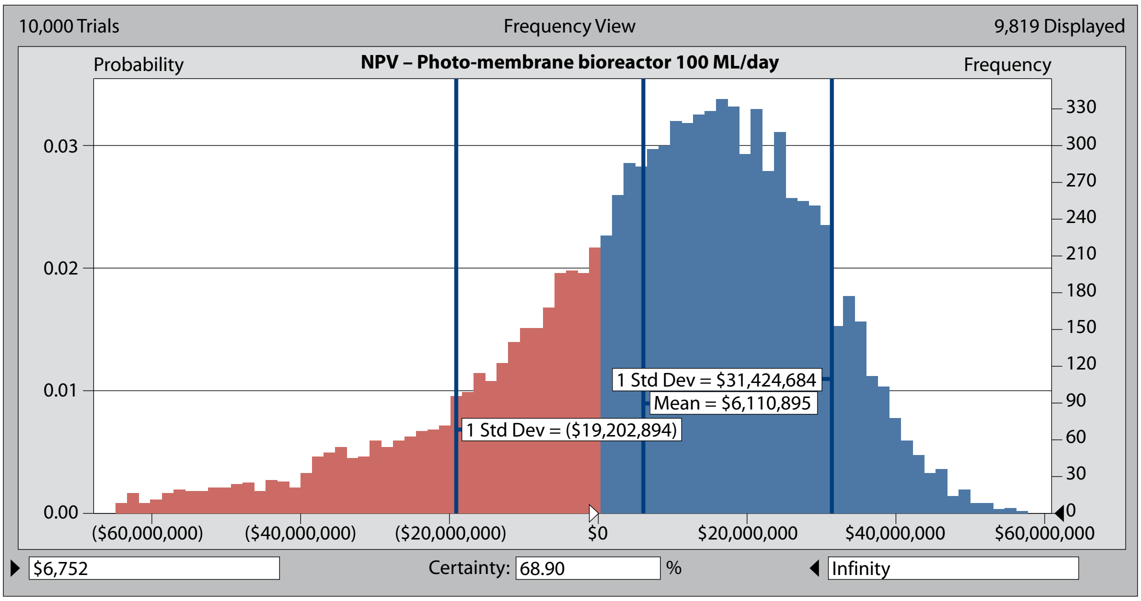


negative NPVs. This is because there is greater probability of capital costs being higher because of the even earlier technology development stage of photo-bioreactor technology. The 'value at risk' is predicted to be similar to the LEM in this case (31%) and the photo-bioreactor technology appears to be economic based on average NPV. This is mainly because of large power production and power reduction savings and sludge disposal savings, with a revenue contribution from struvite production. In this case there is no revenue benefit from the REC. There is also a significantly increased chemicals use with photo-bioreactor technology. Again, the scale up effect is predicted to be significant, with the 10 ML/d case expected to be uneconomic.

NPV sensitivities to key parameters

The NPV probability distributions presented above represent the NPV for all combinations of the financial parameters involved. However, it is useful to examine the sensitivity of the mean NPV to some of the parameters to understand their importance. This has been undertaken for several of the parameters and details are given in Appendix 6. A small number of the sensitivities are shown graphically below to illustrate their impact.

Figure 22 Probabilistic NPV distribution for the photo-bioreactor case for 100 ML/d flow.



Co-digestion case

Figures 23, 24 and 25 below show respectively the sensitivity of mean NPV to changes in the capital cost, the purchased electricity price and the customer price (tipping fees) for organic waste for the co-digestion case. As can be seen, the calculated NPV is very sensitive to all these parameters and they are critical for the financial viability of the co-digestion case. The NPV is not as sensitive to the other parameters (Appendix 6).

LEM case

Figures 26, 27 and 28 show respectively the sensitivity of the LEM case to capital costs, purchased electricity price and export electricity price respectively.

As can again be seen, the mean NPV for the LEM case is very sensitive to the assumed capital costs and purchased and export electricity prices. This means that the economic case will depend significantly on these parameters, and will thus depend on the individual circumstances of the investment (e.g. location, component manufacture costs, electricity price contracts). The sensitivities for the photo-membrane bioreactor case are similar to those of the A-stage and LEM cases (details in Appendix 6).

There is currently a large difference between the price that electricity can be bought from an electricity provider, and that at which it can be sold back to an electricity retailer. Electricity retailers presently will only pay in the order of one third the price for electricity put into the grid, compared to what they receive

Figure 23 Sensitivity of mean NPV to variation in capital cost for the co-digestion case (45 ML/day).

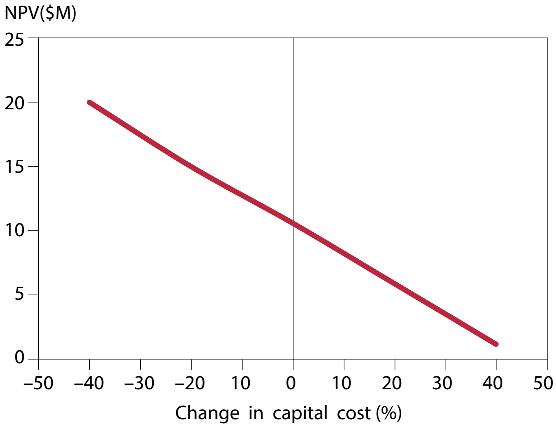


Figure 24 Sensitivity of the mean NPV to purchased price of electricity for the co-digestion case (45 ML/day).

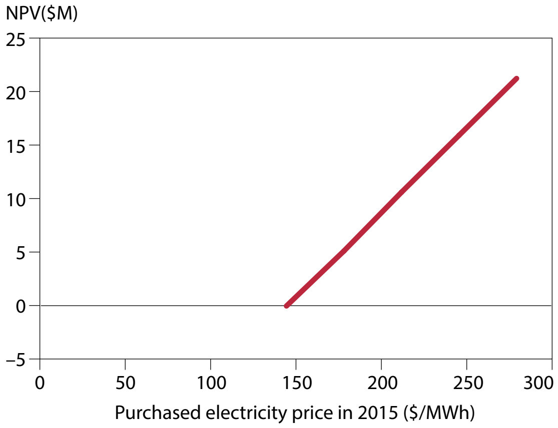


Figure 25 Sensitivity of the mean NPV to the customer price (tipping fees) for the co-digestion case (45 ML/day).

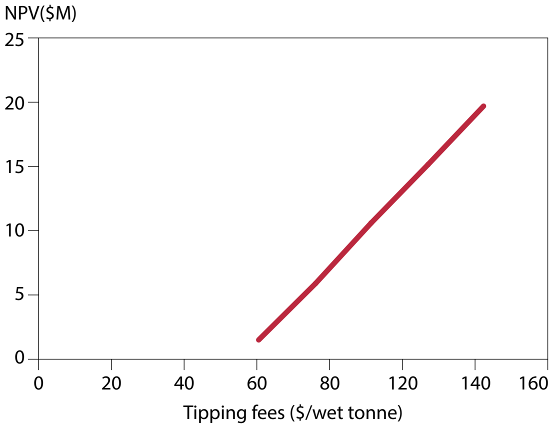
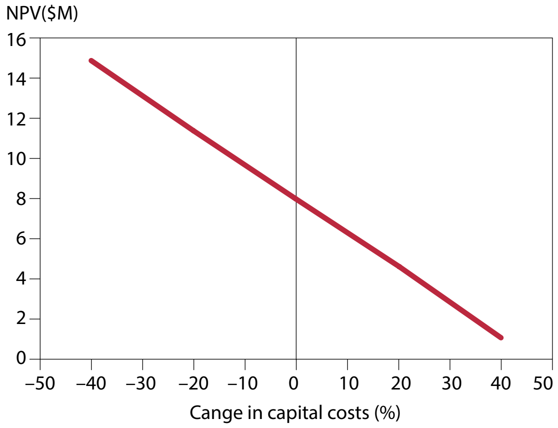


Figure 26 Sensitivity of NPV to change in capital costs for the LEM case (100 ML/day).



for selling the electricity. From a customer perspective, this makes generating electricity less viable from a financial perspective. However, from an electricity providers' perspective most of the cost is associated with transmission rather than energy production. The differential also reflects the fact that continuous generation of power is of less value for some generators than peak generation capacity. These barriers are so critical to energy recovery that it is worth investors exploring and/or encouraging new possibilities to see if the existing situation can be overcome.

While these differences in import and export electricity prices currently exist, it could be argued that there will be some 'closing of the gap' in prices in the timeframe of these financial analyses. This could particularly apply for large users/producers of power, who could potentially negotiate favourable direct bilateral purchase agreements. One method that is proving to be successful is the advent of third party providers using different, more innovative business models. These involve the offer of renewable energy at a lower cost, while assuming responsibility for the capital investment for energy generation, managing the different appetite between the risk of the energy production and supply, and doing this conditional on getting a long term contract with a customer. An example of a company doing this exists in the solar industry, where installation of solar panels on a client's property and the purchase of renewable energy are offered. Clearly, further option analysis on the financial viability of future technology options should include a more sophisticated analysis of power prices, both purchased and sold, together with innovative financing and ownership of power generation facilities.

Real Option Values of the cases studied

Luehrman (1998)[84, 85] described the concept of real options and how they might be used to value new technology choices. Luehrman's papers provide analytical methodologies on the theory of real options and the idea of business strategy comprising a portfolio of real options. Real options are analogous to call options on the share market, where an option price can be calculated today to account for uncertain outcomes in the future. The option price represents the financial value today to an investor contemplating an uncertain financial transaction in the future, where the option to abandon the investment if conditions are unfavourable is available, but where there is also a probability of investment financial upside at that investment time.

Determination of real options is a useful technique when the uncertainty is high, as in this study. The Australian Academy of Technological Sciences and Engineering (ATSE) (2010) took this concept further and calculated the 'Net Present Option Value' of new low-carbon power generating technologies in a report released in December 2010. This ATSE report provides a background to the idea of option value

Figure 27 Sensitivity of NPV to change in purchased electricity price for the LEM case (100 ML/day).

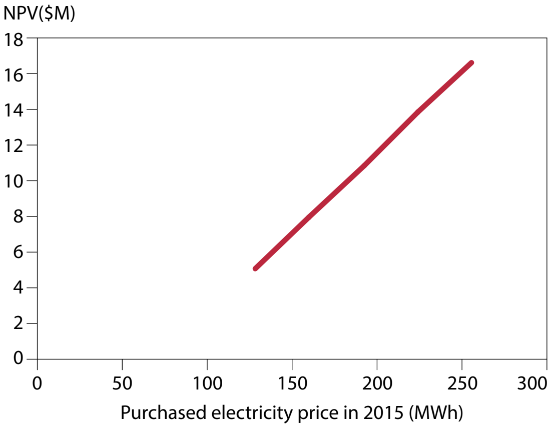


Figure 28 Sensitivity of NPV to export electricity price for the LEM case (100 ML/day).

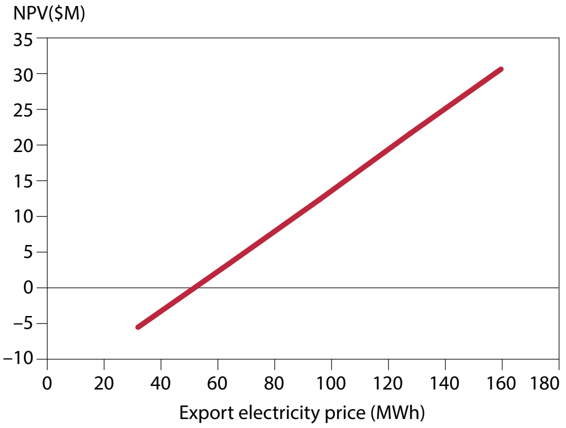


Figure 29 'Options Space Diagram'.

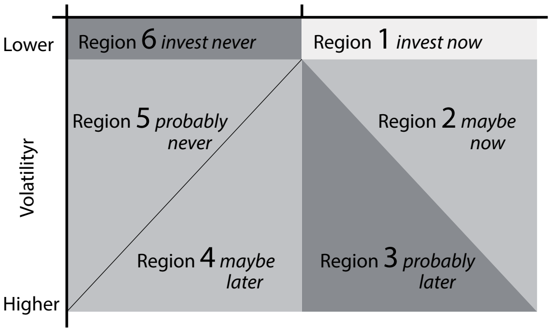


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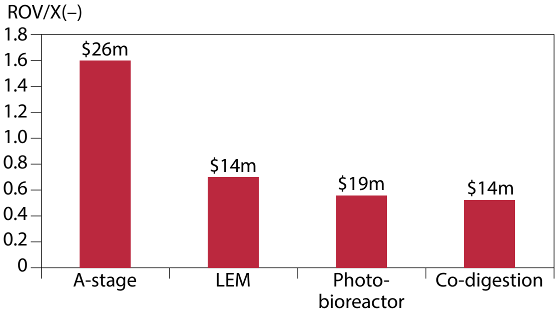
Figure 30 Real Option Values (ROV) of the cases studied.



Axis is ROV divided by capital expenditure required to exercise the option; actual ROV is the monetary value above the bar for investment in one WWTP plant. Co-digestion case is 45 ML/day, while the other cases are 100 ML/day wastewater flow.

and methods for its calculation[86]. Basically, the option value is calculated from a probabilistic analysis of the NPV distribution expected from an investment in the future, taking into account the uncertainty in the variables involved. The option value is the aggregated part of the NPV distribution where the expected NPVs are greater than zero (the 'blue' part of the probability distributions presented above). The idea is that an investor would not invest in the case where the NPV is less than zero when the time comes to exercise the investment. However, viewed from today, there could also be a possibility of upside positive NPV and hence wealth creation due to uncertainty or volatility (variance) in the NPV probability distribution.

Luehrman (1998) has provided a simple diagrammatic method for displaying the outcome of an option value analysis, the so-called 'Options Space Diagram'. This is reproduced with permission in Figure 29. The 'x-axis' of this diagram is 'value-to-cost', or the ratio of the future cash flows from the operations (S) to the capital costs invested (X), expressed as S/X in present value terms. A value of S/X equal to 1.0 represents zero NPV, since NPV=(S-X). The 'y-axis' is the 'volatility', or essentially the variance in the (S-X) probability distribution. As either S/X increases, or the 'volatility' increases, the option value increases. The interested reader is referred to the Luehrman papers for further discussion on these parameters. The 'options space diagram' provides regions where qualitative decisions about investment (or not) may be made. For example, if the volatility is low and the NPV is high, then 'invest now'. On the other hand, if the NPV is negative, and the volatility is low, then 'invest never' since there is no potential for upside in the NPV in the future. If the NPV is moderately low, but there is high volatility, then the investment could be made 'maybe later', after the situation becomes clearer, and so on. In principle, the higher the option value, the better the potential future investment. Details on the calculation here of S, X and the 'volatility' parameter are given in Appendix 6.

Figure 30 shows a bar graph of the 'real option values' for all of the cases studied, where the ROV have been normalised by dividing by the present value of the capital investment for the graph. The actual monetary ROV for the investments are also shown above the bars on the graph. As mentioned, the higher the normalised option value, the better the prospects for the investment. Axis is ROV divided by capital expenditure required to exercise the option; actual ROV is the monetary value above the bar for investment in one WWTP plant. Co-digestion case is 45 ML/day, while the other cases are 100 ML/day wastewater flow.

Clearly, the A-stage case has the highest option value of the cases studied. For A-stage, the option value amounts to $26M. By contrast, the option value of the co-digestion and LEM cases is much smaller at $14M while the photo-bioreactor case is $19M (Appendix 6). As can be seen, the option value approach using both perspectives is useful in discriminating between choices, since the option value represents the present value of the potential NPV upside for the investment while the normalised option value represents the option value per unit of capital investment.

Figure 31 shows the four cases examined probabilistically in this report plotted on an analogy of the Luehrman 'options space diagram'. On this figure, the horizontal axis is the 'value-to-cost' of the investment and the vertical axis is the 'volatility' (increasing in the downwards direction). When the 'value-to-cost' is 1.0, the NPV is zero. The area size of the bubbles on the figure is proportional to the ROV. Tabulated values of these parameters for all the cases studied are given in Appendix 6.

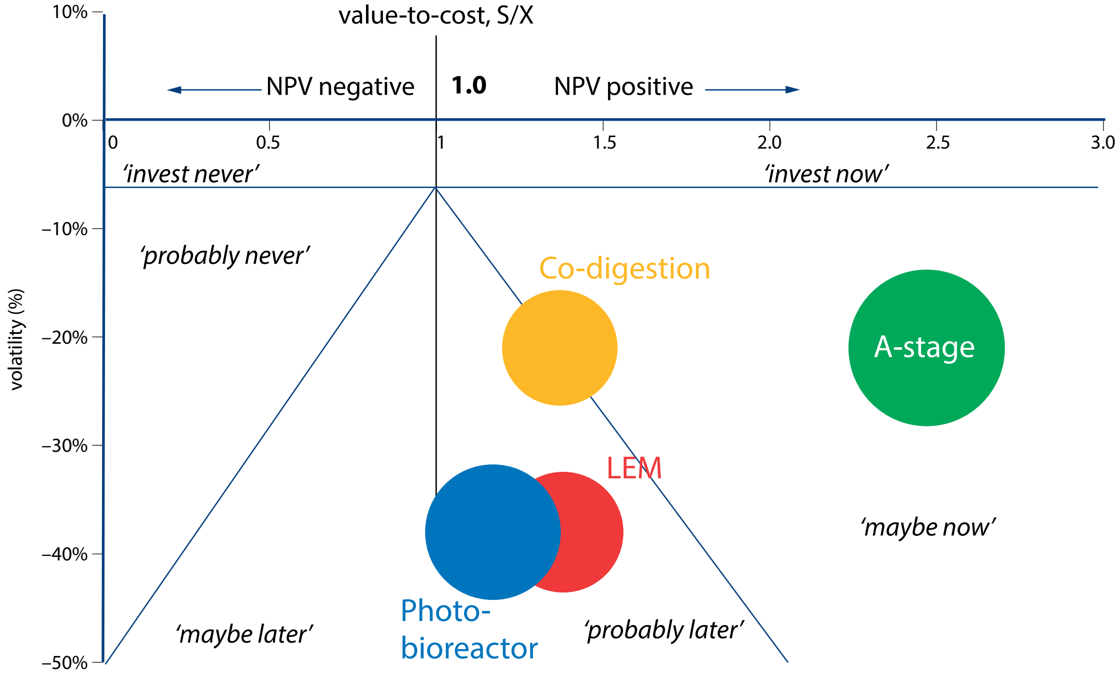
The anaerobic digestion case with co-digestion of waste and cogeneration of power is positive NPV (S/X>1) with lower volatility than both LEM and photo-bioreactor but with similar option value. It sits in the 'probably later' or 'maybe now' part of the 'options space diagram'.

As shown in the figure, the A-stage case has a high option value and sits in the 'maybe now' part of the 'options space diagram'. This means that this technology has a high positive NPV, even now. However, it still has volatility in financial outcomes and there is still time to wait and see if the investment maintains its promise in terms of investment costs and efficiency gains and to undertake research, development and demonstration to prove the technology at commercial scales.

The LEM and photo-bioreactor cases are similar in their option values. They sit in the 'probably later' part of the 'options space diagram' because of their higher capital costs and greater volatility (or uncertainty) in these costs. Again, there is time for knowledge about these costs and their ranges to develop before the investment decision.

It can be argued for the new technology cases studied here that a limited or targeted investment in technology development is warranted to more rapidly develop, pilot and demonstrate the options. This would reduce the uncertainty and timeframe and move the options on the 'options space diagram' above towards the top right hand corner (if such actions are successful) to the 'invest now' part of the diagram. As discussed by Luehrman (1998), this husbandry of technology is equivalent to managing a portfolio of real options to create earlier and better solutions for investors for the future. Theoretically, the ROV represents the maximum monetary sum that should be expended to enable the investor to exercise the

Figure 31 Luehrman analogy 'Options Space Diagram' for co-digestion, A-stage, LEM and photo-bioreactor cases.



option in the future, viewed from today. For the cases analysed here, this amounts to an appreciable monetary sum when aggregated over all future applications of the technology, part of which could be allocated to technology development. The importance of utilities in taking a leading role as 'investors' in technology investment and demonstration, perhaps in partnership with others, is thus stressed by this type of analysis.

Figure 31 represents a portfolio of real options for resource recovery, as outlined by Luehrman (1998). It is essentially a snapshot in time, given what is known or can be estimated now about the technologies. The analysis should be repeated at regular intervals as more and better data becomes available. New, embedded options may also arise and these should be included in the analysis as they emerge.

Summary of the economic opportunity analyses

Struvite

As reported in Chapter 7, struvite recovery on its own does not appear economic in Australia. This is because the revenue from struvite sales minus the magnesium chemicals and other operating costs are insufficient to pay back the capital required to build the facility at feasible struvite prices. However, if the production of struvite leads to reduction in operating costs such as sludge disposal, chemical use and maintenance, struvite can be economically viable as an investment to remove these costs. This conclusion was demonstrated by a series of case study investments in struvite technologies in the USA and Canada where the benefit of avoided costs was shown to be substantial. Avoided costs are high where stringent limits are placed on the phosphorus content of effluent waters and this therefore assists the economic case for struvite recovery.

On the other side of the value creation equation, an increase in the sales margin of struvite would be reflected in higher struvite prices and hence revenue. Increasing the value proposition of struvite to customers would require extensive marketing strategies for the products and potentially even product development R&D for boutique retail markets. It is noted that 'Clean Water Grow®' fertiliser containing blended struvite sells for $US10,000 per tonne in ~1 to 2 kg-sized bags in Oregon.

Struvite production may well be financially viable as part of a more complex process, such as the A-stage or photo-bioreactor process streams considered here where low phosphorus and nitrogen levels are required in effluent waters.

Business case study: Development of granular sludge technology

Although not driven by resource recovery, granular sludge wastewater treatment technology was developed in the Netherlands and is now globally marketed as NEREDA. The initial invention was transferred from TU Delft to DHV, a private engineering/consulting company. The actual technology development was supported by a multi-million Euro joint investment by several Dutch wastewater utilities. A market-ready, proven technology was available to the industry within a reasonable period of time (6-8 years). The technology is now being implemented at several locations in the Netherlands and exported world-wide. Investment by the 'industry' was essential to commercialise the technology to replace less energy and capital efficient technology solutions. It is an example of how '*maybe later*' technology was husbanded through to '*invest now*' through focussed R&D.

Energy from co-digestion

An anaerobic digestion with cogeneration plus co-digestion strategy at a WWTP analysed here, and compared to a base case with no digestion, has good economic prospects, mainly because it has good revenue streams from received organic wastes and electrical power avoided costs, given its capital costs. The economic viability, however, is highly dependent on the purchased price of electrical energy and the revenues from receiving organic waste.

New efficient process technologies

Small-scale new technology applications do not appear to be economic at this stage because the capital cost differentials relative to the base case are large and they do not receive economies of scale.

The medium-term large-scale 'A-stage plus nutrient removal' case is predicted to have excellent economic prospects because:

- it has only marginally different capital costs to the base case;
- it is very energy efficient and saves electricity costs; and
- it saves on sludge disposal costs.

The longer time frame large-scale LEM process is similar to the A-stage, but has a higher capital cost differential relative to the base case. The capital costs are also more uncertain than A-stage. Although its economic prospects are not therefore as favourable as A-stage, it still is predicted to be a reasonable investment in the future.

The large-scale photo-bioreactor case has more embryonic technology than either the A-stage or LEM cases. It has a higher capital cost differential when compared to the base case and it does not receive revenue from a REC. At this stage of its development it is similar to the LEM case and will probably be a candidate for investment in the future. Again, more rapid development and demonstration of this technology could well be justified to improve the probability of value creation and even the receipt of renewable energy credits for the technology.

CHAPTER 9: CONCLUSIONS

Resources embedded in wastewater, aside from water itself, represent significant economic potential, in the order of $15 per person per year. This represents a present value of over $5 billion to Australia if all the resources were recovered.

Resource recovery technologies and products can be classed as 'existing' (currently available and applied, and compatible with existing infrastructure), 'innovative' (available in the 5-15 year timeframe and competitive for replacement of existing infrastructure), and 'embryonic' (20 years and beyond, requiring new processes, downstream processing, or value adding).

Product classes align with technology classes, with existing technology products (biosolids and biogas), innovative technology products (complete recovery of nutrients and energy from sewage), and value-add products from embryonic technologies. Generation of higher value resources is technology-limited, with new technologies needed to economically generate value-added products such as biopolymers, liquid fuels, and next generation fertilisers.

Regulation does not inherently hinder the application of resource recovery technologies, but state-level financial regulation of the water industry may drive business decisions to inadvertently make it more complicated to adopt new technologies and innovation. State level regulations in Australia encompass: (i) treatment plant construction; (ii) treatment plant operations; and, (iii) the regulation framework for the use of the products. The interaction between these components is complex and can provide a very significant barrier to private investment in terms of cost and time. Moreover, each state might not have a sufficiently large market for resource recovery products, and multiple regulatory applications and multiple-jurisdiction negotiations could be extremely costly and time consuming.

Alternative infrastructure investment models such as 'ring-fenced' PPPs or private 'build, own and operate' strategies may enable further resource recovery in the future in Australia.

Environmental legislation that reduces allowable effluent nutrient levels tends to favour development of resource recovery investment. This is because operating costs associated with the regulatory requirements can be avoided through implementation of nutrient recovery. In most cases, resource recovery is not financially viable without consideration of these avoided costs.

Considering existing technologies, economic favourability of resource recovery products is (in order), energy via biogas, phosphorus from sidestreams, and nitrogen. Recovery of energy via co-digestion is generally economically favourable, whereas phosphorus is only financially viable when avoided costs are included, and nitrogen recovery is currently not economical.

Probabilistic financial analysis of different innovative process options in the 0 to 5 and 5 to 15 year timeframes has identified that emerging processes are economically viable for scales of operation greater than 50 ML/d. This is because of the generation and savings of electrical energy associated with these technologies, coupled with an expected modest annual electricity price increase and renewable energy subsidies. Other avoided costs such as sludge disposal and revenue streams such as struvite production and 'tipping fees' for organic waste disposal also contribute to NPV. Favourable options for Australia include the anaerobic co-digestion, high rate aerobic treatment and LEM anaerobic treatment methods. Analysis of the state of development has also indicated that options such as phototrophic membrane bioreactors (15 year timeframe) are not at a suitable development stage for financial investment at the present time, but could prove to be good investment options for the future.

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APPENDICES

APPENDIX 1: Terminology

A-stage: Also termed high-rate activated sludge. Adsorptive and assimilative removal of organics and nutrients at very short solids and hydraulic retention times in a process that removes 80% of organic carbon and approximately 20% of nitrogen at domestic wastewater strength. Can be combined with mainstream deammonification.

Ammanox: an abbreviation for ANaerobic AMMonium Oxidation, a microbial process which removes reactive nitrogen species from marine systems by producing dinitrogen by reacting ammonium with nitrite

Anaerobic digestion: a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels.

AnMBR (Anaerobic membrane bioreactor): Process that utilises in-vessel membrane separation of solids to achieve relatively high space loading and effective removal of organics from wastewater via anaerobic processes. Generally utilised within the overall low energy mainline process.

Beta factor: measure of the volatility of an investment in comparison to the market as a whole. Beta is used in the capital asset pricing model.

Biogas: a gas which has been produced by the biological breakdown of organic matter in the absence of oxygen.

Biorefinery: a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass.

Biosolids: the organic product that results from sewage treatment processes (otherwise referred to as sewage sludge)

Capital asset price model: an economic model for valuing stocks, securities, derivatives and/or assets by relating risk and expected return.

Co-digestion: a process whereby energy-rich organic waste materials (e.g. Fats, Oils, and Grease (FOG) and/or food scraps) are added to dairy or wastewater digesters with excess capacity to produce methane.

Cogeneration: the simultaneous production of heat and electricity using a single fuel. The heat generated is then used to produce steam to meet the customers' requirements as well as boost the production of electricity.

Feedstock: organics suitable for composting, fermentation, mulching and related processes.

Free Cash Flows: A measure of financial performance calculated as operating cash flow minus capital expenditures.

Internal Rate of Return: rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero.

Low energy mainline (LEM): Low energy mainline or mainstream wastewater treatment. The use of a suite of low energy wastewater technologies that operate on the main wastewater stream, such as anaerobic membrane bioreactors, upflow anaerobic sludge blanket (UASB), mainstream deammonification, and phosphorous removal through adsorption.

Municipal water reuse: The term 'municipal' is applied to indicate that the source of reclaimed water is a municipal wastewater treatment plant (WWTP), also known as a sewage treatment plant (STP).

Net Present Value: calculated by the summation of all annual cash flows discounted at the cost of capital of the company, taken at the end of the year in question.

Non-organic fertiliser: mostly contain chemicals with the essential plant nutrients in available forms, the production of which involves some industrial process.

Opex (operating expense): an expense required for the day-to-day functioning of a product, business or system.

Organic fertiliser: made up of organic material derived from animal or vegetable waste, or minerals occurring in nature.

Phototropic bacteria: microorganisms that are efficient in recovering high amounts of nitrogen, inorganic phosphorus, and heavy metals from effluents.

Potash: fertiliser forms of the element potassium (K) in the water-soluble form.

Resource recovery: the extraction and use of resources from waste and/or organic sources. Resources recovered can be used in the manufacture of new products. Recovery of value includes the production of energy by using components of waste as a fuel, production of compost using organics as a medium, and reclamation of land.

Sewage: the waste water from domestic, commercial and industrial sources carried by sewers, which can be in liquid or solid form.

Sewerage: the infrastructure that conveys sewage. It encompasses receiving drains, manholes, pumping stations, storm overflows, screening chambers, etc. of the sanitary sewer. Sewerage ends at the entry to a sewage treatment plant or at the point of discharge into the environment. Struvite: a crystalline substance consisting of magnesium, ammonium and phosphorus in equal molar concentrations.

Sludge: The solids which are removed from wastewater by primary and secondary treatment.

Thermal hydrolysis: a two-stage process combining high-pressure boiling of waste or sludge followed by a rapid decompression.

Wastewater: Water which has been used, at least once, and has thereby been rendered unsuitable for reuse for that purpose without treatment and which is collected and transported through sewers. Wastewater normally includes water from both domestic and industrial sources.

Weighted Average Capital Cost: reflects the overall costs of combined debt and equity capital used to finance business operations or acquisition.

APPENDIX 2: Abbreviations

k_D	Cost of Debt (%)
k_E	Cost of Equity (%)
β	'Beta factor' for sharemarket risk
R_M	Sharemarket risk premium (%)
A-stage	(High rate activated sludge) Adsorptive and assimilative removal of organics and nutrients at very short solids and hydraulic retention times. Can be combined with mainstream deammonification.
As	Arsenic
Ammanox	ANaerobic AMMonium OXidation
ATSE	Australian Academy of Technological Sciences and Engineering
AWRCE	The Australian Water Recycling Centre of Excellence
BEC	Bare Erected Costs
BOD	Biological oxygen demand
CAPM	Capital Asset Pricing Model
CH_4	Methane
CH_4/m^3	Cubic metres of methane per cubic metre of primary sludge
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COD	Chemical oxygen demand
Cr	Chromium
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CSG	Coal seam gas
Cu	Copper
CWS	Clean Water Services
D	Amount of debt of a firm
DDT	dichlorodiphenyltrichloroethane E Amount of Equity of a firm
EBIT	Earnings Before Interest and Taxation
EBITDA	Earnings Before Interest, Taxation, Depreciation and Amortisation
EPA	Environmental Protection Authority
EU	European Union
FCF	Free Cash Flow
H_2	Hydrogen
H_2O_2	Hydrogen peroxide
IRR	Internal rate of return
L/s	Litres per second of liquid or gas flow at operating conditions
LEM	Low energy mainline
LGCs	Large-scale renewable Generation
m^3	Cubic metres of liquid or gas volume at operating conditions
m^3/d	Cubic metres per day of liquid of gas flow at operating conditions
$m^3/kgCOD$	Cubic metres of biogas or methane per kilogram of digested COD
$m^3/kgVS$	Cubic metres of biogas or methane per kilogram of digested VS m^3
mg/L	Milligrams concentration per litre in liquid solution
mL	Millilitres
ML	Mega Litres
ML/d	Mega Litres per day

MMSD	Milwaukee Metropolitan Sewerage District
MW	Megawatts
N	Nitrogen
NaOH	Sodium hydroxide
NEM	National Energy Market
NH_4^+	Ammonium
Ni	Nickel
NPAT	Net Profit After Taxation
NWQMS	National Water Quality Management Strategy
P	Phosphorus
Pb	Lead
PV	Photovoltaic
QUU	Queensland Urban Utilities
R&D	Research and Development
R_F	Risk-free rate (%)
REC	Renewable Energy Certificate
RET	Renewable Energy Target
Se	Selenium
SEPP	State Environment Protection Policy
STP	Sewage treatment plant
TPC	Total Plant Cost
TOC	Total Overnight Cost
VWA	Volume Weighted Average
WACC	Weighted average cost of capital
WAS	Waste Activated Sludge
WERF	The Water Environment Research Foundation
WWTP	Wastewater treatment plant
Zn	Zinc

APPENDIX 3: Evidence gathering

1. Workshop

The Working Group held a strategic planning workshop on December 11th in Melbourne to seek input from key stakeholders to the project, discuss in detail aspects of the project Terms of Reference, and identify ideas and themes that should be included in the project and ultimately develop hypotheses for the project to test.

The Working Group is grateful to have had the opportunity to consult with 14 experts and key stakeholders during this workshop, including:

- Professor Ana Deletic FTSE, Centre for Water Sensitive Cities, Monash University
- Dr Paul Greenfield AO FTSE
- Mr Peter Laver AM FTSE, ATSE Senior Advisor
- Mr Tony Priestley, Independent Consultant
- Mr Charlie Walker, Incitec Pivot Limited
- Mr Ian Law, IBL Solutions
- Professor Frank Larkins FTSE, University of Melbourne
- Professor Geoff Stevens, University of Melbourne
- Professor Cynthia Mitchell FTSE, University of Technology Sydney

- Mr Simon Cashion, Australian Water Recycling Centre of Excellence
- Dr Andrew Hamilton, University of Melbourne
- Mr Murray Jackson, Westernport Water
- Mr Django Seccombe, Sydney Water
- Professor Mikel Duke, Victoria University

During the workshop, discussions led to the development of five opportunity hypotheses for the project to test and analyse. These include:

1. 'Water resource recovery plants are financially, environmentally and socially viable only if alignment of regulatory framework, technology, costs, social licence and market for products is achieved.'
2. 'There are options available for Australia at all temporal and spatial scales for water resource recovery that are financially viable and investible.'
3. 'There are no viable resource recovery product options other than biosolids, biogas, and N, P and K fertiliser products. Moreover, decentralized systems favour solely water recovery at the expense of energy, nutrients and solids.'
4. 'For existing WWTPs, the only investment in water resource recovery that is financially viable is energy recovery. That is, it is not commercially feasible to implement more flexible systems producing more advanced products for these facilities, unless a subsidy is provided.'
5. 'A regulatory framework (environment, economic and public health) is essential to enable and encourage investment in water resource recovery. Such a regulatory framework for both water and resource recovery products exists in Australia'.

2. Consultations

As part of the evidence gathering process, discussions were held with the following individuals and organisations:

- Melbourne Water - *Ms Kelly Brooks (Valued Resources Team, Integrated Planning) and Dr Deepak Joshi (Senior Process Engineer, Eastern Treatment Plant)*
- Barwon Water - *Kate Hocking (Coordinator - Central Water Reclamation Plants) and Mr David Greaves (Coordinator - Central Water Reclamation Plants)*
- Plenary Group – *Mr Carl Retschko (Associate Director)*
- Incitec Pivot Fertilisers – *Mr Charlie Walker (Technical & Development Manager)*
- Sydney Water - *Mr Django Seccombe (Senior Analyst, Servicing and Asset Strategies) and Dr Heri Bustamante (Principal Scientist Treatment)*
- Yarra Valley Water – *Mr Francis Pamminger (Manager, Research & Innovation), Mr Maarten De Beurs (Project Manager) and Mr Andrew Edney (Manager Commercial Services). Dr Yoomin Lee (formerly at Jacobs Engineering) assisted by providing specialized technical feedback and review.*
- M.H. Carnegie & Co - *Mr Mark De Ambrosis (Investment Director)*
- Australian Biolife - *Mr Mike McCosker*
- Cleantech Ventures Pty Ltd - *Mr Jan Dekker (Managing Director)*
- Innovation Capital - *Mr Michael Quinn (Managing Partner)*

APPENDIX 4: Australian resource recovery projects

Table A4.1: Several Australian resource recovery projects

Entity	Location	Type of operation	RR product(s)	RR process, technology or principles	Type	Current status
Water Corporation	Subiaco WWTP	Trummel for biosolid and clay mixing	BioClay	Lime amended biosolids mixed with clay	Stand-alone facility located separately from WWTP	Operations on hold (due to operational and site leasing issues)
	Woodman Point	WWTP with tanker recieveal facility	BioGas from WW,fats,oil and grease and tinkered septage	Anaerobic digester with tanker receivable facilities for co-digestion and cogeneration	Operational facility	Operational
	Beenyup WWTP	Sludge digestion and heating	Biogas	Cogeneration	Business case	Business case approved, facility yet to be fully constructed
SA Water	Bolivar treatment plant	Biogas reuse? Wey co-digestion?				
Smart Water Fund/ University of Queensland	University of QLD	Pilot	N and P streams that can be converted in fertiliser products.	Phototrophic bacteria and anaerobic digestion	Pilot and feasibility report	Began mid-2013 and will finish mid-2016.
SEQ water	Working with QLD utilities and unity water to identify a pilot site	Pilot	Ferric	Replacing allum with ferric as a coagulatent in WWTPs and recovering the ferric from sludges for reuse	Proposal	QLD treatment plants have been approached for Expressions of interest.
Western Water	Melton	WWTP	Methane capture using cogeneration Class A & Class C water recycling	Anaerobic WWTP	Operational facility	Interactive tour available on website: http://www.westernwater.com.au/wsservices/Pages/MeltonRecycledWaterPlantTour.aspx
	Melton	WWTP	Study on nutrient recovery	All technologies	Feasibility study	Further detail available required.
	All treatment plants	WWTP	Recycled water schemes including Sunbury Class B agricultural and water cultural and recreational reserve's	Standard treatment plant processes	Operational facility	Further detail available required.
	Gisborne and Woodend	WWTP	Land application of biosolids for agriculture	Standard treatment plant processes	Operational facility	Further detail available required.

Table A4.1: Several Australian resource recovery projects (Continued)

Entity	Location	Type of operation	RR product(s)	RR process, technology or principles	Type	Current status
Goulburn Valley Water	Shepparton & Tatura	Biogas reuse by third party	Biogas reuse by third party	Covered high rate anaerobic lagoons	Operational facilities	Operational facilities
Victoria University	N/A	Desktop	Ammonia / nitrogen	Ammonia selective membrane distillation		
Yarra Valley Water	Aurora Sewage Treatment Plant	Waste to Energy plant	Biosolids and waste organics	Anaerobic digestion	Business case in development	http://www.yvw.com.au/Home/Aboutus/Ourprojects/Currentprojects/WastetoEnergyfacility/index.htm
	Wollert WWTP	New WWTP	Water and energy	Anaerobic digestion	Research	In planning
Melbourne Water	Melbourne Eastern Treatment Plant (ETP)	WWT media	Air filter media as compost		Pilot in planning	
	Melbourne Western Treatment Plant (WTP)	WWTP	Enhanced methane extraction		Lab trials	
	Melbourne WTP	WW trial	Energy and/or nutrients	Wastewater and cogeneration flue gas	Ponds under construction	
	Melbourne WTP	WWTP	Co-digestion	Anaerobic digestion	Trial planning	
	Melbourne WTP	WWTP	Biosolids application to land		Second trial in progress	
	Melbourne ETP & WTP	WWTP	Biogas	Anaerobic digestion and cogeneration	Operational facilities	
	Melbourne ETP & WTP	WWTP	Biosolids to energy	Range of technologies	Trials	
	Melbourne ETP & WTP	WWTP	Biosolids into bricks		Lab trial progressing pilot in planning	
	Melbourne	Water network	Energy	Mini-hydros	Operational facilities	

Table A4.1: Several Australian resource recovery projects (Continued)

Entity	Location	Type of operation	RR product(s)	RR process, technology or principles	Type	Current status
Sydney Water	Across Sydney Water catchment	11 anaerobic WWTPs, 8 have cogeneration	Biogas	Anaerobic digestion	Operational facilities	Underway (cogeneration facilities producing 5300 MWh/yr)
	Bondi wastewater treatment plant	WWTP	Glycerol reuse to enhance biogas	Anaerobic co-digestion	Pilot trial	Commencing in June 2015, 600,000 L/year (up to cogeneration capacity)
	Wollongong University	Various	Bio-methane potential of beverage waste, municipal and commercial food waste, FOG, dairy	Anaerobic co- digestion	Bench scale trials	Underway
	Across Sydney Water catchment	Mini digester (2x1000L digesters) for control and test case for co-substrate	Biogas	Anaerobic co- digestion	Business Case development	Proposal under consideration
	Malabar	Operational facility considered	5,000 tonnes of municipal waste into plant	Anaerobic co- digestion	Business Case development	EPA grant application being considered for support (needs to be operational within 3 years)
	Cronulla	Operational facility considered	Commercial food & beverage waste	Anaerobic co- digestion	Desktop study	Proposal under consideration
	Across Sydney Water catchment	WWTP	100% biosolid reuse (40-60% direct pasture land application). Remaining digested via composted facility (Class B & C)	Wastewater treatment processes and in some cases composting	Operational facilities	Underway
Hunter Valley	Cessnock	WWTP	Biogas Reuse	Anaerobic digestion	Operational facility	Operating, 200 MWh

Note: This table was developed using data supplied by water utilities in major Australian cities. This table does not include all cities in Australia, nor are we certain that it includes all treatment plants in all major cities.

APPENDIX 5: Resource recovery products

Appendix 5 contains a range of specific products that may be formed from the more general products outlined in Table 3. It also provides financial justification for the pricing in Table 3.

As a product, biosolids are produced at 12-20% dry weight (the remainder is moisture). Approximately 7% of the dry solids is nitrogen and 1%-2% is phosphorous[88]. Therefore, a wet tonne of biosolids contains approximately 10 kgN, and 2 kg P. Given current bulk nitrogen costs of \$800/tonne, and phosphorous of \$3000/tonne (see elsewhere in this report), the value of nutrients is \$10/tonne. The cost of reuse is mainly transport and is \$30-\$70/wet tonne[89]. Simply the cost of spreading has been estimated at \$5/wet tonne. Dry biosolids is more valuable simply because it is concentrated to effectively 100% dry solids.

Humans emit organics with an energy value of 1.3 MJ/d[13], 2g P, and 10g N per day. Approximately 25% of this can be recovered in the sidestream from conventional activated sludge processes, or up to 100% of energy and phosphorous, and varying amounts of nitrogen through emerging processes as analysed further in this report. The base values of \$3/kgP, and \$0.8/kgN have been elsewhere established in this report. Energy has a value of \$5/GJ as gas, and uniformly assumed through this report to have an offset cost of \$0.16/kWh (\$160/MWh). Cogeneration efficiency is approximately 40%, and hence, 1 GJ generates 0.12 kWh of electricity.

Value of embryonic products are order of magnitude only (2015 AUD) and based on similar commodity products in the Australian market, including current next generation organic polymer fertilisers (including composites and products such as amino acid fertilisers and biochars), cost of organic feeds for algae, cost of fuels for biofuels, and commodity costs for plastics and biopolymers.

Table A5.1 Summary of chemical nutrient products from wastewater

Common Name (%N, %P, %K, %Mg, %Ca,%Fe, %S)	Form	Extraction Process	Comparable Commercial/ Industrial Process	Use
Biosolids 3-2-0-0-0-0-0 to 6-4-0-0-0-0-0	Solids	Processing of final WWTP sludge, possible drying and pelletising.	None	■ Land application as a low nutrient enhancer with contained carbon. ■ Grade and value affected by whether inorganic fertiliser has previously been extracted (e.g. struvite) ■ May be suitable for land application where P and N limits exist. ■ 'Established' technology.
Struvite $NH_4MgPO_4.6H_2O$ 5-13-0-10-0-0-0	1-3 mm dry crystalline solid	Chemical crystallisation (e.g. Ostara, others)	DAP: $(NH_4)_2HPO_4$ MAP: NH_4HPO_4	■ Ornamental & specialist fertiliser. Turf application. ■ Slow release of P and N. ■ 'Established' technology, with many technology suppliers.
Hydroxyapatite $Ca_5(PO_4)_3OH$ 0-19-0-0-40-0-0	1-3 mm dry solid	Chemical crystallisation (e.g. CRYSTALACTOR)	Triple Superphosphate $CaH_4P_2O_8$	■ Ornamental and specialist fertiliser. Niche applications where a combination of Ca and P is required. ■ Medical applications to replace bone, or as a bone coating. ■ 'Innovative' technology.
Vivianite $Fe_3(PO_4)_2.8H_2O$ 0-12-0-0-0-33-0	Dry solid	No commercial process.	No product identified	■ Potential ornamental crop fertiliser – source of iron. Turf and nursery applications. ■ 'Embryonic' technology.
Phosphoric Acid H_3PO_4	Liquid	No commercial process	Phosphoric acid	■ 'Embryonic' technology. ■ Agriculture and ornamental crop fertiliser. ■ Rust removal, additive to foods, anti-nausea medications, fuel cells, de-scaling of boiler tubes.
Aqueous Ammonia NH_3 82-0-0-0-0-0-0	Liquid solution	Liquid-gas stripping. Requires high NH_4-N concentrations (>2000mg/L) High operating cost.	Anhydrous ammonia produced by Haber-Bosch process using natural gas or naphtha.	■ 'Established' technology. ■ Liquid fertiliser directly injected into ground. ■ Precursor to ammonium salts (below).
Ammonium Nitrate NH_4NO_3 35-0-0-0-0-0-0	Liquid solution, Solid crystals	Liquid-gas stripping (using HNO_3) Requires high NH_4-N concentrations (>2000mg/L) High operating costs	Haber-Bosch process. HNO_3 solutions. Crystallised ammonium nitrate (made by reacting NH_3 with HNO_3)	■ Established' technology. ■ Agricultural fertiliser. ■ Explosives, when mixed with hydrocarbons (may limit general usage).
Ammonium Sulphate $(NH_4)_2SO_4$ 21-0-0-0-0-0-24	Liquid solution, solid crystals	Liquid-gas stripping (using H2SO4). Requires high NH4-N concentrations.	Ammonium Sulphate crystals, solutions.	■ 'Established' technology. ■ Agricultural fertiliser. ■ Water soluble insecticides, herbicides; medical vaccines ingredient; food additive; flame-retardant materials.

Based on information from the WERF report by Latimer *et al.* (2014)[7]

Table A5.2: Summary of chemical non-nutrient products from wastewater

Common Name	Form	Extraction Process	Comparable Commercial/Industrial Process	Use
Biogas	60 – 100% methane gas (CH_4)	Anaerobic digestion	Natural gas.	Energy. Combined heat and electrical power (CHP). 'Established' technology.
Biofuel	Liquid	Algal growth in wastewater. Large growth ponds or photo-bioreactors. Separation of algal lipids and conversion to biodiesel.	Petroleum refined products; bio-oil, diesel, ethanol.	Bio-fuels. Animal feed (from spent algae). Biogas (from anaerobic digestion of spent algae). CO_2 sequestration. 'Innovative' to 'Established' technology.
Hydrogen, Hydrogen Peroxide, Sodium Hydroxide H_2, H_2O_2, NaOH.	Gas, liquids	Electrical current applied to an anaerobic cell to yield H_2 gas. H_2O_2 and NaOH under different conditions in the liquid phase within the cell.	Industrial chemicals, steam reformation of hydrocarbons, catalytic industrial processes.	'Embryonic' technology.
Polyhydroxyalkanoates (PAH)	Polyhydroxyalkanoates (PAH)	Mixed microbial fermentation (being researched). Yields 0.08 to 0.4 g PAH/g substrate.	Commercial biodegradable plastic from petroleum raw materials.	Precursors to thermo-stable biodegradable plastics. Cost $US13 to $US15/kg at present (compared with $US5 to $US10/kg from petroleum feedstocks). Additional R&D required to reduce costs. 'Embryonic' technology.
Microbial products	Microbial protein, pure cell biomass	Growth of microbes in enriched or pure culture through chemotrophic, phototrophic, or photosynthetic growth on wastewater organics	Industrial and feed proteins	Animal feeds, pure commodity proteins. 'Embryonic' technology.
Alginate	Commodity chemical	Grown in algae or microbial biomass through microbial fermentation	Commercial alginate	Emulsion stabiliser, polymer, binder, etc.

Based on information from the WERF report by Latimer *et al.* (2014)[7]

Table A5.3: Typical phosphorus fertiliser properties

Compound	Formula	Nutrient content (% P)
Superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	8–9
Monoammoniumphosphate(MAP)	$NH_4H_2PO_4$	21–24
Diammoniumphosphate (DAP)	$(NH_4)_2HPO_4$	20–23

Table A5.4: Value and potential generation of the various resource recovery products

Established	Product Variants	Prod/(ep.d)	Value ($)	Value/(ep.y)	Cost of generation	Cost of use	Issues
Biosolids (wet) agricultural	Compost	400g	$8/tonne	$1	NIL	$30-$70	Nitrogen limiting application rate. Metal contaminants. Microbial contaminants
Biosolids (dry) agricultural	None	50g	$70/tonne	$1	10 GJ/tonne	$30-$50	Nitrogen limiting application rate. Metal contaminants. Dust issues.
Energy (biogas from sludge digestion)	Electricity, biomethane (fuel, grid) includes co-digestion or enhanced anaerobic digestion	0.04-0.1+ kWh	$0.20/kWh	$3	$0.015/kWh	NEG	Feed in contract. Co-digestion or enhanced anaerobic digestion can double energy output from comparable infrastructure.
Energy (biogas from low energy sewage treatment)	Electricity biomethane (fuel, grid)	0.15-0.4 kWh	$0.20/kWh	$9	$0.015/kWh	NEG	Feed in contract/gas grid compatibility
Phosphate products (recovered from sidestream)	struvite, $\mathrm{CaPO_4}$, $\mathrm{MgPO_4}$	0.5 g P=5g product	$3/kg P	$0.5	$1/kg P	NEG	Specialised market
Innovative							
Phosphate products (recovered from mainline)	struvite, $\mathrm{CaPO_4}$, $\mathrm{MgPO_4}$, $\mathrm{H_3PO_4}$	2 g P = 20g product	$3/kg P	$2	$1/kg P	NEG	Limited market
Ammonium products (sidestream and mainline)	liquid fertilisers $\mathrm{NH_4Cl}$, $\mathrm{NH_4SO_4}$, $\mathrm{(NH_4)_3PO_4}$ $\mathrm{NH_3}$	3-10g N	$0.8/kg N	$2	$0-$1/kg N	NEG-$0.2/kg N	Concentrates require local market
Embryonic							
Next generation fertilisers	Microbial products, high-nitrogen organics	10gN, 2gP	Increased effect	$10	MED	LOW	Needs enabling science to identify products.
Commodity inorganic chemicals ($\mathrm{H_2O_2}$, S, $\mathrm{Cl_2}$ etc.)	peroxide. sulfur, chlorine, metals, caustic	Varies	Varies		HIGH	LOW	Needs extensive downstream processing and new technologies.
Microbial products	algae, chemotrophs, phototrophs	100g	$0.2/kg	$10	MED	UKN	Market needed. May enable manufacture of by-products etc.
Biofuels	algae derived, chemical derived, all fuels	100g+	$1/kg	$40	HIGH	MED	Requires algal reactors or biorefinery to generate oils from heterotrophic growth
Commodity organic chemicals	organic acids, alcohols	100g	$0.5/kg	$20	HIGH	LOW	Extraction/downstream processing expensive
Biopolymers	polyhydroxyalkanoates alginate	20-50g	$1-$3/kg	$20-$40	HIGH	HIGH	Extraction/downstream processing expensive
Speciality chemicals	vitamins, caproate, propandiol,etc	-	$10-$100/kg		V. HIGH	V. HIGH	

ep.y = equivalent persons.year. ep.d= equivalent persons.day

APPENDIX 6: Financial analysis detail

The financial model calculation is based on a free cash flow analysis (Higgins, 2001). Free Cash Flow (FCF) for a given year is defined as follows:

EBITDA = Revenues – Costs (1)
where: EBITDA is 'Earnings Before Interest, Taxation, Depreciation and Amortisation'

EBIT = EBITDA – depreciation (2)
where: EBIT is 'Earnings Before Interest and Taxation'

FCF = Free Cash Flow = EBIT (1-tax rate) + depreciation – capital investment (3)

NPV is calculated by the summation of all annual cash flows discounted at the cost of capital of the company, taken at the end of the year in question. The after-tax cost of capital for the investor is given by:

WACC = [D (cost of debt) (1-tax rate) +E (cost of equity)]/(D+E) (4)
where: D and E denote proportion of debt and equity funding respectively.

Interest payments and payments to equity investors are accounted for by discounting the FCFs at the above WACC, which includes the after-tax cost of debt and the cost of equity.

Revenues for a resource recovery technology will include the value of any by-products produced and sold, including energy. Costs for the technology will include the variable and operating costs of the facility. Capital investment is handled in the calculation by allowing negative FCF in terms of overnight capital costs prior to commencement of operation of the facility in equation 3 when EBIT and depreciation are zero.

There are three ways that resource recovery technologies may be analysed financially:

1. Undertake a NPV or an IRR analysis for an investment and undertake sensitivity analyses around the base case for variation of key operating and financial parameters. The IRR is the calculated discount rate when the NPV is zero, and may be compared with the firm's cost of capital. If IRR is less than the cost of capital, then value is being destroyed if the investment is made now.
2. Determine a probabilistic IRR of an investment, given values for by-products, operating costs and required capital investment. A Monte-Carlo based probability distribution of IRR may be determined where input revenue and cost data are not deterministic. The probability of IRR being less than the firm's cost of capital then becomes the 'value at risk'.
3. Determine the ROV of the technology, by calculating a Monte-Carlo based NPV probability distribution for the investment or using (say) the Black-Scholes option value pricing method. This method is particularly applicable where the investment has a large 'value at risk' now, but could become positive NPV in the future due to uncertainty in future financial parameters.

In the present analysis, both income tax and depreciation have been taken into account, so the discount rate to determine the discounted cash flows must also reflect these assumptions. Also, the F in this study are expressed in nominal terms (increasing each year due to inflation) so the discount rate must also be expressed in these terms as well.

For state-owned water corporations, the Capital Asset Pricing Model (CAPM) (outlined above) applies[74]. In order to calculate the cost of Equity (k_E), most State corporations are required to assume a 'market risk premium' of 6%, and then apply the CAPM equation for cost of Equity:

$$k_E = R_F + \beta(R_M - R_F)$$

where: k_E is the cost of Equity
β is the appropriate 'beta factor' for risk of the firm or project compared to the sharemarket
R_M is the market risk premium (6%)
R_F is the risk-free rate (10 year government bond rate for the last 6 months)

For water infrastructure, the value assigned to β by governments is 0.5[74].

Typical values for these parameters enable the after-tax cost of capital to be determined[61]:

$$k_C = (D(k_D)(1\text{-tax}) + E(k_E))/(D + E)$$

where k_C is the weighted average cost of capital (WACC).
D is the relative interest-bearing amount of Debt of the organisation.
E is the relative amount of Equity of the organisation.
k_D is the cost of Debt (interest rate paid) of the corporation.

Higgins, in the book 'Analysis for financial management' provides a rigorous methodology for the calculation of true NPV. It involves the following sequence of calculations for every year of an investment life:

EBITDA = revenue – costs
EBIT = EBITDA – depreciation
Free Cash Flow = EBIT (1 – tax rate) + depreciation – capital investments
NPV = sum of (all annual free cash flows discounted using the WACC)

If a discount rate of 4.3% (nominal, after tax) is applied to nominal free cash flows from an investment and the free cash flows over the life of the investment are summed, then this gives the NPV. If the NPV is positive, then the investment should go ahead, provided the investment risk is no higher than the existing assets of the business. It will create value under these circumstances. If the NPV is zero, then the investment will only earn the cost of capital, so the investment is marginal. If the NPV calculated from the free cash flows is negative, then the investment will destroy value for the corporation. If the risk of the new investment is higher than the risk of the present assets of the business, then a higher discount rate than the Weighted Average Cost of Capital (WACC) is justified. This needs to be a decision by management, taking into account the risks associated with the new investment.

The above WACC value applies to nominal free cash flows. If real free cash flows are used in the NPV calculation then a real WACC must be used to discount them. Taking the above example and correcting the k_D and k_E for inflation, the current real WACC is 2.2%. In the calculations of NPV presented in this report using real free cash flows, a real WACC of 2.5% has been used as the after-tax discount rate.

Details of the 'Options for Australia' Financial Modelling (Chapter 8)

Several detailed probabilistic financial models have been applied in the present study to resource recovery technologies. For this, the capital and operating costs and revenues are required to calculate the NPV using the above relationships.

Capital costs

Capital costs have been taken from two sources for this work: (i) a study by Yarra Valley Water of a proposed new WWTP at Kalkallo in Victoria, and (ii) capital costs developed for the ASWROTI study of new WWTP technologies[81]. Erection cost data for these two cases was supplied by Jacobs Consultancy and GHD respectively.

The investment costs for a new project are required in order to undertake a financial analysis. Project cost estimates may be derived either by extrapolation from past experience with similar plant or by a cost build-up from the individual facility components. With novel technologies there is usually little previous experience and therefore cost build-ups are necessary. In such cases, process flow sheets and their supporting engineering deliverables are used to identify the major components of the project and to develop cost estimates for them. However, there are numerous costs additional to those of the basic equipment that will be incurred in delivering a large-scale project. It is important that consistent allowances be made for these across technologies in order that a true comparison may be made.

A number of organisations have developed standard cost estimating methodologies. The approach recommended by the US DOE National Energy Technology Lab (NETL)[90], and briefly described below, has been used here in providing capital costs for the alternative technologies under consideration.

The NETL approach is based on the cost build up method. The costs estimated for the process equipment components, with contingency applied as appropriate to the level of development of that component technology, are summed to give a Bare Erected Cost (BEC). Additional costs, fees and contingencies that are a normal part of delivery of a large engineering project are then added to arrive at a Total Overnight Cost (TOC). TOC is the total capital cost, excluding escalation and interest during construction, expressed in base date dollars.

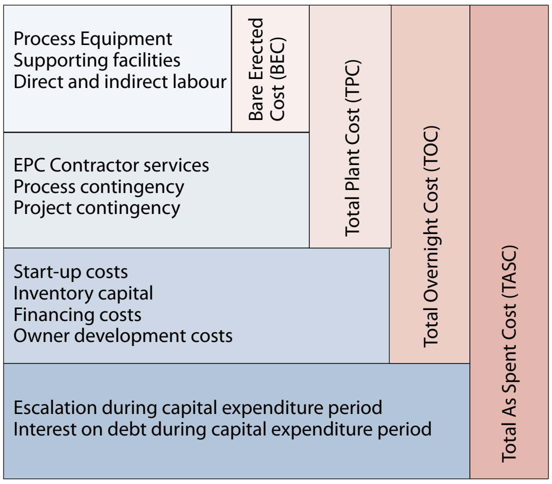
The components that contribute to project costs are illustrated in Figure A6.1.

Process contingency: This is applied to each plant section based on the current development status of that component technology. It is intended to compensate for uncertainties in line with the development status of that technology. NETL provide the guidelines given in Table A6.1. The technologies considered in this report range from 'existing' to 'innovative', or in terms of the table above from 'process used commercially' to 'concept with small-scale data'. The contingencies applied to account for technology readiness level were taken in this work as:

Process used commercially	0%
Full sized modules previously operated	10%
Small-scale pilot plant data	25%
Concept with bench scale data	35%

Individual technology components of the process were each considered individually and the contingencies were applied to their capital costs in order to calculate the bare erection costs (BEC).

Figure A6.1 'Capital cost levels and cost components'.



EPC contractor services (EPC): are estimated by NETL at 8 to 10 % of BEC and taken here to be 10% of BEC.

Project contingency (PC): are estimated by NETL at 15 to 30% of (BEC + EPC+ process

contingency) and taken here to be 15%.
Total project costs (TPC): were calculated by adding BEC, EPC and PC.

Table A6.1 Process contingency allowances

Component technology status	Component contingency
New concept with limited data	+ 40% of associated capital
Concept with bench scale data	30 - 70% of associated capital
Small pilot plant data	25 - 35% of associated capital
Full size modules previously operated	5 - 20% of associated capital
Process used commercially	0 -10% of associated capital

Start-up costs (SUC): are estimated on inputs necessary to bring plant into operation. In this work they were estimated as 2% of TPC.
Inventory capital (IC): was estimated as 0.5% of TPC.
Financing cost (FC): was estimated at 2.7% of TPC.
Other owners costs (OC): were estimated at 15% of TPC. The total overnight cost (TOC) in this analysis was then given by:

$$TOC = TPC + SUC + IC + FC + OC$$

In each case, the capital costs for the financial analysis were determined from the difference between the base case and the newer technology.

Calculation of NPV

NPVs for investment in resource recovery have been calculated in the present work using the following methodology.

1. Data for a base case investment in a standard technology wastewater treatment plant and one with the new technology were obtained. This included both capital costs of components and operating costs. The capital costs were evaluated using the US DoE NETL methodology (above) for determining contingencies for the final capital costs to completion. Details of the costs used for the cases in this report are given below. The capital and operating costs shown do not include common facilities for the various options such as: land, inlet works, tertiary treatment, control rooms, labour, maintenance, operations staff, decommissioning, etc.
2. The differences in capital costs (compared with the base cases) were used as the investment capital cost, and the differences in operating costs used as the operating costs for the NPV calculation. Where these operating cost differences were negative (the costs were avoided) the costs were taken as revenue to fund the investment. Where appropriate, revenue streams for struvite and nitrogen recovery were also used in the NPV calculations.
3. For sensitivity analyses, a deterministic NPV calculation (not involving probability distributions) was employed.
4. For some cases, probability distributions were ascribed to key parameters. This was achieved using the Oracle 'Crystal Ball' software package[91], which is a 'plug-in' to Microsoft Excel. Details of the probability distributions employed are given below.

Tables A6.3 and A6.4 provide summaries of the capital costs for the four options considered, while Table A6.4 provides a summary of the operating cost and revenue differentials of the options. Full data for the cases studied are given tables A6.5 to A6.18 following.

Table A6.2: Summary of capital cost data for the 45 ML/day co-digestion case

	Base Case	Anaerobic Digestion plus Co-digestion Option
Bare erection cost	$65.8M	$85.2M
Total capital cost	$100.0M	$129.6M
Difference from the base case		$29.6M

Table A6.3 Summary Of Capital Cost Data For The 100 Ml/Day And 10 Ml/Day Cases

	Base Case	A-stage Option	Low Emission Mainline Option	Photo-bioreactor Option
100 ML/day				
Bare Erection Cost	$81.4M	$109.3M	$113.9M	$130.0M
Total Capital Cost	$148.5M	$166.2M	$173.1M	$197.6M
Difference from the Base Case		**$17.7M**	**$24.6M**	**$49.1M**
$M Capital/ML		$0.18M/ML/d	$0.25M/ML/d	$0.49M/ML/d
10 ML/day				
Bare Erection Cost	$22.1M	$27.8M	$29.2M	$35.9M
Total Capital Cost	$33.7M	$42.3M	$44.4M	$54.6M
Difference from the Base Case		**$8.6M**	**$10.7M**	**$20.9M**
$M Capital/ML		$0.86M/ML/d	$1.07M/ML/d	$2.09M/ML/d

The above capital cost values do not include common facilities such as land, inlet works, tertiary treatment, control rooms and decommissioning.

Table A6.3 above shows the differential capital cost of the 100 ML/d and the 10 ML/d options in terms of both the capital costs and the capital costs per ML/d. As can be seen the capital costs per ML/d are relatively much higher in the smaller scale 10 ML/day cases.

Table A6.4 Avoided costs, revenues and additional operating costs of the options considered

Revenues and costs ($/year)	Co-digestion	A-stage option (100 ML/day)	Low Emission Mainline option (100 ML/day)	Photo-bioreactor option (100 ML/day)
Avoided costs				
Sludge disposal	$0.12M	$0.70M	$1.55M	$1.13M
Purchased electricity	$2.00M	$2.72M	$1.46M	$3.07M
Revenues				
REC	$0.39M (15 years)	$0.28M (10 years)	$1.14M (5 years)	-
Struvite	-	$0.59M	-	$0.98M
Nitrogen products	-	-	-	$1.01M
Electricity sales	-	-	$2.29M	-
Additional operating costs				
General O&M	$1.61M	$1.24M	$1.34M	$2.66M
Chemicals	-	$0.27M	$1.65M	$0.86M

The 10 ML/day cases have operating costs and revenues one-tenth of the 100 ML/day cases, except general O&M which is 8.3% of total capital cost per year in all cases.

Co-digestion case - Yarra Valley Water data (45 ML/day)[92]

For the anaerobic digestion plus co-digestion analysis, the base case capital included sludge handling and standard activated sludge secondary water processing facilities. The comparison case included similar sludge handling facilities, a Membrane Biological Reactor (MBR) and the anaerobic digesters, power generators and a waste receiving station. Since the volumes of sludge being handled are different in each case (anaerobic digestion lowers the sludge volume to be handled by around 60%), the sludge handling capital costs were adjusted for scale of operation in the base case, taking into account the sludge generated by the extra input material associated with the co-digestion waste. The scale of operation of the co-digestion case is 45 ML/day.

Capital cost contingencies to calculate BEC were not applied in the base case, since the technology is well established. In the anaerobic digestion case a 10% process contingency was applied to the MBR. In addition, the cost of replacing the biogas reciprocating engines was included every 5 years in the analysis.

Table A6.5 Capital costs (2015 costs, investment date 2015, NETL contingencies)

Component Item (Common plant items not included)	Base Case (k$)	Component Item (k$)	Anaerobic Digestion + Cogeneration and co-digestion (k$)
Secondary reactor	$28,379	Primary Clarifier	$3,440
Secondary clarifier	$6,339	Odour control	$116
Sludge thickeners	$3,774	MBR reactor (incl. 10% process contingency)	$33,000
Sludge tanks	$3,684	Sludge thickeners	$2,757
Sludge dewatering	$3,780	Sludge tanks	$2,697
Building	$8,840	Sludge dewatering	$2,762
		Building	$6,457
		AD + cogen	$16,783
		Waste receiving station	$3,000
Components Sub-total	**$54,804**	Components Sub-total	$71,012
Engineering (20%)	$10,959	Engineering (20%)	$14,202
Bare Erection Costs (BEC)	**$65,755**	**Bare Erection Costs (BEC)**	**$85,214**
EPC Contractor Services (10% of BEC)	$6,576	EPC Contractor Services (10% of BEC)	$8,521
Project contingency (15% of BEC+EPC)	$10,850	Project contingency (15% of BEC+EPC)	$14,060
Total Plant Costs (TPC)	**$83,181**	**Total Project Costs (TPC)**	**$107,795**
Start-up and Other Owners Costs (20.2%)	$16,803	Start-up and Other Owners Costs (20.2%)	$21,775
Total Overnight Costs (TOC)	**$99,984**	**Total Overnight Costs (TOC)**	**$129,570**
DIFFERENCE (k$)	**$29,586**		

Operating costs (2015 $)

Energy

Energy savings	9,855 kWh/year (600 kWh/ML)
Electricity price	$200/MWh in 2015
Electricity price escalator (real)	1.5% per year
REC price	$40/MWh
REC applicability	2020-2030
Engine replacement costs (refurbishment)	$1M each 5 years

Sludge Disposal

Management costs	\$300/ dry tonne
Solids reduced with Anaerobic Digestion	60% reduction
WAS rate	4,800 kg/day dry
Co-digestion waste	4,500 kg/day dry
Total sludge solids, base case	4,800 kg/day dry
Total sludge solids, AD case	(4,800+4,500)(1-60%) = 3,720 kg/day dry
Scale factor for sludge handling capital costs	$(4{,}800/3{,}720)^{0.6} = 1.17$
Tipping Fees	\$100/ wet tonne @ 8% moisture
Other operating costs	8.3% of capital costs (YVW assumption)

Table A6.6 Probabilistic data

Item	Probability Function	Std Deviation
Sludge disposal savings	Normal distribution	10%
Other operating costs	Normal distribution	10%
Tipping fees	Triangular distribution	\$50 to \$150/dry tonne
RECs (\$40/MWh)	Normal distribution	10%
Electricity price escalator	Normal distribution	10%
Capital items	Normal distribution	10%
Capital - MBR reactor	Normal distribution	20%

Base case - ASWROTI data (10 ML/day and 100 ML/day)[81]

Table A6.7 Capital costs (2015 costs, investment date 2020, NETL contingencies)

Component Item (Common plant items not included)	10 ML/day Case (k\$)	100 ML/day Case (k\$)	Process Contingency (%)
Oxidation ditch	\$5,055	\$25,302	0%
Clarifier	\$3,300	\$13,100	0%
Gravity drainage deck	\$300	\$2,300	0%
Anaerobic digester	\$3,000	\$21,000	0%
Dewatering centrifuge	\$2,936	\$5,872	0%
Polymer dosing station	\$177	\$783	0%
Pump stations	\$610	\$2,429	0%
Other capital items	\$3,075	\$10,618	0%
Components Sub-total	\$18,453	\$81,404	
Engineering (20%)	\$3,691	\$16,281	
Bare Erection Costs (BEC)	**\$22,144**	**\$97,685**	
EPC Contractor Services (10% of BEC)	\$2,214	\$9,768	
Project contingency (15% of BEC+EPC)	\$3,654	\$16,118	
Total Plant Costs (TPC)	**\$28,012**	**\$123,571**	
Start-up and Other Owners Costs (20.2%)	\$5,658	\$24,959	
Total Overnight Costs (TOC)	**\$33,670**	**\$148,530**	

Excluded common costs: site, labour, control rooms, inlet works, tertiary treatment, other common costs.

Table A6.8 Operating costs (2015 $)

Item	10 ML/day (k$/year)	100 ML/day (k$/year)
Power consumption	$498	$3,384
Power production	$0	$0
Sludge disposal	$260	$2,600
Struvite production	$0	$0
Chemicals use	$40	$391
Other Operating Costs (8.3% of BEC)	$1,837	$8,107
Total	$2,635	$14,482

Table A6.9 Probabilistic data

Item	Probability Function	Std Deviation
Sludge disposal savings	Normal distribution	10%
Other operating costs	Normal distribution	10%
RECs	Normal distribution	10%
Electricity price escalator	Normal distribution	10%
Capital items	Normal distribution	10%

Electricity consumption cost	$200/Mwh for 10 ML/day $160/Mwh for 100 ML/day
REC price	$40/MWh

A-stage case - ASWROTI data (10 ML/day and 100 ML/day)

Table A6.10 Capital costs (2015 costs, investment date 2020, NETL contingencies)

Component Item (Common plant items not included)	10 ML/day Case (k$)	100 ML/day Case (k$)	Included Process Contingency (%)
High rate aerobic tank	$711	$4,400	10%
A-stage clarifier	$1,500	$5,500	0%
B-stage SBR	$5,610	$28,600	10%
Thickener centrifuges	$2,340	$10,872	0%
2-phase anaerobic digestion	$4,325	$17,915	0%
Dewatering centrifuge	$3,420	$7,172	10%
Struvite crystalliser	$104	$524	0%
Anammox Granular SBR	$394	$1,619	5%
Pump stations	$1,060	$2,590	0%
Other capital items	$3,734	$11,905	0%
Components Sub-total	$23,198	$91,097	
Engineering (20%)	$4,638	$18,220	
Bare Erection Costs (BEC)	**$27,824**	**$109,317**	
EPC Contractor Services (10% of BEC)	$2,782	$10,932	
Project contingency (15% of BEC+EPC)	$4,591	$18,037	
Total Plant Costs (TPC)	**$35,197**	**$138,286**	
Start-up and Other Owners Costs (20.2%)	$7,110	$27,934	
Total Overnight Costs (TOC)	**$42,307**	**$166,220**	
Difference to ASWROTI base case	**$8,637**	**$17,690**	

Excluded common costs: site, labour, control rooms, inlet works, tertiary treatment, other common costs.

Table A6.11 Operating costs (2015 $)

Item	10 ML/day (k$/year)	Difference to Base Case (k$/year)	100 ML/day (k$/year)	Difference to Base Case (k$/year)
Power consumption	$292	-$206	$1,774	-$1,610
Power production	-$140	-$140	-$1,113	-$1,113
Sludge disposal	$190	-$70	$1,898	-$702
Struvite production	-$59	-$59	-$588	-$588
Chemicals use	$67	$27	$273	$273
Other operating costs (8.3% of BEC)	$2,509	$472	$9,073	$966

Table A6.12 Probabilistic data

Item	Probability Function	Std Deviation
Sludge disposal savings	Normal distribution	10%
Other operating costs	Log-Normal distribution	10%
Struvite Sales	Log-Normal distribution	30%
RECs	Normal distribution	10%
Electricity price escalator	Normal distribution	10%
Capital items	Normal distribution	10%
Capital Items (10% process contingency)	Normal distribution	20%

Electricity consumption cost	$200/Mwh for 10 ML/day $160/Mwh for 100 ML/day
REC price	$40/MWh

Low Energy Mainline case (LEM) ASWROTI data (10 ML/day and 100 ML/day)

Table A6.13 Capital costs (2015 costs, investment date 2025, NETL contingencies)

Component Item (Common plant items not included)	10 ML/day Case (k$)	100 ML/day Case (k$)	Included Process Contingency (%)
High rate anaerobic MBR	$10,432	$38,886	25%
Methane stripping column	$810	$6,885	35%
N Anammox MBBR	$3,739	$23,409	35%
Floc. settling clarifier	$2,900	$9,800	0%
Dewatering centrifuge	$2,504	$4,404	0%
Pump stations	$300	$501	0%
Other capital items	$3,659	$11,000	0%
Components Sub-total	$24,344	$94,885	
Engineering (20%)	$4,869	$18,977	
Bare Erection Costs (BEC)	**$29,213**	**$113,862**	
EPC Contractor Services (10% of BEC)	$2,921	$11,386	
Project contingency (15% of BEC+EPC)	$4,820	$18,787	
Total Plant Costs (TPC)	**$36,954**	**$144,035**	
Start-up and Other Owners Costs (20.2%)	$7,465	$29,095	
Total Overnight Costs (TOC)	**$44,419**	**$173,130**	
Difference to ASWROTI base case	**$10,749**	**$24,600**	

Excluded common costs: site, labour, control rooms, inlet works, tertiary treatment, other common costs.

Table A6.14 Operating costs (2015 $)

Item	10 ML/day (k$/year)	Difference to Base Case (k$/year)	100 ML/day (k$/year)	Difference to Base Case (k$/year)
Power consumption	$252	-$246	$1,929	-$1,455
Power production	-$571	-$571	-$4,573	-$4,573
Sludge disposal	$105	-$155	$1,052	-$1,548
Struvite production	$0	$0	$0	$0
Chemicals use	$204	$164	$2,041	$1,650
Other operating costs (8.3% of BEC)	$2,425	$588	$9,450	$1,343

Table A6.15 Probabilistic data

Item	Probability Function	Std Deviation
Sludge disposal savings	Normal distribution	10%
Chemicals	Normal distribution	10%
Extra Operating costs (8.3% of BEC)	Log-Normal distribution	20%
RECs	Normal distribution	10%
Electricity price escalator	Normal distribution	10%
Capital items (10% process contingency)	Normal distribution	20%
Capital Items (25% process contingency)	Log-Normal Distribution	20% (std. dev.) 20% (location)
Capital Items (35% process contingency)	Log-Normal distribution	40% (std. dev.) 40% (location)

Electricity consumption cost $200/Mwh for 10 ML/day
$160/Mwh for 100 ML/day
REC price $40/MWh
Import electricity assumed as $160/MWh, export energy as $80/MWh for the LEM case.

Phototrophic Case - ASWROTI data (10 ML/day and 100 ML/day)

Table A6.16 Capital costs (2015 costs, Investment date 2030, NETL Contingencies)

Component Item (Common plant items not included)	10 ML/day Case (k$)	100 ML/day Case (k$)	Included Process Contingency (%)
Photo-anaerobic MBR	$13,746	$51,237	35%
Thickening centrifuges	$2,340	$10,872	0%
2-phase anaerobic digestion	$4,757	$19,707	10%
Dewatering centrifuge	$3,419	$7,172	10%
Struvite crystalliser	$104	$524	0%
Electrodyalysis N recovery	$608	$3,713	35%
Pump stations	$682	$1,575	5%
Other capital items	$4,250	$13,500	0%
Components Sub-total	**$29,906**	**$108,300**	
Engineering (20%)	$5,981	$21,660	
Bare Erection Costs (BEC)	**$35,887**	**$129,960**	
EPC Contractor Services (10% of BEC)	$3,589	$12,996	
Project contingency (15% of BEC+EPC)	$5,921	$21,443	
Total Plant Costs (TPC)	**$45,397**	**$164,399**	
Start-up and Other Owners Costs (20.2%)	$9,170	$33,209	
Total Overnight Costs (TOC)	**$54,567**	**$197,607**	
Difference to ASWROTI base case	**$20,897**	**$49,077**	

Excluded common costs: site, labour, control rooms, inlet works, tertiary treatment, other common costs.

Table A6.17 Operating costs (2015 $)

Item	10 ML/day (k$/year)	Difference to Base Case (k$/year)	100 ML/day (k$/year)	Difference to Base Case (k$/year)
Power consumption	$480	-$18	$3,533	-$149
Power production	-$402	-$402	-$3,216	-$3,216
Sludge disposal	$147	-$113	$1,471	-$1,129
Struvite production	-$97	-$97	-$978	-$978
Nitrogen production	-$101	-$101	-$1,012	-$1012
Chemicals use	$125	$85	$1,250	$859
Other operating costs (8.3% of BEC)	$2,978	$1,141	$10,787	$2,655

Table A6.18 Probabilistic data

Item	Probability Function	Std Deviation
Sludge disposal savings	Normal distribution	10%
Chemicals	Normal distribution	10%
Extra Operating costs (8.3% of BEC)	Log-Normal distribution	20%
RECs	Normal distribution	10%
Electricity price escalator	Normal distribution	10%
Capital items (5% & 10% process contingency)	Normal distribution	20%
Capital Items (35% process contingency)	Log-Normal distribution	40% (std. dev.) 40% (location)

Electricity consumption cost	$200/Mwh for 10 ML/day $160/Mwh for 100 ML/day
REC price	$40/MWh

Typical probability distributions of input variables

Figures A6.2 to A6.11 show typical input probability distributions of variables to the NPV calculations. The full range of characteristics of these distributions are given in Tables A6.6, A6.9, A6.12, A6.15, and A6.18 above. The examples in the figures below are for selected key input parameters so that the reader can visualise the range and nature of some of the assumed probability distributions. The A-stage case is not represented in the examples since its probability distributions for input variables are generally simple normal distributions (Table A6.12).

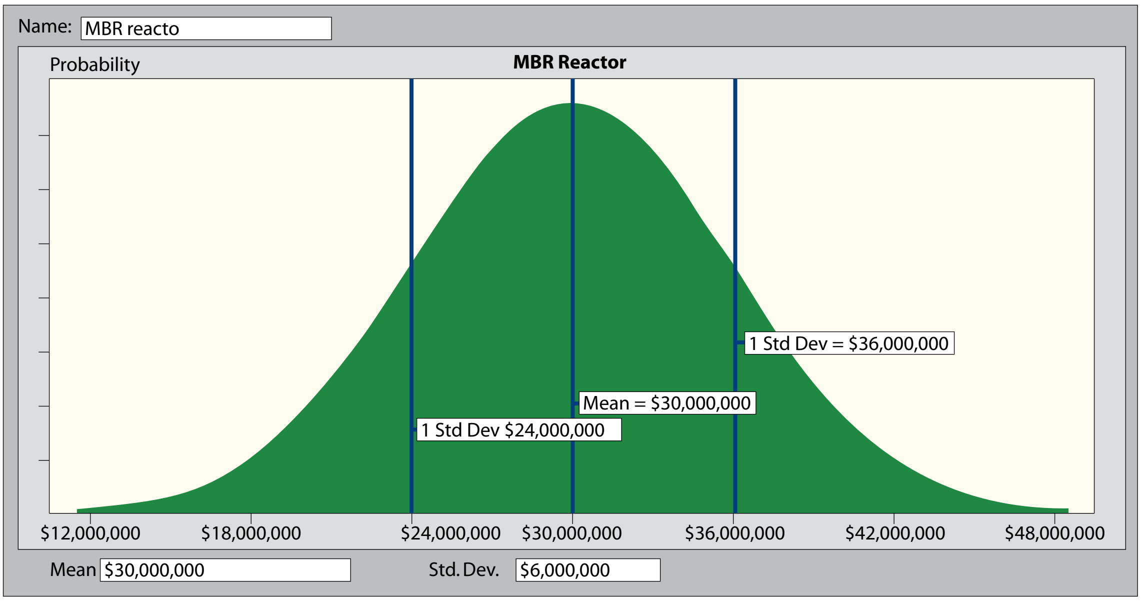
The green probability distributions below are the defined input distributions in Crystal Ball. The blue distributions below are calculated distributions after 10,000 iterations of the calculation. Some capital costs are shown as calculated distributions because they were derived from an input distribution multiplied by a technology contingency factor (see Tables above). In the case of the probability distribution of electricity costs in 2040, the output distribution was calculated from an input normal distribution on the rate of escalation of electricity price (1.5%/yr).

Co-digestion case (45 ML/day)

Since the technologies in question in this case are well known, the input probability distributions for bare erection capital cost are normal distributions (Table A6.6 above). Note that under the NETL contingencies applied (Table A6.5), actual capital costs are approximately double the bare erection costs shown in the figures. The scale of operation of the co-digestion case is 45 ML/day.

The electricity price in 25 years is an output distribution showing the range in potential electricity prices in 2040, starting at $200/Mwh in 2015.

Figure A6.2 Input probability distribution for the 'bare erection' capital costs of the MBR reactor in the co-digestion case.

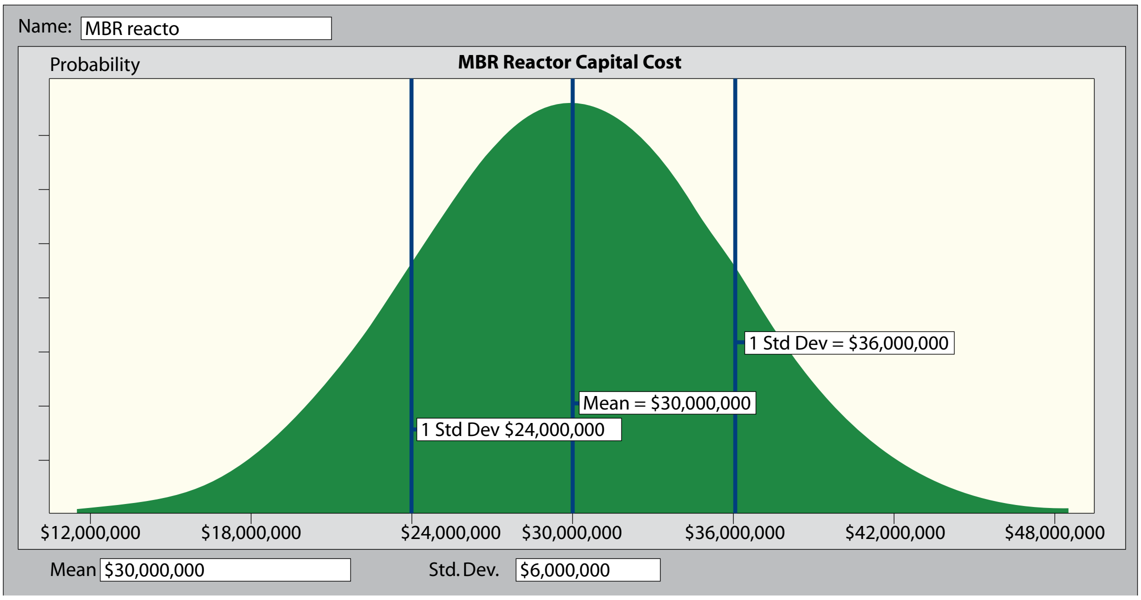

Name: MBR reacto

Mean $30,000,000 Std. Dev. $6,000,000

Low Energy Mainline (LEM) case (100 ML/day)

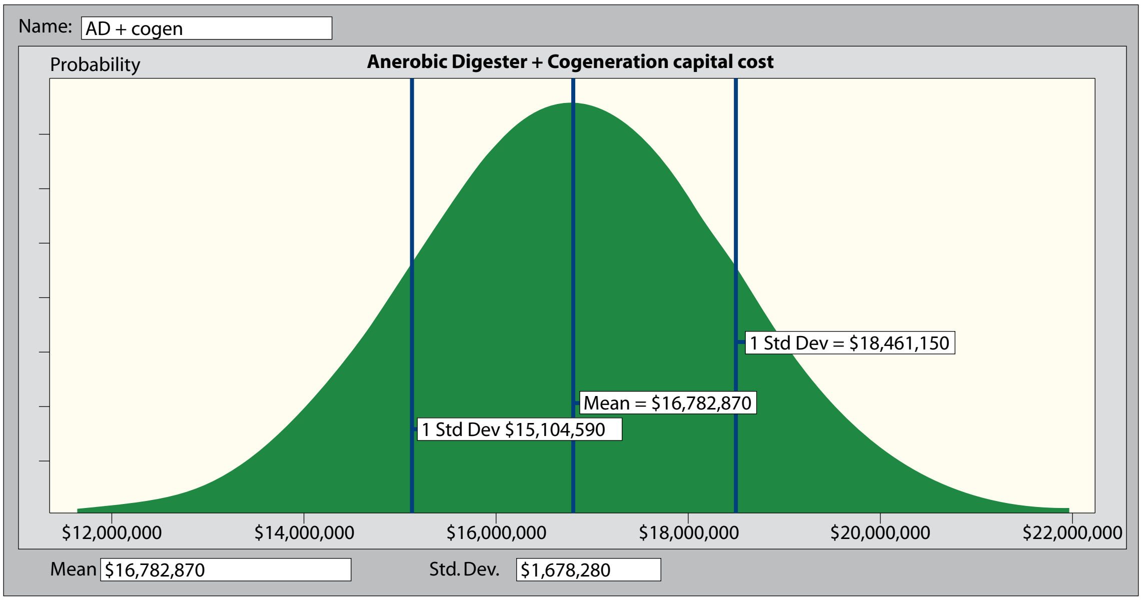
In this case some of the technologies are not commercial, so contingencies have been applied to the mean capital costs using the NETL methodology (Table A6.13 above), and the probability distributions have been made more skewed to account for the uncertainty in capital costs especially at the high end (using a log-normal distribution, Table A6.15 above). Examples of the key capital cost items are shown below. They are shown as calculated distributions after applying the NETL technology contingency during the probabilistic calculation (Table A6.16).

Figure A6.3 Input probability distribution for the 'bare erection' capital costs of the anaerobic digester and cogeneration in the co-digestion case.


Name: MBR reacto

Mean $30,000,000 Std. Dev. $6,000,000

Figure A6.4 Input probability distribution for the tipping fees in the co-digestion case.



Name: AD + cogen

Mean $16,782,870

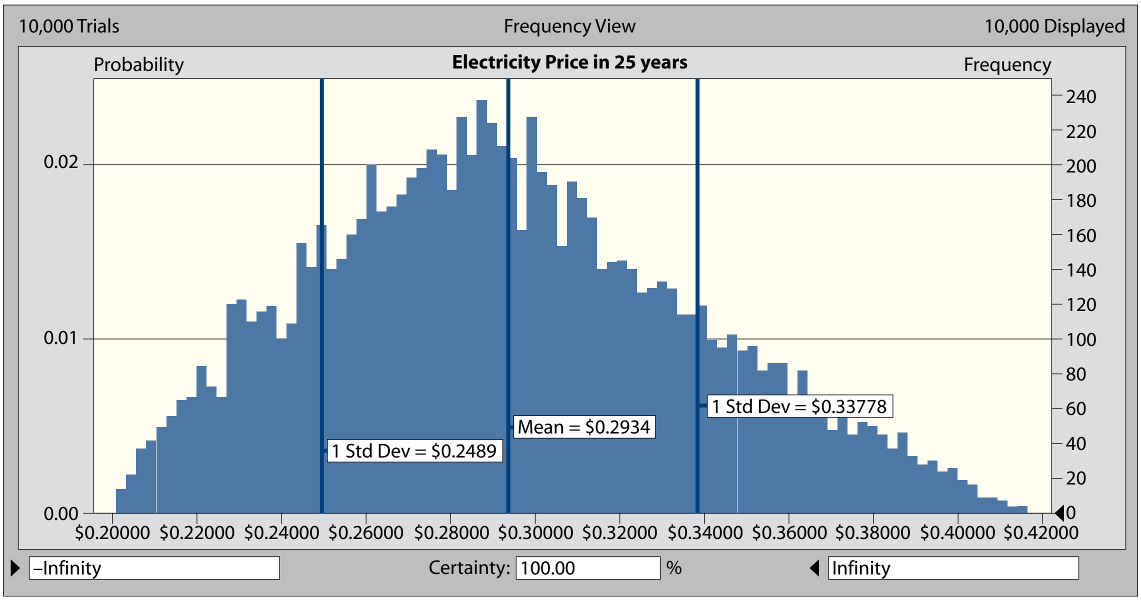
Std. Dev. $1,678,280

Photo-bioreactor case (100 ML/day)

The input probability distribution for the bare erection capital cost of the struvite crystalliser is shown in Figure A6.9 below. The full cost of the struvite crystalliser is approximately double that of the bare erection cost after applying the NETL contingencies (Table A6.16 above).

The struvite sales revenue is uncertain, so an input probability distribution for struvite sales revenue (from the ASWROTI data) was input to the calculation, as shown in Figure A6.10 in the photo-bioreactor case. A distribution of this type was also employed for the A-stage case, but with a different mean and standard deviation (Table A6.18).

Figure A6.5 Output distribution for the electricity price in 2040 probability distribution for the co-digestion case.



▶ -Infinity

Certainty: 100.00 %

◀ Infinity

Figure A6.6 Probability distribution of the 'bare erection capital cost' of the high rate anaerobic MBR after applying the 25% NETL technology uncertainty contingency in the LEM case.

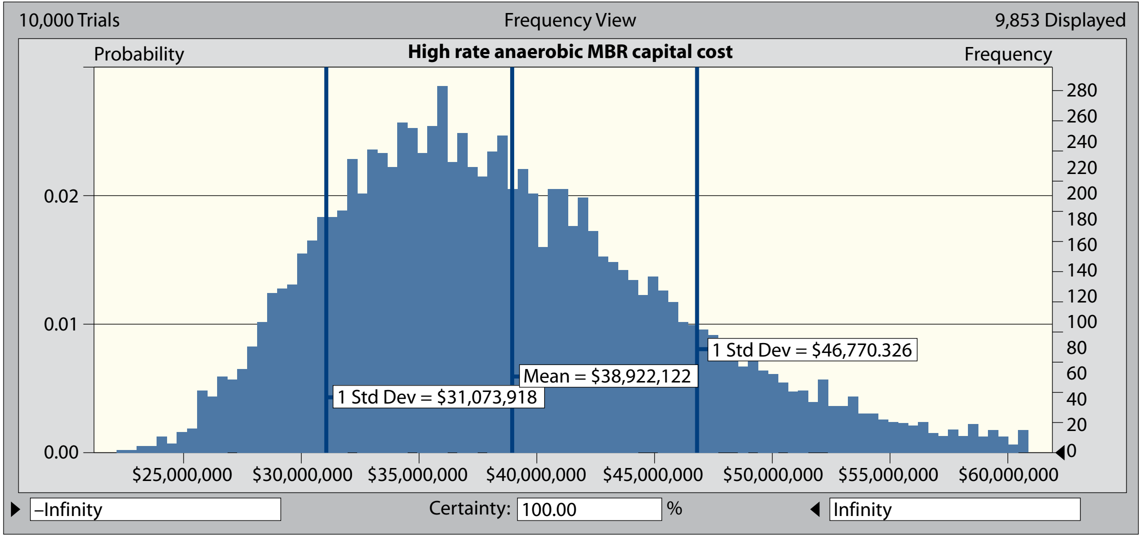


Figure A6.7 Probability distribution of the 'bare erection capital cost' of the nitrogen anammox MBR capital cost after applying the 35% NETL technology uncertainty contingency in the LEM case.

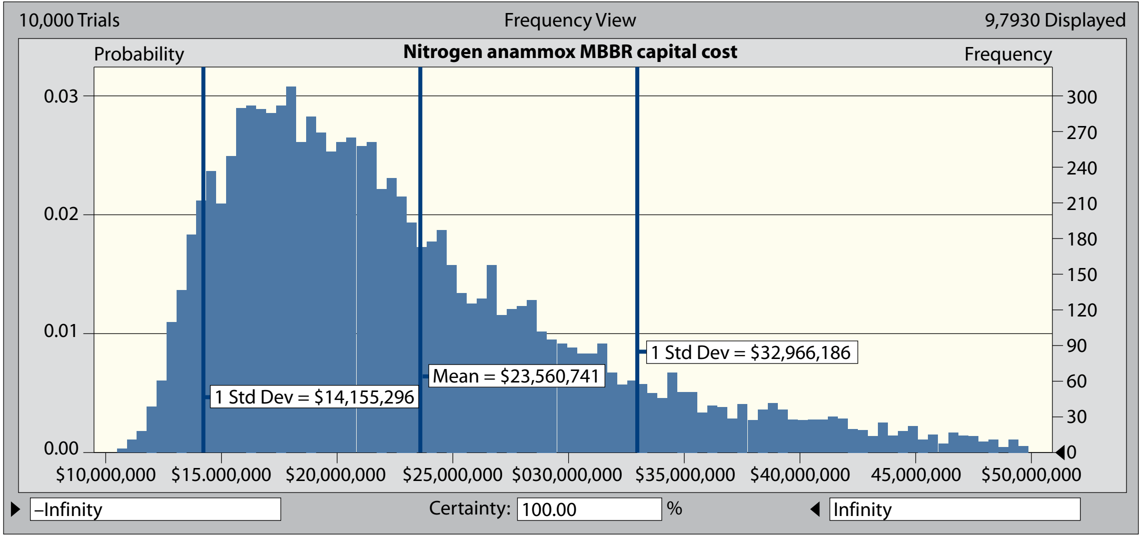


Figure A6.8 Probability distribution for electricity price in 2040 for the starting $160/MWh for the 100 ML/day cases.

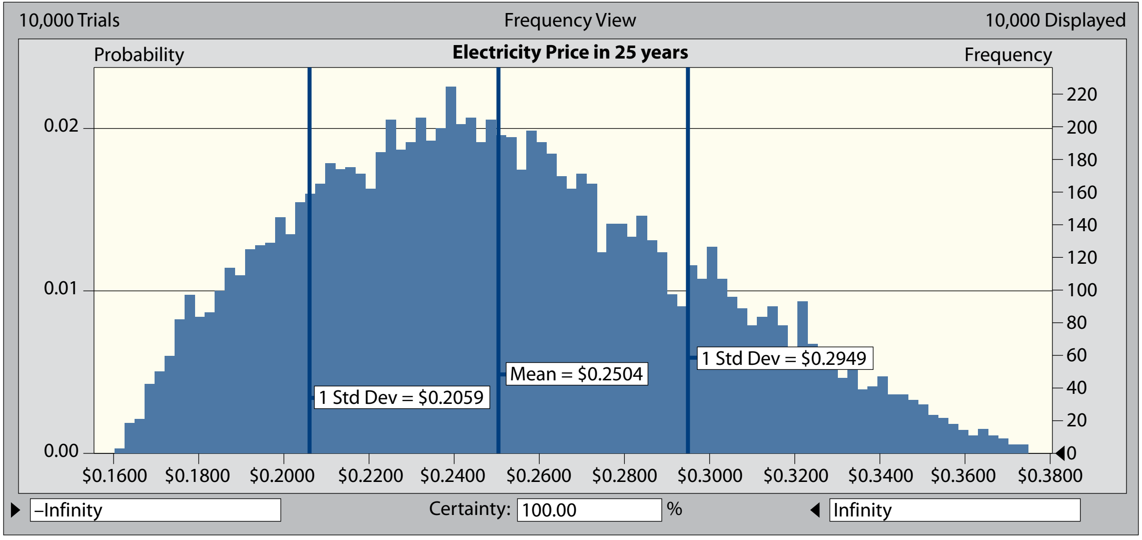
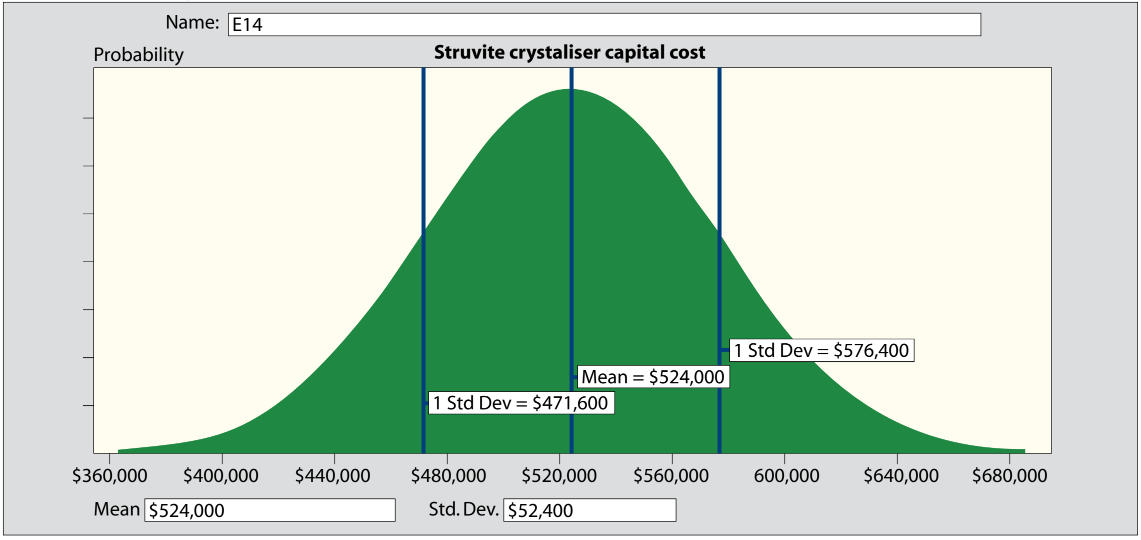


Figure A6.9 Input probability distribution for the 'bare erection capital costs' of the struvite crystalliser in the photo-bioreactor case.

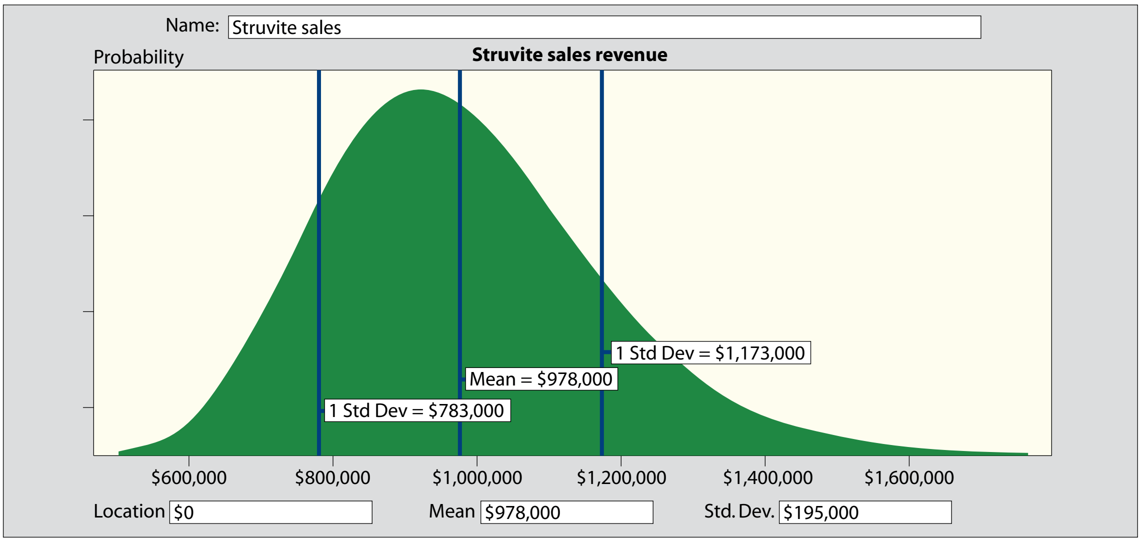


Name: E14

Mean $524,000

Std. Dev. $52,400

Figure A6.10 Struvite sales revenue in the photo-bioreactor case.



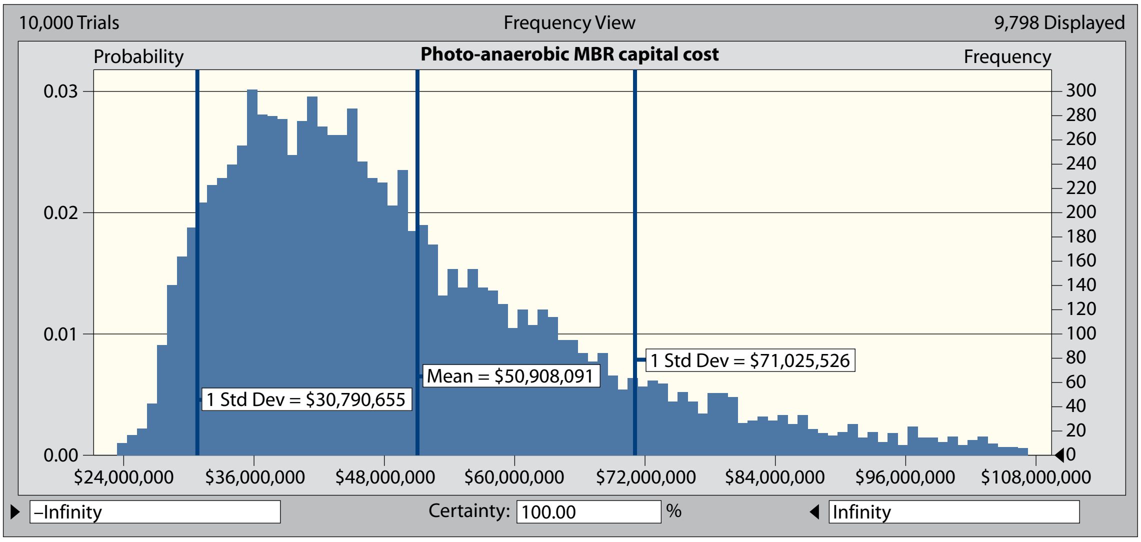
Name: Struvite sales

Location $0

Mean $978,000

Std. Dev. $195,000

Figure A6.11 Probability distribution of the 'bare erection capital cost' of the photo-anaerobic MBR capital cost after applying the 35% NETL technology uncertainty contingency in the LEM case.



10,000 Trials

Frequency View

9,798 Displayed

–Infinity

Certainty: 100.00 %

Infinity

The photo-bioreactor anaerobic MBR capital cost is uncertain. Figure A6.11 shows the probability distribution for the bare erection capital cost of this reactor after application of a technology contingency of 35% using the NETL methodology.

Sensitivities to key parameters

The tables below show the sensitivities of deterministic NPV to the assumptions made:

Table A6.19 Co-digestion case

Capital cost sensitivity

Change in parameter	NPV
+40%	$1.2M
+20%	$5.9M
0%	$10.6M
-20%	$15M
-40%	$20M

Purchased electricity price sensitivity

Change in parameter	Purchased Electricity Price ($/MWh)	NPV
+40%	$280	$21.3M
+20%	$240	$15.9M
0%	$200	$10.6M
-20%	$160	$5.2M
-40%	$120	-$0.1M

(Purchased price is escalated at 1.5% per year real from the above starting price in 2015).

Electricity price escalator sensitivity

Change in parameter	Price Escalator (%/yr)	NPV
+40%	2.1%	$12.7M
+20%	1.8%	$11.6M
0%	1.5%	$10.6M
-20%	1.2%	$9.6M
-40%	0.9%	$8.6M
-100%	0%	$5.9M

REC price sensitivity

Change in parameter	REC Price ($/MWh)	NPV
+40%	$56	$11.7M
+20%	$48	$11.1M
0%	$40	$10.6M
-20%	$32	$10.0M
-40%	$24	$9.4M

Tolling fees cost sensitivity

Change in parameter	Tolling Fee ($/wet tonne)	NPV
+40%	$140	$19.7M
+20%	$120	$15.1M
0%	$100	$10.6M
-20%	$80	$6.0M
-40%	$60	$1.5M

Power generating engine refurbishment cost sensitivity

Change in parameter	NPV
0%	$10.6M
-20%	$10.9M
-40%	$11.3M
-60%	$11.7M

Other operating costs sensitivity

Change in Parameter	% of BEC Capital Cost	NPV
+40%	11.6%	-$16.4M
+20%	10.0%	-$12.8M
0%	8.3%	-$10.3M
-20%	6.6%	-$5.6M
-40%	5.0%	-$2.1M

Table A6.20 ASWROTI A-stage case

Capital cost sensitivity

Change in parameter	NPV
+60%	$18.7M
+40%	$21.6M
+20%	$24.4M
0%	$27.3M
-20%	$30.1M
-40%	$33.0M

Purchased electricity price sensitivity

Change in parameter	Purchased Electricity Price ($/MWh)	NPV
+60%	$256	$51.0M
+40%	$224	$43.1M
+20%	$192	$35.2M
0%	$160	$27.3M
-20%	$128	$19.4M

(Purchased price is escalated at 1.5% per year real from the above starting price in 2015).

Total operating cost sensitivity

Change in parameter	NPV
+40%	$21.7M
+20%	$24.5M
0%	$27.3M
-20%	$30.1M
-40%	$32.9M

Table A6.21: ASWROTI Low Energy Mainline (LEM) case

Capital cost sensitivity

Change in parameter	NPV
+40%	$1.1M
+20%	$4.6M
0%	$8.0M
-20%	$11.4M
-40%	$14.9M

Purchased electricity price sensitivity

Change in parameter	Purchased Electricity Price ($/MWh)	NPV
+60%	$256	$16.6M
+40%	$224	$13.8M
+20%	$192	$10.9M
0%	$160	$8.0M
-20%	$128	$5.1M

(Purchased price is varied independently to export price in the above table. Purchased price is escalated at 1.5% per year real from the starting price above in 2015).

Export electricity price sensitivity

Change in parameter	Export Electricity Price ($/MWh)	NPV
100%	$160	$30.6M
80%	$128	$21.6M
60%	$96	$12.5M
50%	$80	$8.0M
40%	$64	$3.5M
20%	$32	-$5,5M

(LEM case in report assumes export power is sold at 50% of purchased price, or $80/MWh)
(Export price varied independently from purchased price)

Table A6.22: ASWROTI phototrophic case

Capital cost sensitivity

Change in parameter	NPV
+40%	-$5.2M
+20%	$0.7M
0%	$6.6M
-20%	$12.5M
-40%	$18.4M

Purchased electricity price sensitivity

Change in parameter	Purchased Electricity Price ($/MWh)	NPV
+60%	$256	$30.2M
+40%	$224	$22.4M
+20%	$192	$14.6M
0%	$160	$6.6M
-20%	$128	-$1.3M

(Purchased price is escalated at 1.5% per year real from the above starting price in 2015).

Real options methodology

In the present study the (S-X) probability distributions were analysed using the real option approach of Luehrman (1998). S and X were calculated separately, comprising the present values of the free cash flows less the capital expenditure (S) and the capital costs at commercialisation (X), respectively. The 'value-to-cost' parameter was then given by S/X. The present 'real option value' for the investment was calculated from the mean value of the blue part of the (S-X) distribution in the figures where NPV>0. The 'volatility' ($\sigma\sqrt{t}$) was calculated from the individual variances in the S and X distributions obtained from the probabilistic Monte-Carlo analysis as follows:

$$\sigma\sqrt{t} = \sqrt{(\sigma_S^2+\sigma_X^2)}/(S+X)$$

The analysis is similar to, but not exactly the same, as the analytical approach developed by Black and Scholes (1973)[87]. In their approach the exercise price (or capital investment) is discounted at the risk-free rate instead of the WACC and the probability distribution of S is log-normal with no probability distribution ascribed to X. Strict application of the analytical Black-Scholes method to the present data would therefore give a quantitatively different answer to the Monte-Carlo approach adopted here.

An analogy with the Luehrman 'options space diagram' can be drawn if the individual cases are plotted in the form of value-to-cost (S/X) versus 'volatility'. An investment is potentially more valuable when both the 'value-to-cost' and the 'volatility' increase. This is because there is more probability of positive NPV in the distribution when one or both of these occur. Both of these parameters thus contribute to the ROV. In the cases considered in this study, increased volatility occurs with increased uncertainty in capital costs and electricity price into the future (and some of the other variables), while S/X is obtained from the mean NPV value of the distribution, so higher NPV gives a higher value of S/X.

Table A6.23: Results of 'Real Option Value' analysis

Case	ROV ($M)	$\sigma_{(S-X)} = \sigma\sqrt{t}$	S/X	ROV/X	(S-X) ($M)	Certainty of NPV>0
Co-digestion	$14M	21%	1.37	0.53	$10.6M	79%
A-stage	$25M	20.5%	2.47	1.61	$25.7M	98.4%
LEM	$14M	38.0%	1.38	0.71	$6.0M	71.3%
Photo-bioreactor	$19M	38.4%	1.17	0.57	$5.5M	68.0%

ROV = real option value
$\sigma_{(S-X)}$ = standard deviation of NPV or (S-X)
S/X = value to cost ratio
ROV/X = real option value divided by X
(S-X) = NPV

APPENDIX 7: Regulatory framework in Australia

Table A7.1 NSW DEC classes of biosolids based upon contaminants

Contaminant	Grade A (mg/kg)	Grade B (mg/kg)
Cadmium	3	5
Copper	100	375
Chromium	100	250
Zinc	200	700
Chlordane	0.02	0.2
Dieldrin	0.02	0.2

Table A7.2 NSW DEC classes of biosolids based upon pathogen stabilisation

Pathogen Stabilisation Grade A		Pathogen Stabilisation Grade B	
Treatment	**Vector Reduction**	**Treatment**	**Vector Reduction**
Thermally treated >50°C for specified time, or high pH + Thermal treatment for specified time, or *E.Coli* < 100 MPN / g (dry weight), Faecal coliforms < 1000 MPN / g dry weight, and *Salmonella sp.* not detected in 50 g dry weight.	Mass of volatile solids reduced by at least 38%, or Anaerobically digested solids do not have further reduction of volatile solids in aerobic laboratory tests exceeding 15-17%, or specific oxygen uptake rate <1.5 mg O_2/hr/g solids at 20°C, or pH > 12 for 2 hrs and >11.5 for additional 22 hrs, or stabilised solids contains at least 75% dry solids, or unstabilised primary solids contains at least 90% dry solids, or biosolids are aerated for at least 14 days >40°C where the average temperature exceeds 45°C.	Solids are treated by either: anaerobic digestion, aerobic digestion, air drying, composting, lime stabilisation, extended aeration or other process accepted by the EPA.	As per Stabilisation Grade A or at least 20 days extended aeration including aerobic digestion time followed by six months storage or biosolids are injected below the surface of the land or applied to land surface and incorporated into soil within six hours of application.

Note: A biosolids product must meet at least one pathogen reduction requirement and at least one vector reduction requirement. MPN = most probable number.

Table A7.3 Typical nutrient removal levels by crops in Australia

Crop type	Total uptake in harvestable portion (kg/ha)				
	N	P	K	Ca	Mg
Vegetable					
Capsicum	41	4	69	52	7
Tomato	361	84	615	33	29
Grain crops					
Barley	27-31	6-7	11		
Canola	69	11	11		
Corn/Maize	93-112	17-21	31		
Oats	19-27	4-6	4-6		
Wheat	33-42	6-8	9-12		
Pastures					
Perennial ryegrass	210	18	120		
Phalaris	99	27	252		
Kikuya	780	90	840		
Lucerne	1015	116	725		

Data obtained from [3, 58, 93, 94]

Table A7.4 Maximum permissible concentrations (MPC) of impurities in fertilisers

Fertiliser type	MPC
Cadmium (Cd)	
Phosphatic (2% P or higher)	300 mg Cd/kg phosphorus
Trace elements	50 mg Cd/kg product
Other fertilisers	10 mg Cd/kg product
All fertilisers	
Lead (Pb)	
Wholly Constituted of Trace Elements	2000 mg Pb/kg product
Partially Consituted Trace elements	500 mg Pb/kg product
Fertiliser >25% organic matter	300 mg Pb/kg product
Other fertilisers	100 mg Pb/kg product
All fertilisers	
Mercury (Hg)	
All	5 mg Hg/kg product
Fluorine (F)	
Superphosphate	2.5%
Rock phosphate	4.0%

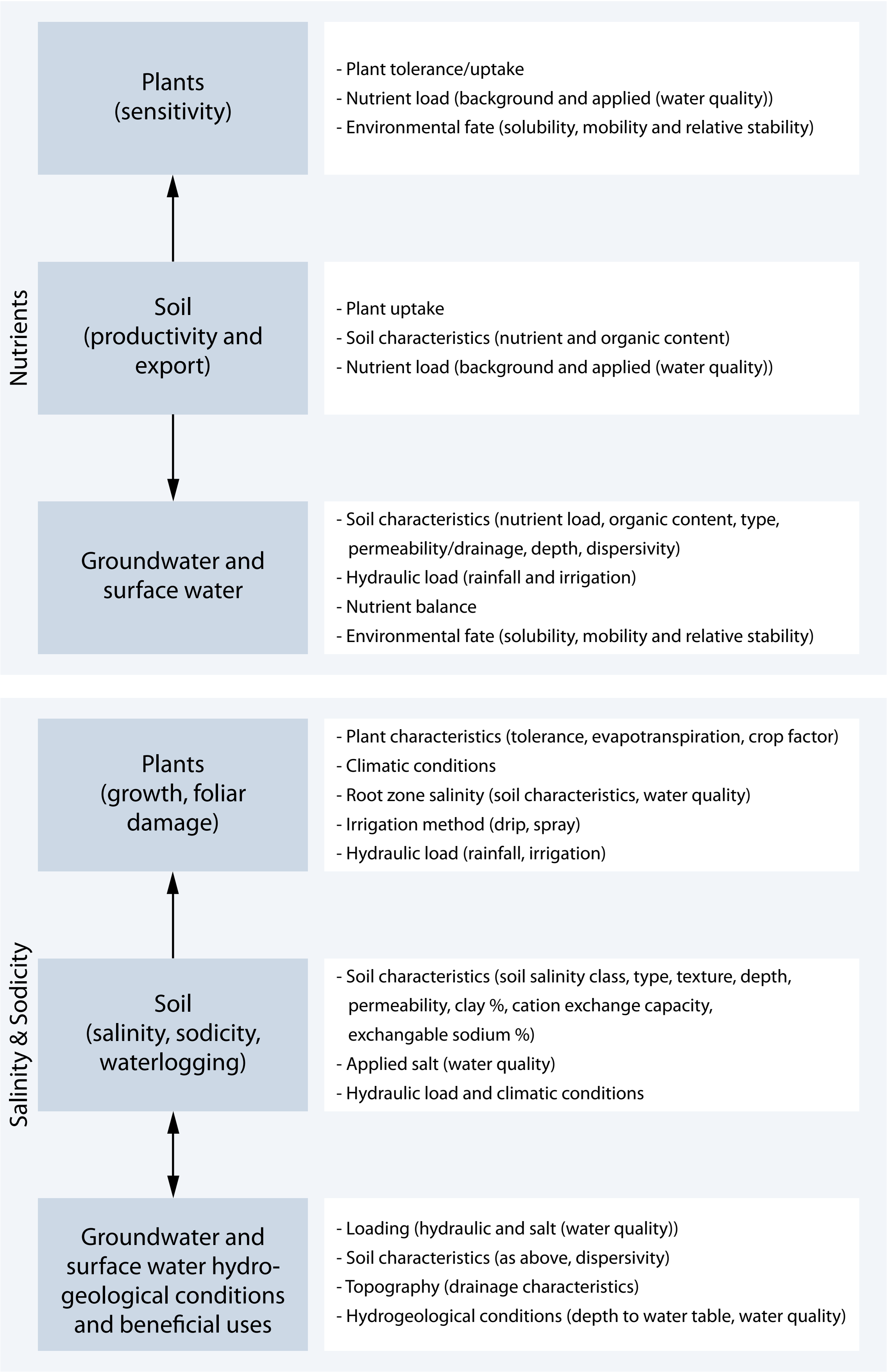
Data obtained from[95]

Table A7.5 Classes of reclaimed water and corresponding standards for biological treatment and pathogen reduction

Class	Water quality objectives - medians unless specified	Treatment processes	Range of uses– uses include all lower class uses
A	Indicative objectives ■ < 10 E.coli org/100 mL Turbidity < 2 NTU4 ■ < 10 / 5 mg/L BOD / SS ■ pH 6 – 9 ■ 1 mg/L Cl2 residual (or equivalent disinfection)	Tertiary and pathogen reduction with sufficient log reductions to achieve: ■ <10 E.coli per 100 mL ■ <1 helminth per litre ■ < 1 protozoa per 50 litres; and ■ < 1 virus per 50 litres.	*Urban (non-potable)*: with uncontrolled public access. *Agricultural*: e.g. human food crops consumed raw. *Industrial*: open systems with worker exposure potential
B	■ <100 E.coli org/100 mL ■ pH 6 – 9 ■ < 20 30 mg/L BOD/SS	Secondary and pathogen (including helminth reduction for cattle grazing) reduction	*Agricultural*: e.g. dairy cattle grazing. *Industrial*: e.g. washdown water
C	■ <1000 E.coli org/100 mL ■ pH 6 – 9 ■ < 20 / 30 mg/L BOD / SS	Secondary and pathogen reduction (including helminth reduction for cattle grazing use schemes)	*Urban (non-potable)*: with controlled public access. *Agricultural*: e.g. human food crops cooked/processed, grazing/fodder for livestock. *Industrial*: systems with no potential worker exposure
D	■ <10000 E.coli org/100 mL ■ pH 6 – 9 ■ < 20 / 30 mg/L BOD / SS	Secondary	*Agricultural*: non-food crops including instant turf, woodlots, flowers

This table was taken from: Table 1 (pg. 20) in *Guidelines for environmental management - Use of reclaimed water*, EPA Victoria, 2003[96].

Figure A7.1 Environmental risk assessment considerations.



(Extract from - *Guidelines for Environmental Management: Dual Pipe Water Recycling Schemes - Health and Environmental Risk Management* (EPA publication 1015).

Table A7.6: Contaminant upper limits for classifying biosolids as grade C1 or C2 (values are mg/kg dry weight)

Contaminant	Grade C1 and RSCL	Grade C2
Arsenic	20	60
Cadmium	1	10
Chromium[1]	400	3000
Copper	100 (150)[2]	2000
Lead	300	500
Mercury	1	5
Nickel	60	270
Selenium	3	50
Zinc	200 (300)[3]	2500
DDT & derivatives	0.5	1
Organochlorine pesticides[4]	0.05	0.5
PCBs	0.2	1

1. Chromium (III) limit due to expectation that this will be the dominant form.
2. 150 mg/kg copper limit for biosolids products composted to AS 4454.
3. 300 mg/kg zinc limit for biosolids products composted to AS 4454.
4. Organochlorine pesticide limit applied individually to: dieldrin, Aldrin, chlorodane, heptachlor (and the epoxide), hexachlorobenzene and lindane.

Table A7.7: Treatment grades based on treatment process, microbial criteria and other suggested controls

Treatment process	Associated controls
Treatment Grade T1 Microbiological criteria **Verification** (of prescribed processes listed below) < 1 Salmonella/50g (dw), <100 E.coli MPN/g (dw) and ≤1 enteric virus PFU/100g. Verification of inhibition of pathogen regrowth is also required **Routine monitoring** (of prescribed processes listed below) is based on <100 E.coli MPN/g (dw) **Alternative process** microbiological verification described on case-by-case basis. Alternative process microbiological verification described on case-by-case basis.	
Composting processes that simultaneously heat all material (e.g. in-vessel) Temperature of all compost material to be maintained at ≥55°C for ≥3 continuous days with process control as per AS-4454.	Relevant vector attraction reduction controls (refer Table 4) and production of product that does not generate offensive odours. Weed seed controls may be needed in landscaping or agricultural applications.
Composting window method Temperature of compost material maintained at ≥55°C for ≥15 days, including 5 turnings of the window. Process control as per AS-4454.	Relevant vector attraction reduction controls (refer Table 4) and production of product that does not generate offensive odours. Weed seed controls may be needed in landscaping or agricultural applications.
High pH and high temperatures Biosolids pH raised to ≥12 for ≥72 continuous hours and during this period, maintained at ≥52°C for ≥12 continuous hours. Final biosolids product to be air-dried to a solids content of ≥50%.	Relevant vector attraction reduction controls and production of product that does not generate offensive odours
Heating and drying Biosolids dried by heating particles to ≥80°C to a final solids content of ≥90%.	Relevant vector attraction reduction controls and production of product that does not generate offensive odours.
Long-term storage Sludge is digested, dewatered to >10% w/w solids and stored for > 3 years.	Product must be stored in manner that ensures no recontamination and not generate offensive odours.
Thermophilic digestion processes EPA endorsement of processes operating at greater than 55°C will be considered on a case-by-case basis depending on retention time, process stages and batch versus continuous feed/draw.	Relevant vector attraction reduction controls and production of product that does not generate offensive odours.
Suggested Treatment Process	**Other suggested controls**
Treatment Grade T2 Microbiological criteria **Routine monitoring** (of prescribed processes listed below) <10 Salmonella/ 50g dw, <1000 E.coli MPN/g dw **Alternative process** Based on achieving Salmonella and E.coli criteria and demonstration of 2 log Taenia saginata and enteric virus removal or batch testing to demonstrate < 1 Taenia ova per 10g and < 2 enteric virus PFU per 10g. Vector attraction reduction controls also required	
Composting method The temperature of all compost material to be ≥53°C for ≥5 continuous days or ≥55°C for ≥3 continuous days. (NB. Although this criteria is comparable to T1, it is also included as a T2 process in reflection that achieving the stringent T1 E.coli limits may require specialised techniques.	Relevant vector attraction reduction controls (see Table 4) and product that, coupled with management controls, does not generate offensive odours. Weed seed controls may be needed in landscaping or agricultural applications.
Heating and drying Biosolids are heated to ≥70°C and dried to a solids content of at least 75% w/w.	Relevant vector attraction reduction controls and product that, coupled with management controls, does not generate offensive odours.
Aerobic thermophilic digestion Aerobic conditions at 55-60°C for ≥10 continuous days. Final product dried to ≥50% solids. (NB. Could also achieve T1 process).	Relevant vector attraction reduction controls and product that, coupled with management controls, does not generate offensive odours.
Treatment Grade T3 **Routine monitoring** (of prescribed processes listed below) <2,000,000 E.coli MPN/g (dw). **Alternative process** Based on E.coli criteria atalso required	
Anaerobic digestion ≥15 days at ≥35°C or ≥60 days at ≥15°C.	For all Grade T3 treatment processes: Relevant vector attraction reduction controls and product that, coupled with management controls, does not generate offensive odours. Weed seed controls may be needed in landscaping or agricultural applications
Aerobic digestion ≥40 days at ≥20°C or ≥60 days at ≥15°C.	
Composting Aerobic conditions maintained ≥5 days at ≥40°C including ≥4 hours at ≥55°C.	

Pg. 21-22. *Guidelines for environmental management biosolids land application*, EPA.

Table A7.8: Biosolids classification and permissible end uses

		"Unrestricted"	"Restricted Uses"					
			Agricultural Uses			Non-Agricultural Uses		
			Human food crops consumed raw in direct contact with biosolids	Dairy and cattle grazing/ fodder (also poultry), human food crops consumed raw but not in direct contact	Processed food crops	Sheep grazing and fodder (also horses, goats), on food crops, woodlots	Landscaping (unrestricted public access)	Landscaping, (restricted public access), forestry, land rehabilitation
T1	C1	√	√	√	√	√	√	√
T2	C1	X	X	√	√	√	√	√
T3	C1	X	X	X	√	√	X	√
T1	C2	X	√	√	√	√	√	√
T2	C2	X	X	√	√	√	√	√
T3	C2	X	X	X	√	√	X	√

√ the biosolids grade will generally be acceptable for the enduse. Biosolids grades less than T1C1 will be subject to management controls.
X biosolids of this quality are not acceptable for the end use (would require a risk assessment and site specific EPA approval/licensing).
Pg. 34. *Guidelines for environmental management biosolids land application*, EPA.

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ATSE – in brief

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WASTE WATER – AN UNTAPPED RESOURCE

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