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Realising the Economic Value of Renewable Energy from Biosolids

Exploring Hunter Water's long term biosolids options

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ABSTRACT

Biosolids management poses a range of financial, regulatory, environmental and social challenges for wastewater utilities. However, alternative biosolids management approaches can offer opportunities to derive greater environmental and economic value from biosolids, improve resilience and enable a more circular economy through co-treatment of organic waste.

Hunter Water, AECOM and the Institute for Sustainable Futures (ISF) have assessed a range of centralised biosolids and co-treatment (biosolids and organic waste) options involving energy recovery as an alternative to the current biosolids management approach to an alternative centralised approach. Four scenarios were constructed to examine the resilience of various investment pathways under a range of plausible futures. The resilience of each pathway to a range of market and regulatory shocks, such as the banning of land application of biosolids and changes to regulation, was also explored.

A centralised anaerobic digestion (AD) facility with energy recovery is more cost effective than Hunter Water's current biosolids management approach. It will also improve resilience to future market and regulatory shocks and reduce Hunter Water's carbon footprint by up to 10%.

Thermal treatment offers greater resilience to potential regulatory and market shocks than both the current biosolids management approach and AD options. However, thermal treatment options have higher life cycle cost and a relatively immature regulatory approval pathway.

The financial and economic benefits of co-treatment are countered by new commercial and financial risks. Co-treatment is not critical to the business case for centralised biosolids treatment and energy recovery at Hunter Water.

INTRODUCTION

With much of the water industry having a focus on reducing carbon emissions, the role of renewable energy from biosolids has an important place in developing a long-term strategy. Hunter Water recognises that renewable energy from biosolids can contribute towards achieving its aspirational goal of carbon neutrality.

There are a range of biosolids treatment technologies available to exploit biosolids and produce renewable energy, including biological processes such as anaerobic digestion (AD) and thermal processes such as pyrolysis and gasification. These technologies are typically only cost effective at scale and would require a more centralised treatment approach for medium sized communities like the Lower Hunter.

The same technologies used to generate renewable energy from biosolids can be used to treat organic waste such as timber and source separated food waste. The acceptance of organic waste could vary from opportunistically accepting small quantities to improve energy recovery, to a co-treatment facility for biosolids with larger volumes of organic waste. The existence of mandated landfill levies in several states provides an opportunity for water authorities to provide an alternative solution to divert waste from landfill, while earning revenue from charging a competitive gate fee to accept organic waste.

This paper summarises work undertaken by Hunter Water and AECOM in 2018 and 2019 to assess a range of alternative biosolids management options involving energy recovery. A range of biosolids and co-treatment (biosolids and organic waste) options were assessed.

METHOD

Assessment Approach

The approach adopted for this assessment involved:

1. **Define the current situation** to establish the foundation for the assessment, including:

- Existing operations (assets, biosolids production, etc.)
- Assessment context (drivers, regulatory climate, strategic priorities, economic considerations, etc.)

2. **Review literature and case studies** of various biosolids processing technologies around the globe to understand best practice in generating renewable energy from biosolids, and inform quantitative and qualitative assessment of options.

3. **Options identification and screening** to generate a shortlist of options.

4. **Technical and economic modelling** to evaluate the implications of the shortlisted options specific to Hunter Water's operation (e.g. net heat and energy production, generation of various product streams). The analysis considered both financial costs and benefits to Hunter Water as well as broader societal costs and benefits, and included:

- **scenario analysis** to explore how each pathway performed under a range of plausible futures or combinations of future trends (such as wastewater quality and quantity and organics quality and quantity); and
- **sensitivity testing** to assess impacts of uncertainty around key inputs (e.g. market rates) and examine the effect of future market and regulatory shocks (such as banning of biosolids land application; regulatory change).

5. **Non-cost assessment** of options considering factors unable to be reliably monetised (such as regulatory risk).run length of below median rainfall is far greater (twice as long) for the reconstruction compared to the observed (Figure 2).

Current Situation

Hunter Water services an equivalent population (EP) of 550,000 through 19 wastewater treatment works (WWTWs) in the Lower Hunter Region. Approximately 45,000 wet tonnes per annum (tpa) of biosolids are recovered for beneficial reuse as a soil conditioner in agriculture and mine rehabilitation. Biosolids are recovered from 15 of Hunter Water's 19 WWTWs, with 80% generated from eight WWTWs located within two main population centres at Lake Macquarie and Maitland (refer Figure 1).

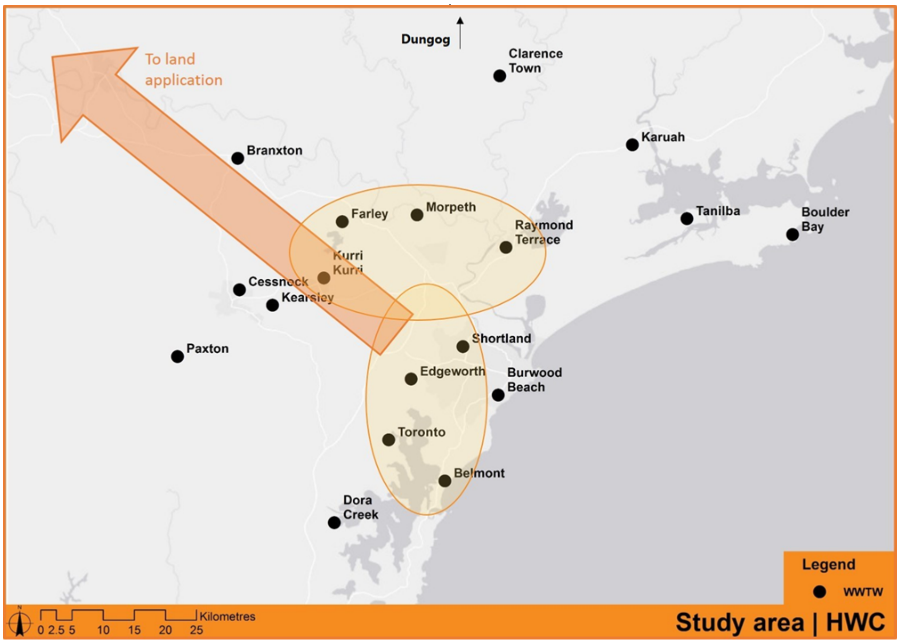

Figure 1: Hunter Water's Wastewater Treatment Works

Biosolids

Hunter Water's treatment plants typically utilise the activated sludge process. Waste activated sludge (WAS) stabilisation is achieved through sludge lagoons at smaller plants (3,200 EP – 40,000 EP capacity), and extended aeration or aerobic digestion at medium sized plants (21,500 EP – 93,000 EP capacity).

Beneficial reuse of biosolids is undertaken in accordance with the NSW Biosolids Guidelines (NSW EPA, 1997) to manage pathogen risks and contaminant risks such as heavy metals. These guidelines are currently under review by the NSW Environment Protection Authority (EPA). Whilst the outcomes of this review are not yet known, potential changes may include:

- Moving to a risk-based approach, similar to the Australian Drinking Water Guidelines and Australian Guidelines for Water Recycling;
- Introduction of indicator organism monitoring requirements; and
- Tightening of vector attraction reduction requirements.

Significant investment in biosolids management is required over the coming decade to service growth. Potential changes to the NSW Biosolids Guidelines involving more stringent processing requirements could drive substantial further investment.

At 80 GWh per year, electricity consumption accounts for approximately 10% of Hunter Water's operating costs. Recent electricity price increases and uncertainty regarding future energy prices place increasing cost pressure on Hunter Water. Fossil fuel-based electricity consumption is also the largest component (70%) of Hunter Water's carbon footprint of 93,000 tonnes of CO2-e per year (refer Figure 2). About 40% of this footprint is due to energy used in wastewater treatment (30 GWh per year).

These conditions present an opportunity for Hunter Water to change its biosolids management approach to:

- Develop a more resilient wastewater business considering energy needs and energy price risks.
- Optimise capital investment, reduce operating costs and bring new revenue streams.
- Improve resource recovery from biosolids.
- Reduce carbon emissions by producing renewable energy and moving away from energy intensive treatment processes.
- Reduce waste to landfill and move to a more circular economy by importing organic waste that would otherwise be disposed to landfill.

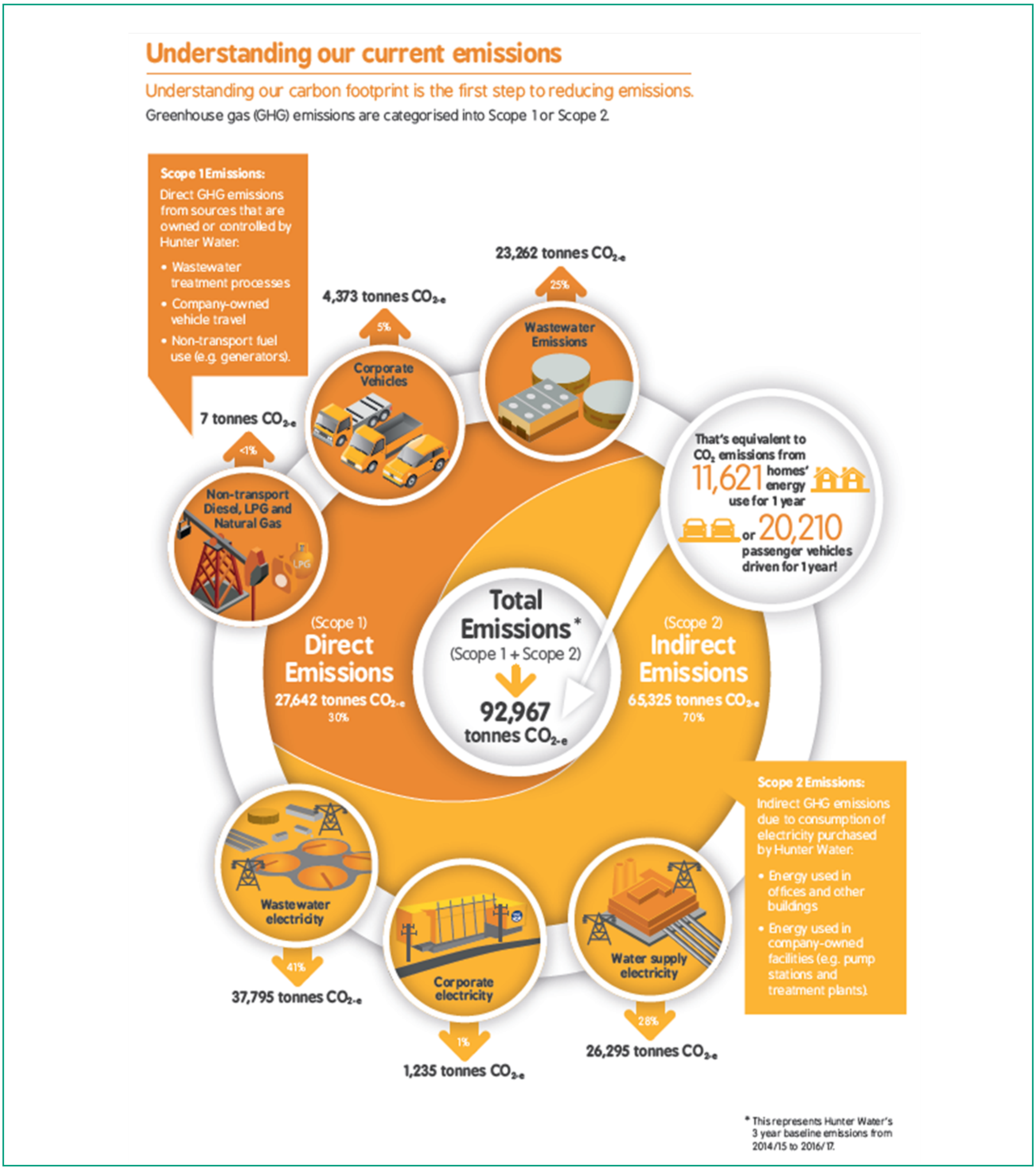

Figure 2: Hunter Water's Carbon Footprint

Literature Review

A broad review of biosolids processing technologies adopted both locally and internationally was used to document "best practice" (in terms of renewable energy production) and explore key learnings from past projects. Local and international case studies were examined to understand the applications and potential challenges of the various waste to energy technologies. This work highlighted the importance of pre-treatment for organic waste feedstocks and understanding organic waste and end-product markets.

Based on literature values and preliminary modelling, the potentially exploitable energy in the biosolids produced from various technological configurations involving AD was estimated (Figure 3). Thermal hydrolysis can increase the amount of energy available through AD of WAS. Primary sludge inherently contains more energy than WAS. Thermal treatment of biosolids post digestion can increase the amount of energy generated.

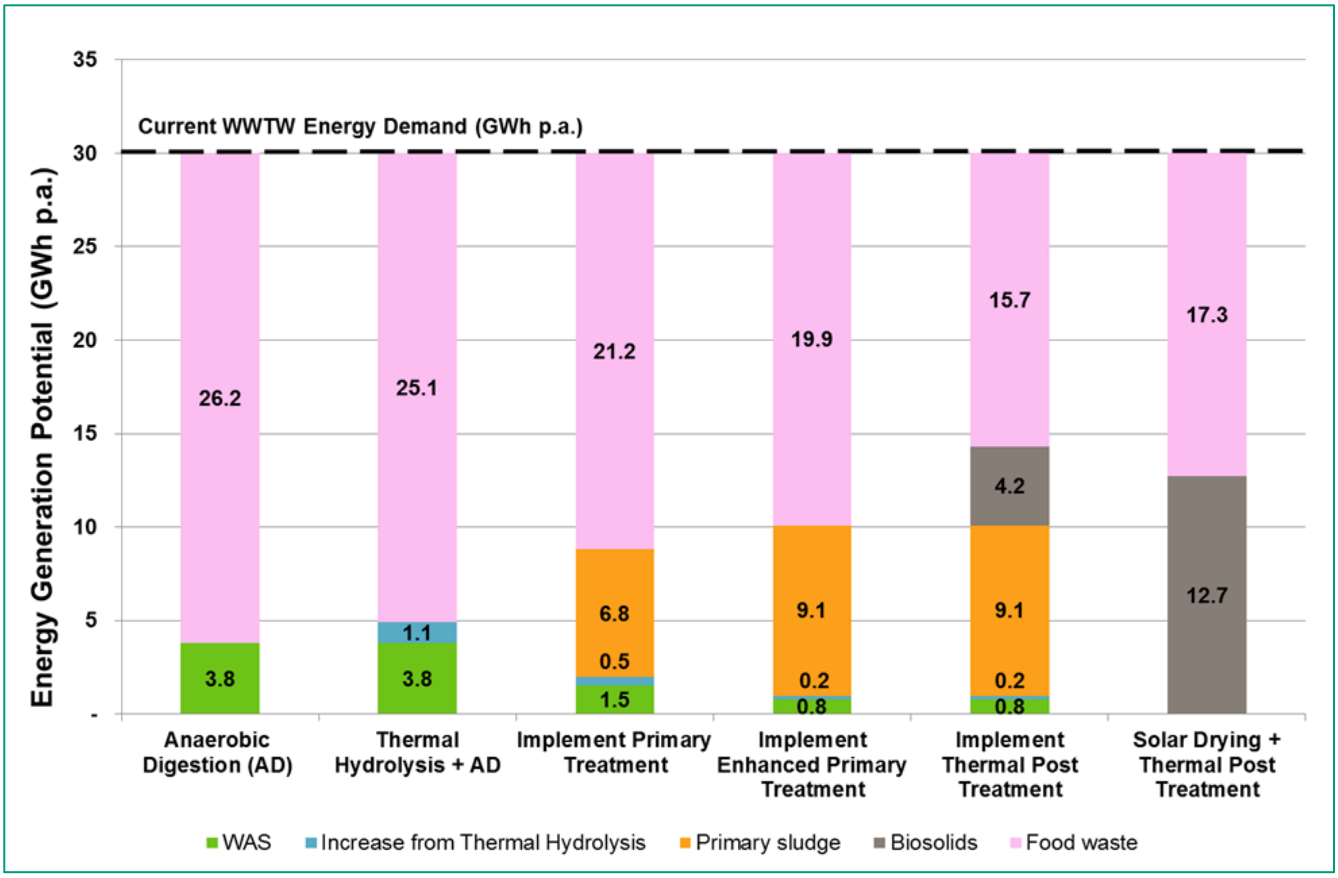

Figure 3: Gross energy generation potential from alternative biosolids approaches

The pink bars in Figure 3 show the additional energy required from co-digestion with food waste to approach energy neutrality for wastewater treatment (assuming no changes to existing energy demand). Energy neutral wastewater treatment would not be achievable with Hunter Water's biosolids alone. It is estimated that augmenting biosolids with over 80,000 wet tpa of food waste would be required to achieve energy neutral wastewater treatment.

Analysis of organic waste feedstock markets in the Lower Hunter Region suggests insufficient volumes of food waste are currently landfilled to achieve energy neutrality through co-digestion of waste diverted from landfill.

Options Identification and Screening

Options for generating renewable energy from biosolids were identified and then screened using cost and non-cost factors such as technology maturity and community impacts. The adopted short-list of options incorporated:

1. Biosolids production:

- Secondary treatment as per existing infrastructure
- Addition of primary treatment

2. Biosolids exploitation to recover energy:

- Biological pathways centred around AD of biosolids, both with and without thermal hydrolysis
- Thermal pathways centred around gasification (following thermal drying)

3. Biosolids augmentation to increase energy production and bring new revenue opportunities:

- Biological pathways involving co-digestion of biosolids with source separated food waste
- Thermal pathways involving gasification of biosolids with timber waste.

The energy recovery technologies considered are typically only cost effective at scale. For a medium sized community such as the Lower Hunter, this would require a more centralised treatment approach compared to the current distributed biosolids treatment approach.

Technical and Economic Modelling

Technical modelling included high level mass balances and heat and energy balances for all pathways. Economic modelling included assessment of financial costs and benefits to Hunter Water, with consideration of broader societal costs and benefits.

The financial analysis included capital and operating and maintenance (O&M) costs, reduced electricity bills, avoided cost of upgrades, revenue from gate fees, sale of large-scale generation certificates, and sale of products. The economic analysis included avoided greenhouse gas emissions and diversion of organic waste from landfill, and considered gate fee revenue a transfer. A summary of the key variables adopted in the financial and economic analysis is provided in Table 1. Sensitivity testing was used to explore the impact of changes to key inputs including capital and operating costs, market rates and biosolids energy content.

Variable	Adopted Value (2019)	Adopted Value (2050)	Units
Equivalent population	698,275	1,010,700	Equivalent persons (EP)
Total biosolids production	45,111	65,295	Wet tonnes per annum (tpa)
Biochemical methane potential (BMP) of WAS	0.15	0.15	m^3 CH4/kg VS
Calorific value of WAS	15	15	MJ/kg (dry basis)
BMP of primary sludge	0.45	0.45	m^3 CH4/kg VS
Calorific value of primary sludge	22	22	MJ/kg (dry basis)
Available food waste	10,000	14,474	Wet tpa
BMP of food waste	0.46	0.46	m^3 CH4/kg VS
Food waste contamination rate	10	10	%
Available timber waste	57,000	82,503	tpa
Calorific value of timber waste	17	17	MJ/kg (dry basis)
Timber waste contamination rate	5	5	%
Gas price	60	60	$/MWh
Electricity price	144.6	171.3	$/MWh
LGC Price	75	16.7	$/MWh
Ash landfill gate fee	400	400	$/t
Organic pre-treatment reject landfill gate fee	335	335	$/t
Biochar price	100	100	$/t
Economic cost of greenhouse gas emissions	51.8	51.8	$/t CO_{2e}
Economic cost of landfill	14.8	14.8	$/t

Table 1: Key variables adopted in financial and economic analysis

A key element of this study was the characterisation of relevant uncertainties in the assumptions about the future. The uncertainties considered in the analysis were firstly identified through a process led by the Institute for Sustainable Futures (ISF) where a range of significant, yet uncertain assumptions associated with wastewater, energy and waste systems, were identified. Strategic influences, categorised as trends or plausible sudden events (shocks) within the planning horizon, were identified through a horizon scan, using techniques such as the Futures Triangle and the STEEPV (Social, Technical, Economic, Environmental, Political/Regulatory, Values) Framework to characterise emerging risks and opportunities.

Four plausible alternative futures scenarios (in addition to the most likely scenario) were developed. Scenarios provide a mechanism to expand the thinking about the future, account for future uncertainty, and understand trade-offs. The intention is not to decide which scenario is most likely and plan for that, but rather to make planning and investment decisions that make the most sense across a range of plausible future scenarios.

The scenarios were developed by building on work done by CSIRO and Hunter Water to assist in exploring the resilience of strategic water and wastewater planning initiatives across the organisation. A narrative was developed for each scenario to articulate significant potential influences within the planning horizon. The scenario narratives are intended to be divergent from current trends and explore extremes. As shown in Figure 4, the scenarios were developed using a two by two matrix approach, with the x-axis representing independent governance vs. connected governance and the y-axis representing community focus vs. individual focus. The narrative for each scenario is summarised in Table 2.

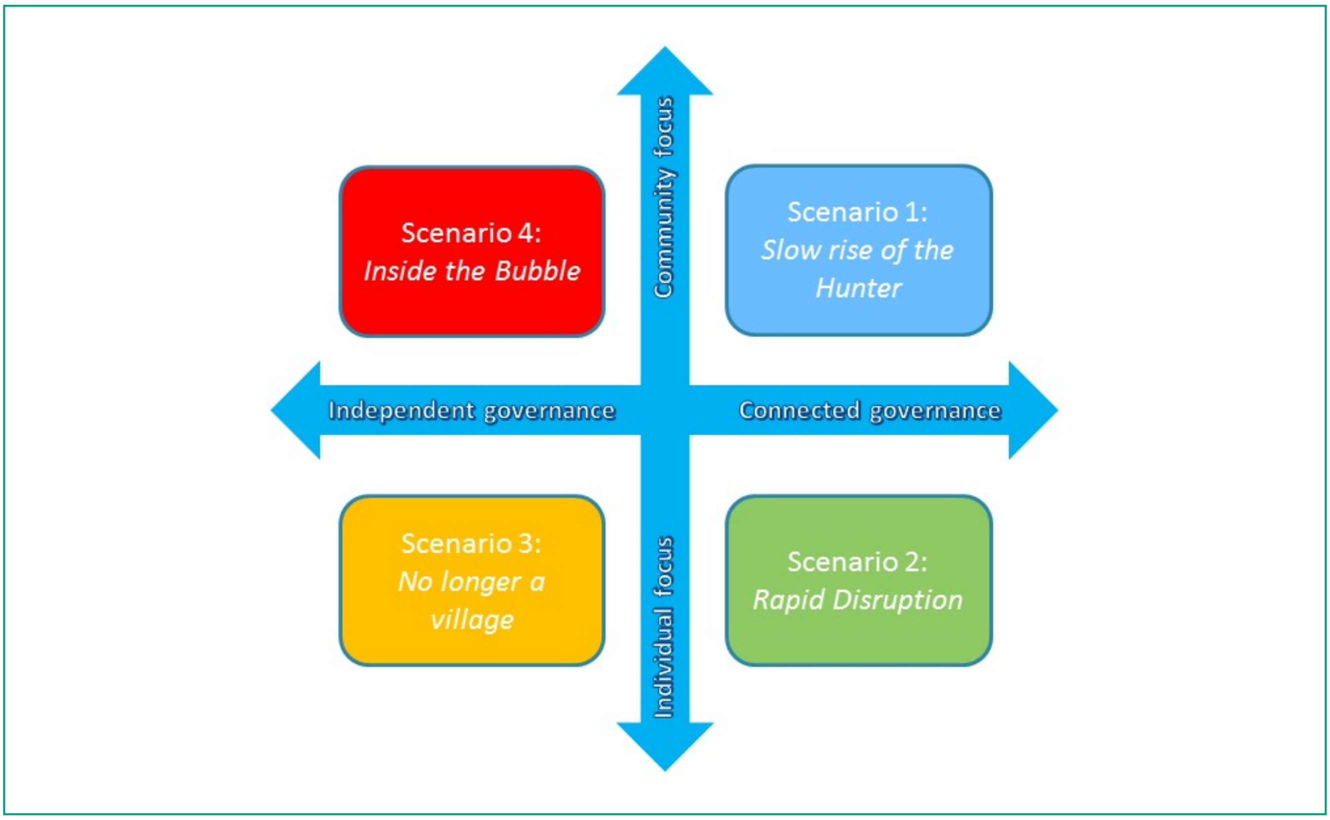

Figure 4: Overview of futures scenarios

	Slow rise of the Hunter	Rapid disruption	No longer a village	Inside the bubble
Overview	Hunter communities and governance have become more interconnected, creating improved environmental outcomes, strong uptake of technologies, and enhanced outcomes-based regulations. More coordinated governance provides a strong and diversified economy and increasing government revenue. Public investment in green infrastructure leads to improved liveability and environmental outcomes. The Hunter becomes noted as a "Smart Region" where government, community and industry collaborate and use new technologies to improve interconnectedness, leading to a better use of resources across the region. Hunter Water has a strong role in regional planning as community trust grows.	Increased availability of a range of technologies drives increased individualism within the community. Technology conversely enables a more connected governance between government, industry and the community enabling the supply of water and the management of wastewater as more individualised services. Cheaper renewable energy and new technologies increases the number of people going "off-grid" for water supply and wastewater recycling/ treatment. Technology enables regulators to maintain high water quality standards, and thus good liveability.	Industry is replacing many of the traditional government roles. Fragmented governance results in a reduction in effective regulations and declining revenue. Increased sense of individualism at the expense of community cooperation, decreasing effectiveness of government services and private companies increasingly providing services such as water and wastewater treatment and supply creates an increasing level of social inequity and decline in environmental standards.	The Hunter region has a strongly connected community however governance arrangements are fragmented. There is a reduction in the delivery of basic services and infrastructure leading to communities operating in self-managed enclaves. Well-off enclaves increasingly go "off-grid". Those less well-off suffer from the loss of basic levels of services and poor access to valuable resources causing public health issues.

Table 2: Futures scenarios narratives

For each scenario, a revised set of modelling inputs was constructed by varying key inputs based on the narratives developed. A summary of how key variables for the financial and economic analysis varied across the scenarios is provided in Table 3.

Variable	Input Percentage Variation from Most Likely Scenario			
	Slow rise of the Hunter	**Rapid disruption**	**No longer a village**	**Inside the bubble**
Population and wastewater production	10% increase	10% increase	2% increase	9% reduction
Available organic waste	50% increase	No change	100% reduction	60% reduction
Organic waste contamination rate	50% reduction	50% increase	50% reduction	50% reduction
Energy content of wastewater influent	40% increase	No change	20% reduction	40% reduction

Table 3: Key variables adopted in scenarios

The study also examined the resilience of each pathway to a range of market and regulatory shocks, such as changes to stabilisation requirements in the NSW Biosolids Guidelines, banning of organics to landfill and banning of biosolids application to land.

Non-Cost Assessment
Non-cost factors including regulatory risk, technology robustness and maturity, system versatility and modularity, feedstock and product market risks, and local community impacts were considered qualitatively.

RESULTS & DISCUSSIONS

The results of the financial and economic analysis are shown in Figure 5 and Figure 6 respectively. Financial results are presented as absolute net present values (NPV), while economic results are presented as NPV relative to the current biosolids management approach.

The results of analysis of potential futures scenarios are shown in Figure 7. Figure 8 shows the results of analysis of potential market and regulatory shocks.

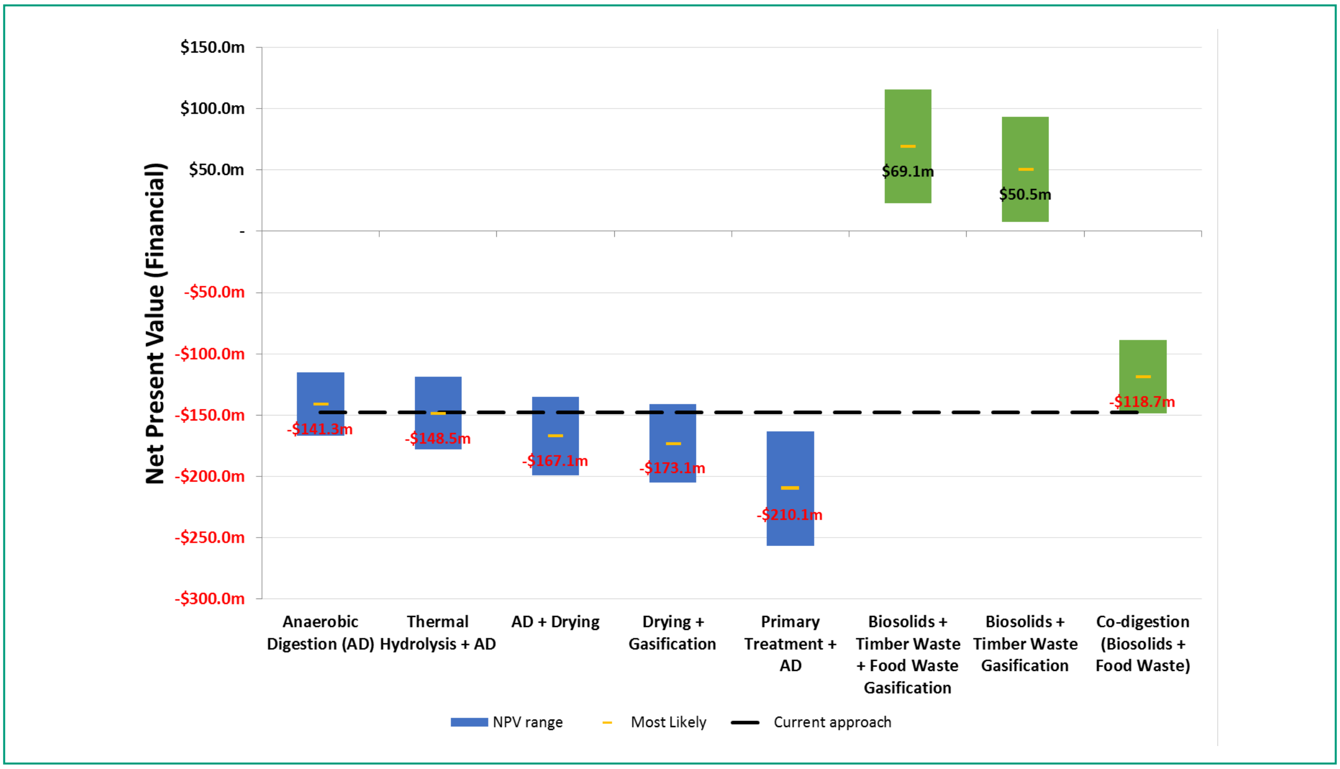

Figure 5: Financial results of biosolids and co-treatment options with capital cost ±40% (biosolids-only options in blue; co-treatment options in green)

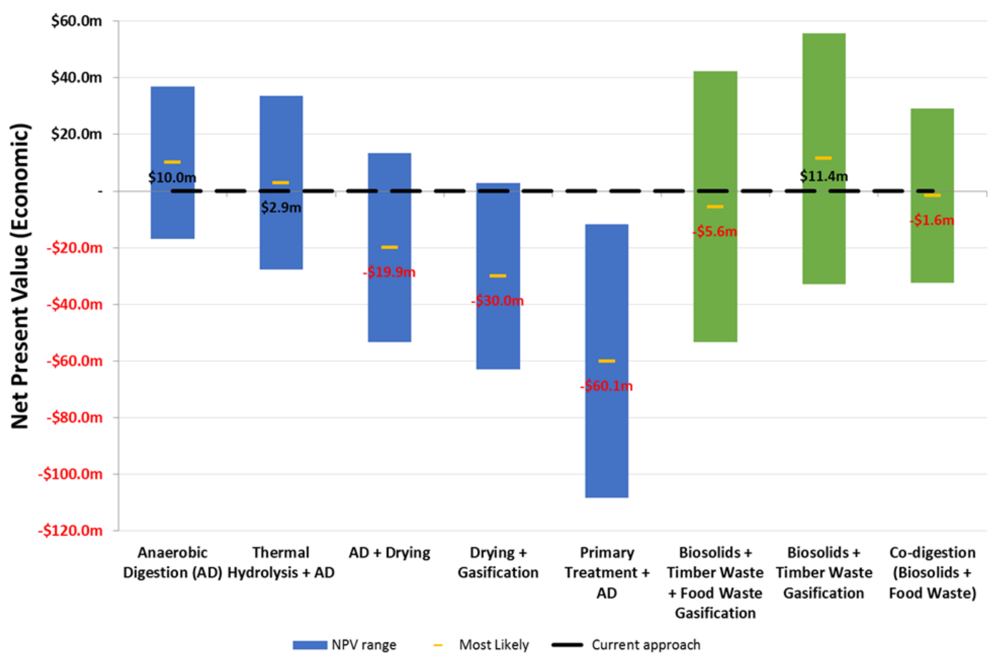

Figure 6: Economic results of biosolids and co-treatment options with capital cost ±40% (biosolids-only options in blue; co-treatment options in green)

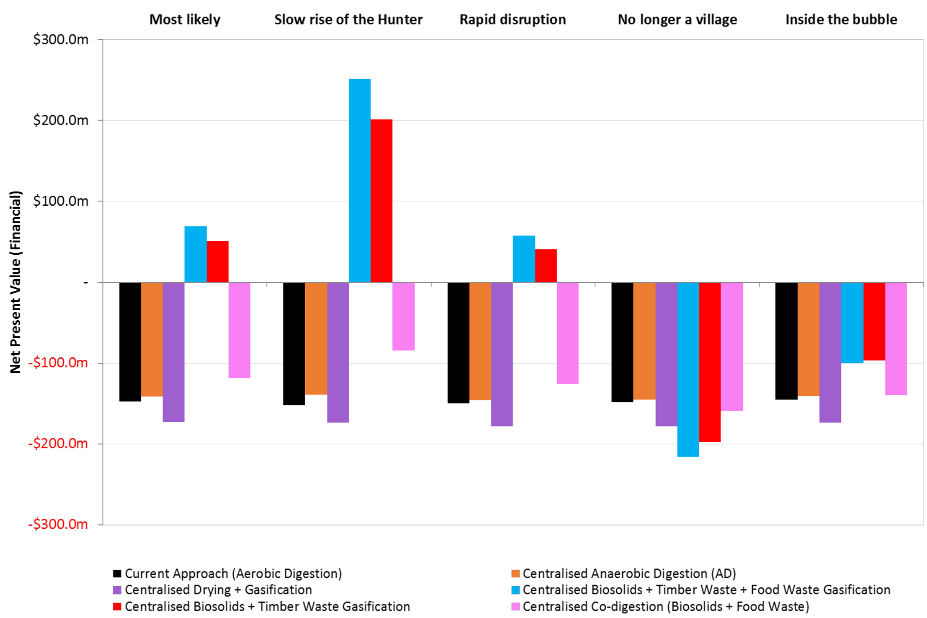

Figure 7: Analysis of potential scenarios for biosolids and co-treatment options

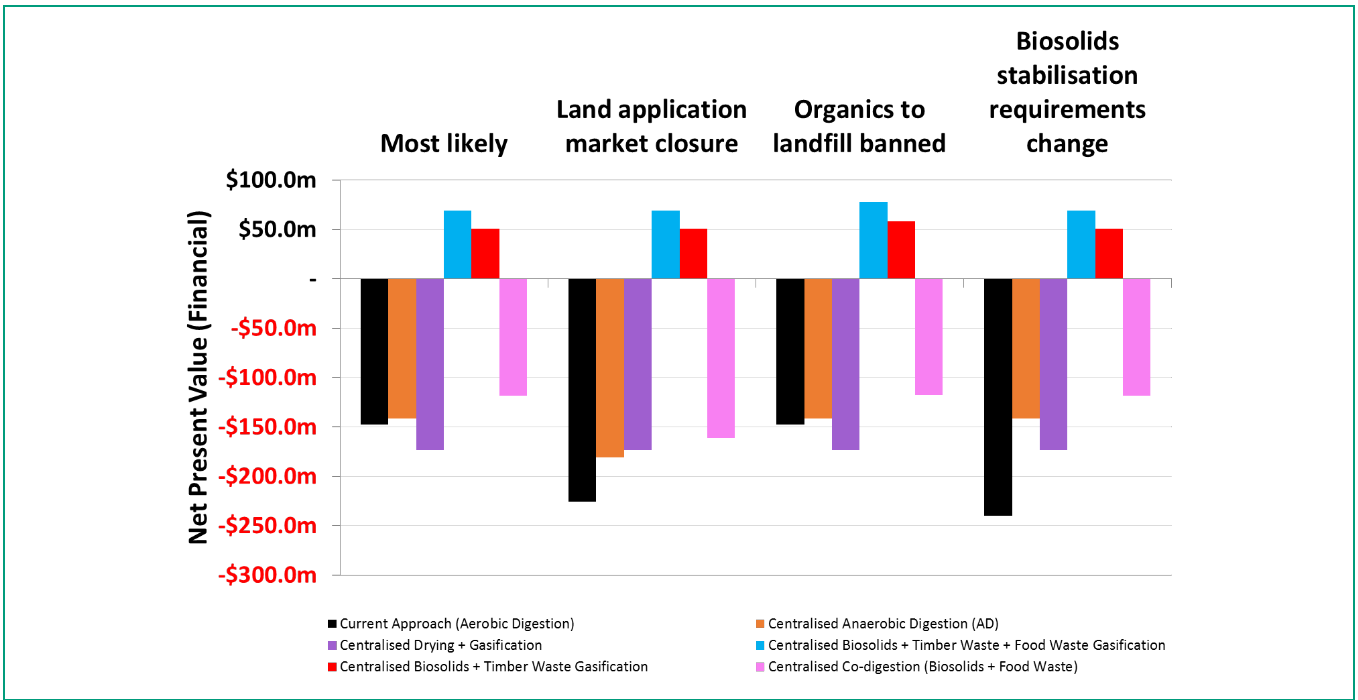

Figure 8: Analysis of potential shocks for biosolids and co-treatment options

In Hunter Water's case, a centralised AD facility is the most cost-effective option for biosolids treatment (Figure 5 and Figure 6). This is driven largely by avoided capital costs compared to Hunter Water's current biosolids management approach, and operational savings from renewable energy generation and biosolids volume reduction as a result of anaerobically digested biosolids being more easily dewatered.

The financial and economic results are sensitive to both capital and O&M costs. Other factors such as product offtake market price and energy content of biosolids have little impact on financial and economic results.

The use of thermal hydrolysis as a pre-treatment to AD increases biogas production and therefore improves energy recovery. The thermal hydrolysis option provides little financial or economic benefit, as capital and O&M cost savings due to reduced digester volume, biosolids volume reduction and additional energy production are countered by the additional capital cost of thermal hydrolysis. However, there are more reference sites for anaerobically digested hydrolysed WAS compared to un-hydrolysed WAS. Further, thermal hydrolysis introduces the potential to produce higher quality biosolids (Stabilisation Grade A as classified under NSW Biosolids Guidelines).

Despite primary treatment capturing more of the inherent energy in wastewater compared to WAS, adding primary treatment was not cost-effective in this case due to the significant capital cost of building primary treatment at multiple WWTWs (Figure 5 and Figure 6). Further, there are challenges associated with the transport of primary sludge. However, if Hunter Water pursues centralised biosolids treatment using AD, there may be incentive to incorporate primary treatment into future WWTWs upgrades.

The resilience of various biosolids-only treatment options across the futures scenarios tested were relatively consistent as wastewater quantity and quality have little impact on financial performance (Figure 7).

Centralised AD improves resilience to potential changes to biosolids pathogen and stabilisation requirements and biosolids market closure, as this process tends to produce a lower volume of higher quality, low odour biosolids product compared to the current aerobic digestion approach (Figure 8). The centralised AD option also reduces Hunter Water's carbon footprint by up to 10%.

Thermal treatment of biosolids has higher life cycle cost than the current biosolids management approach. However, thermal treatment options are more resilient to anticipated changes to biosolids pathogen and stabilisation requirements and biosolids market closure (Figure 8). The regulatory approval pathway for thermal treatment technologies and products in NSW is uncertain as there are limited, if any, applications of the use of gasification technology on a biosolids only feedstock, making this option challenging in the short term. However, thermal technologies are likely more resilient to emerging contaminants such as PFAS.

Co-treatment options improve financial performance though gate fees and increased energy production (Figure 5). However, they have a higher financial risk and are sensitive to future scenarios as financial performance is driven largely by waste availability and gate fee revenue and there is uncertainty around feedstock availability and potential gate fees (Figure 7). Co-treatment options introduce regulatory risk, with approval uncertainty for thermal processes and product markets in NSW. Further, co-treatment options require organisational capabilities for new treatment technologies and managing feedstock and product offtake contracts.

CONCLUSION

In Hunter Water's case, a centralised AD facility with energy recovery is more cost effective than the current biosolids management approach. It will also improve resilience to future market and regulatory changes and reduce Hunter Water's carbon footprint by up to 10%.

Options for thermal treatment of biosolids have higher life cycle cost. The regulatory approval pathway for thermal treatment technologies and products in NSW is also uncertain. However, thermal treatment offers greater resilience to potential regulatory and market shocks than both aerobic digestion and AD.

There are financial and economic benefits associated with co-treatment of biosolids with organic waste. However, co-treatment brings new commercial and financial risks, and is not critical to the business case for centralised biosolids treatment and energy recovery. Further work is required to understand the business case for co-treatment of organic waste.

A staged approach to centralised biosolids management, with AD as a likely first stage, provides a flexible and adaptive strategy that will improve resilience to regulatory and market uncertainty. This approach will not lock out future opportunities for thermal treatment or co-treatment of organic waste feedstocks.

ACKNOWLEDGMENTS

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