



  
**WATER SERVICES**  
 ASSOCIATION OF AUSTRALIA

# WEIGHING UP THE OPTIONS

## Sustainable biosolids management across Australia & New Zealand



### Acknowledgement of Country

Water Services Association of Australia (WSAA) acknowledges Aboriginal and Torres Strait Islander people as Australia's First Peoples and as the traditional owners and custodians of Country throughout Australia. We recognise their continuing connection to land, waters and community, and we pay our respects to Elders past and present.

WSAA acknowledges that water is core to life for Aboriginal and Torres Strait Islander peoples and is essential to their identities, cultures and livelihoods. Protecting and managing water is a custodial and intergenerational responsibility.

### About WSAA

Water Services Association of Australia (WSAA) is the peak body representing Australian and Aotearoa New Zealand water utilities. Our members provide water and wastewater services to over 24 million customers in Australia and Aotearoa New Zealand including many of Australia's largest industrial and commercial enterprises.

### Acknowledgements

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This work is adapted from the *Weighing Up The Options: Sustainable Biosolids Management Assessment* project undertaken by WSAA with the appointment of AtkinsRéalis UK Limited to deliver the technical assessment.

We used generative artificial intelligence tools to support idea development, drafting and editing. All material has been reviewed and finalised by WSAA to ensure it meets our objectives and standards.

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## FOREWORD

As the sector responsible for delivering essential water and wastewater services, we maintain an unwavering commitment to safeguarding the health of both communities and the environment through every aspect of our operations.

Internationally, the water sector has been shifting from a linear 'once through' process and value chain, to a far more circular and value-added process chain. Exciting opportunities in extraction of cellulose, biomethane, ammonia, heat and production of alternative products such as biochar and sustainable aviation fuel are 'taking off'.

This is true here in Australia and New Zealand, where the water sector has invested in water recycling and beneficial reuse of biosolids mostly on agricultural land but increasingly in alternative value-added products of biochar and others.

More recently, the sector is also experiencing increasing regulatory controls and tightening limits, primarily aimed at reducing pollutants and contaminants at the end of the pipe, with insufficient attention paid to source control.

These challenges are compounding, shifting our ability to deliver safe, secure, and quality water and wastewater services, and particularly concerning biosolids management.

Together, tightening environmental regulations on land application of biosolids with concerns about emerging contaminants, and the move to circularity offers new challenges and opportunities for the sector.

This report provides a timely and urgent assessment and call to action. The production of biosolids is not a tap we can simply turn off.

We must embrace new innovations and technologies. Whilst recognising the high value of land applied biosolids, we must seek out new pathways that not only provide sustainable alternatives for biosolids management but also offer the chance to increase benefits and regenerate our environment.

This report, based on the technical analysis of AtkinsRéalis, with support of WSAA's water utility members, is intended to demonstrate the nature of the challenge we face collectively as a sector, while providing information to help inform and engage on available options and possible new pathways for biosolids management.

The technical analysis indicates the untapped potential in transitioning to a new approach for biosolids management. In navigating the transition, we recognise the importance of continuing to work collaboratively with regulators, state agencies, government departments, across sectors, and, most importantly, our customers.

We are grateful for the collaboration between WSAA and the Australian & New Zealand Biosolids Partnership (ANZBP), in conceptualising this piece of work and leveraging the insights generated by the ANZBP biosolids survey across Australia and New Zealand.

As the water sector faces challenges and pressures head-on to deliver a service that customers can trust and that protects the environment, this report gives confidence that we can embrace the new frontier of biosolids management.



Adam Lovell  
Executive Director,  
WSAA

## EXECUTIVE SUMMARY

The way biosolids are managed in Australia and New Zealand has changed significantly over the last few decades, progressing from simple disposal, to more structured regulation and management, and now focusing on creating value and treating biosolids as a useful resource in a circular economy, while managing health and environmental risks.

Today, biosolids are recognised as a valuable source of organic matter and nutrients. Many utilities routinely plan for beneficial reuse of biosolids as an integral part of wastewater treatment, with high rates of land application in Australia and growing reuse initiatives in New Zealand. The new frontier for biosolids management is being shaped by a push for a circular economy combined with tougher regulations and changed community expectations about emerging contaminants like PFAS and microplastics.

New guidelines and regulations in Australia and New Zealand are likely to further limit reuse of biosolids on land, especially in agriculture and composting. Because of these changes, utilities and regulators are looking at new and advanced options such as thermal conversion, hydrothermal processes which convert biosolids into new products like biochar. These methods can reduce waste and destroy contaminants, but they generally cost more and are harder to get started. To maintain support from customers and the community, it is important for water utilities to be transparent, share evidence about risks, and listen to customer and community concerns and expectations. With uncertainty about future regulation requirements, careful planning is needed for a sustainable future.

To support water utilities in planning for the future of biosolids management, this report presents the results of an assessment that evaluates 20 existing and emerging approaches for managing biosolids across Australia and New Zealand.



A multi-criteria assessment designed with water utilities, was used to assess biosolids management options. The options were assessed on environmental outcomes, affordability and value, how easily they could be delivered, and whether there is market and community support (ie, social licence). The analysis included feedback from stakeholders, research, and applying different scenarios to help understand the pros and cons of each option. By applying the assessment at a national scale across Australia and New Zealand, the report identifies overall trends, shows what works well and what doesn't, and helps guide better planning for the future by water utilities and policymakers.

The results show a clear picture of *where we stand today*. Under current conditions, the best performing ways to manage biosolids are those that turn them into safe products to use on land – including anaerobic digestion options, stabilisation processes, composting, and thermal drying and pelletisation. These methods perform strongly because they are affordable, have reliable environmental performance, have established markets and are widely accepted by the community. Newer methods, such as advanced conversion technologies (for example making biochar or biocrude), do not perform as well under current conditions because they cost more to build and run, face uncertain or complex regulation, and do not yet have mature markets for their products.

If using biosolids on land is significantly constrained or no longer possible, the best options become those that destroy or mineralise contaminants, like incineration and advanced thermal conversion – because they can safely deal with persistent contaminants like PFAS. Meanwhile, options that reuse biosolids for agricultural or land rehabilitation lose their appeal, as it gets harder to find buyers, the environmental benefits associated with soil application are removed, and management costs go up.

The analysis makes clear there is no one-size-fits-all solution, and instead, utilities face a landscape of trade-offs that will change materially with regulatory and market conditions.

The report further summarises the assessment by using a subset of common biosolids management options into four categories (quadrants) based on how practical and easy they are to use. Right now, applying biosolids to land is the most practical and straightforward option (Figure 1). Newer methods, like advanced thermal technologies, look promising but are harder and cost more to set up. If land application becomes restricted, methods that destroy contaminants become more attractive, but they are still complex and difficult to start, and the traditional methods lose their value (Figure 2). The key point is the water sector needs to balance what works today with what will work in the future, and avoid relying on only one option, because that can be risky.

This report does not represent a formal strategy or prescriptive pathway for biosolids management, and should not be used as a direct input into site-specific business case assessments for biosolids management.

## WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

Figure 1. Quadrant-based framework for biosolids management approaches assessed under current operating conditions (see Figure 11 in report for further detail).

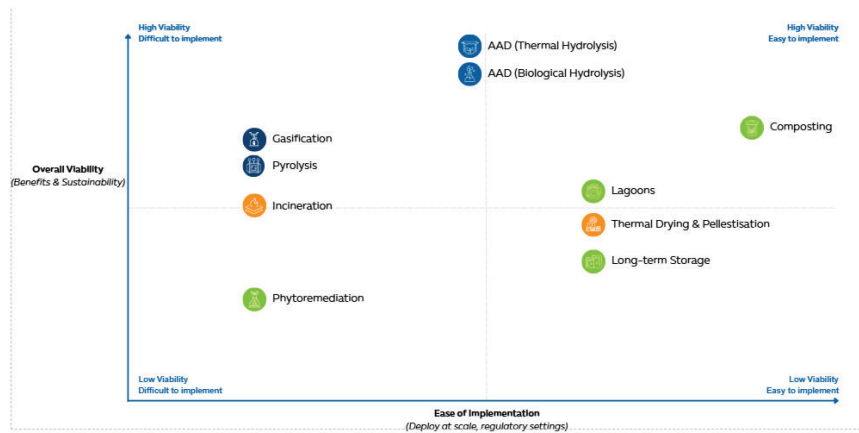
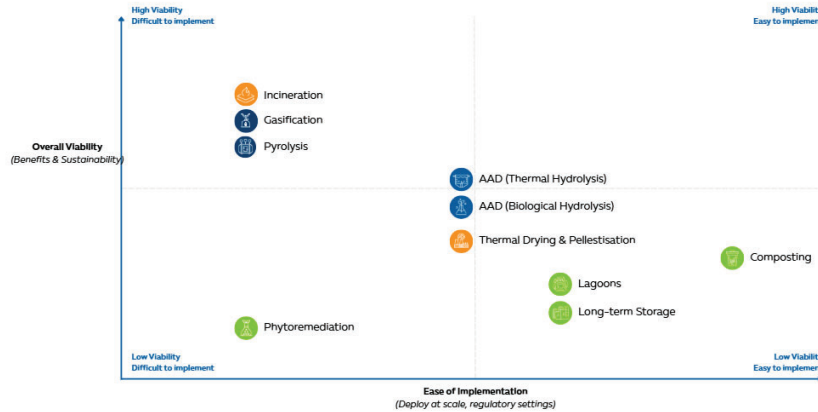


Figure 2. Quadrant-based framework for biosolids management approaches assessed if biosolids can no longer be applied to land (see Figure 12 in report for further detail).



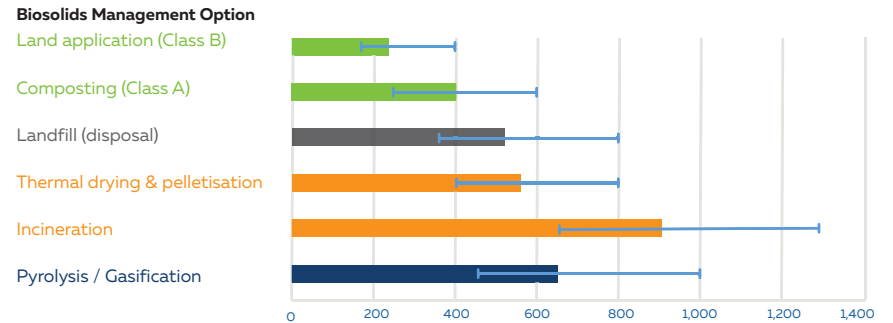
Right now, there is no easy and ready-to-go option that combines high viability with easy implementation to replace the option of biosolids to land, should the current practice become unviable at scale in the near term.

## WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

A preliminary levelised cost analysis showed a significant price spectrum among biosolids management options (Figure 3). Land Application (Class B) as the lowest-cost option at A\$250/t DS, while high-assurance Advanced Thermal Conversion pathways like Pyrolysis represent the higher end, up to \$1000/t DS. This comparative cost data frames the trade-offs between affordability and long-term security.

Figure 3. Indicative levelised cost comparison of biosolids management options (see Figure 9 in report for further detail)



To ensure there are viable options for the future, coordinated action is needed:

- Maintaining viable land application where it can meet tightening contaminant limits
- Investing in innovation, pilots and reference projects to mature and de-risk advanced thermal and other emerging approaches
- Strategic product analysis and development, together with product standards for biosolids-derived materials
- Aligning regulatory frameworks, end-of-waste pathways and planning settings to support circular, low-carbon solutions.

This report gives everyone – water utilities, regulators, policymakers and the community – clear information and a shared way to consider biosolids management options. This will help water utilities make informed decisions, plan adaptive transition pathways, and work together on practical and resilient biosolids strategies that are good for customers, communities and the environment across Australia and New Zealand.



# BIOSOLIDS MANAGEMENT ACROSS AUSTRALIA AND NEW ZEALAND

**A**ustralia currently generates 350,000–400,000 tonnes of dry biosolids annually, reflecting its population of 26 million and widespread coverage of municipal wastewater treatment.

As of 2023, approximately 85% of Australia's biosolids are beneficially reused, most of which is applied to land. This is a slight decrease from the peak of over 90% in 2017–2019. The small remainder is largely stockpiled, or used in landfills only under special circumstances, such as when contamination issues temporarily prevent land application. Australian water utilities now routinely plan biosolids reuse as part of their wastewater treatment projects.



Australia is also exploring energy recovery from biosolids: a few wastewater treatment plants have begun to co-digest biosolids with food waste to generate more biogas for electricity, and pilot projects are examining pyrolysis of biosolids to create biochar, which can lock up carbon and potentially immobilise heavy metals. These innovative approaches are in early stages, but they represent a shift toward viewing biosolids as not just fertiliser but also as a source of renewable energy and carbon-rich products.



**N**ew Zealand currently generates approximately 75,000 tonnes of dry biosolids annually, from a population around 5 million. The majority of biosolids across New Zealand are disposed of in landfills or purpose-built sludge monofills. However, the increase in beneficial reuse over the past decade indicates a transition is underway.

Notably, direct agricultural use of biosolids remains very low across New Zealand – a 2023 ANZBP (Australia & New Zealand Biosolids Partnership) survey found only 2% of biosolids in New Zealand are applied to pasture or cropland. Forestry accounts for a modest share of around 6%, composting into soil products about another 7%, and land rehabilitation or engineered monofills, like the Auckland quarry rehabilitation project accounts for a major share of over 40%. Around 7% of biosolids are still being stockpiled by small plants yet to find a sustainable reuse outlet. These figures illustrate both progress and remaining gaps, noting that one large municipal project can significantly influence the national picture.

# UNDERSTANDING BIOSOLIDS

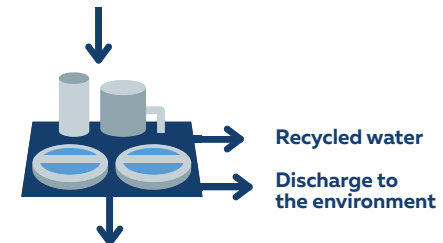
**What are biosolids?**  
Biosolids are the treated organic materials produced from wastewater (sewage) treatment. They start as sewage sludge and become "biosolids" only after further treatment that greatly reduces disease-causing pathogens and odours. This treatment stabilises the material so it is safe and suitable for beneficial use.

**Why are biosolids useful?**  
Biosolids contain organic matter and nutrients that can improve soil health. They are commonly used as a soil conditioner or fertiliser in agriculture, forestry and land rehabilitation.

**What is not included?**  
The term "biosolids" does not include: untreated sewage sludge, other untreated wastewater sludges, or industrial sludges.



Wastewater treatment



Sludge



Anaerobic Digestion (AD)



Conventional Thermal



Nature-based and general



Advanced thermal conversion

**BIOSOLIDS**



## REGULATION IS RESHAPING BIOSOLIDS MANAGEMENT

**Increasing regulation of environmental contaminants is leading to a progressive tightening of acceptable contamination limits for land-based reuse of biosolids, and a corresponding increase in standards for treatment and quality assurance. Regulation, as well as evolving community standards, are likely to be the key drivers for a continued recalibration of biosolids management toward solutions that are technologically advanced, socially licensed, and environmentally robust.**

Recent regulatory reforms in Australia and New Zealand are reshaping the biosolids management landscape by introducing more stringent contaminant controls, expanded monitoring obligations, and increasing the scrutiny of environmental and social impacts. The introduction of Australia's PFAS National Environmental Management Plan 3.0 in March 2025 and New Zealand's 2025 Beneficial Use Guidelines in May 2025, signal a decisive shift towards tighter contaminant thresholds and application constraints, particularly for per- and polyfluoroalkyl (PFAS) substances. These reforms are impacting the viability of land application and composting programs.

For facilities relying on agricultural reuse, the regulatory reforms are creating uncertainty in market access and may require capital upgrades to biosolids treatment trains, including the addition of carbon-based filtration or pre-treatment to control PFAS mobilisation.

Thermal processes such as pyrolysis and gasification are gaining relevance due to their capacity to reduce volume, destroy organics, and produce stable end-products such as

biochar with potentially low residual contaminant risk. However, the deployment of thermal processes is capital intensive and contingent on regulatory acceptance of new product pathways, including clarity on the classification and reuse of biosolids-derived biochar under amended environmental regulations.

In parallel with these regulatory reforms and technological shifts, maintaining the social licence for biosolids reuse will depend on structured, proactive community engagement. The [ARC Training Centre for the Transformation of Australia's Biosolids Resource](#) (2025) recommends water utilities engage early and consistently with their customers and communities, build a social-science evidence base of community preferences, and segment community sub-groups rather than making assumptions about customer attitudes. Effective engagement requires accountability, transparency and acceptance of alternative views, and communication strategies must move beyond one-way messaging to participatory approaches that build trust and social licence.

## HOW WE GOT HERE THE STORY OF BIOSOLIDS IN AUSTRALIA AND NEW ZEALAND

### 1900s Early recognition of the value of sewage sludge

- Sewage sludge was treated mainly as a waste by-product, with common disposal practices including ocean dumping, incineration, and landfilling.
- Limited and unregulated use of untreated sludge or "night soil" occurred on farmland, largely experimental and inconsistent.
- Public health priorities centred on removing waste from urban environments to prevent disease, rather than environmental protection or resource recovery.
- No formal standards or regulatory frameworks guided sludge management or land application.

### 1970s Regulatory introductions and environmental reform

- Growing environmental awareness drove the creation of pollution control agencies and laws, such as NSW's Clean Waters Act 1970 and New Zealand's early sludge disposal guidance (1973).
- Discharge of untreated sewage and sludge to waterways became socially and politically unacceptable, prompting scrutiny of existing practices.
- Expanded secondary wastewater treatment increased sludge volumes, highlighting the need for improved sludge management.

### 1990s Introduction of 'biosolids' and the move toward beneficial reuse

- The term "biosolids" emerged, reframing treated sludge as a resource rather than a waste, and encouraging reuse opportunities.
- Australian states developed biosolids guidelines (e.g., NSW 1997), establishing quality criteria and promoting safe agricultural and land rehabilitation uses.
- Early reuse initiatives grew, including composting, land application, mine rehabilitation, and commercial biosolids enterprises.
- In New Zealand, the Resource Management Act 1991 introduced consent requirements for land application, heightening regulatory oversight and community involvement.
- Pioneering NZ projects, such as Nelson's Rabbit Island forestry application and New Plymouth's "Bioboost", showed successful reuse, though public and cultural concerns limited broader adoption.

### 2000s Advances in treatment and regulatory evolution

- National guideline frameworks were formalised: NZ released its 2003 Biosolids Guidelines and Australia adopted the 2004 National Biosolids Guidelines under the NWQMS.
- Both countries embraced risk-based grading systems, with greater emphasis on pathogen reduction, metals limits, and protection of sensitive cultural sites.
- Major technological improvements expanded production of high-quality biosolids, including thermophilic digestion, lime stabilisation, composting, and thermal drying.
- Australia and NZ invested in coordinated R&D, including CSIRO's National Biosolids Research Program, which built scientific confidence in biosolids reuse.
- Landfilling became increasingly discouraged as a disposal route, with policy and regulatory frameworks prioritising beneficial reuse.

### 2010s How far can beneficial reuse go?

- Beneficial reuse expanded significantly in Australia, with reuse rates rising from ~65% to ~90% over the decade.
- Agriculture, mine-site rehabilitation, landscaping, and forestry remained main reuse pathways, supported by the production of composted and pelletised biosolids products.
- New Zealand's reuse increased sharply, largely driven by the Māngere monofill landform restoration project, reducing national reliance on landfill to ~30% by 2023.
- Public perception emerging as a critical factor, with utilities improving treatment processes and communication strategies to maintain community confidence.
- Emerging contaminants, particularly PFAS, pharmaceuticals and microplastics, have prompted new regulatory attention, expanded testing requirements, and consideration of even further advanced treatment technologies.



## UNDERSTANDING OPTIONS AVAILABLE FOR BIOSOLIDS MANAGEMENT

WSAA, in partnership with the ANZBP, engaged AtkinsRéalis to prepare a comprehensive overview and comparison of biosolids management options in Australia and New Zealand through the WSAA member subscription project, Weighing Up the Options: Sustainable Biosolids Management Assessment.

This public report on the deliverable of that project supports both WSAA's and ANZBP's initiative to improve the information available on biosolids management options for water utilities, customers and stakeholders. The report also aims to stimulate discussion about current and future biosolids management, as utilities face increasing pressure to respond to known and emerging contaminants, impacts from climate variability, growing capital constraints, and shifting community expectations.

Biosolids management has undergone significant evolution over the last few decades, transitioning from traditional practices such as land application and landfill disposal, to more diversified and resilient approaches. This shift has been driven by a growing recognition of biosolids as a resource in the circular economy, alongside increasing public scrutiny and regulatory complexity.

Traditional methods that were once cost-effective and broadly accepted are now subject to heightened environmental standards, stricter contaminant thresholds, and social licence considerations. In response, the water sector is exploring the application of emerging technologies such as thermal conversion, advanced digestion, and nature-based solutions, while needing to work through challenges related to scale, readiness, and integration of new technologies within existing systems.

### Methodology

AtkinsRéalis compiled a comparative assessment of 20 identified existing and emerging biosolid options (Figure 4). WSAA members involved in the project provided input into the finalisation of the assumptions, application of criteria requirements and scenarios considered. The assessment was further informed through extensive interviews with participating water utilities and key stakeholders relevant to the management of biosolids, including environmental regulators.

This report does not presume a universal solution but rather seeks to clarify the relative strengths and limitations of each option. There is no one-size-fits-all approach. The results intend to help guide thinking towards more resilient goals while identifying gaps and recommending action.

## WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

Figure 4. Biosolid management approaches selected for the assessment



Anaerobic Digestion (AD)



AAAD (Thermal Hydrolysis)



Mesophilic AD in parallel (MAD)



Mesophilic AD in series (MAD - series)



AAAD (Biological Hydrolysis)



Conventional Thermal



Solar Drying Greenhouses



Solar Drying Bed



Incineration



Thermal Drying & Pelletisation



Nature-based and General



Phytoremediation



Reed beds



Liming



Composting



Lagoons (inc. Geobag Dewatering)



Long-term Storage



Advanced Thermal Conversion



Pyrolysis



Gasification



Hydrothermal Liquefaction (HTL)



Hydrothermal Carbonisation (HTC)



Wet Air Oxidation (WAO)



Supercritical Water Oxidation

The comparative analysis was designed as a structured response to these needs, underpinned by the objective to empower utility stakeholders to make informed, adaptive decisions.

A methodology and tool were developed that enable consistent assessment of both existing and emerging biosolids management approaches across multiple criteria. Each criterion included sub-criteria (see Figure 5). The grouping of criteria did not alter the assessment or calculation; it ensured balanced consideration so that, for example, cost optimisation is not pursued at the expense of social licence, and contaminant management is not considered without regard to the practicality of delivery.

Figure 5. An overview of the main criteria and sub-criteria developed for the assessment.

<b>Environmental Outcomes</b> overall impacts on emissions, residues and the natural environment	<b>Affordability &amp; Value</b> upfront cost, ongoing cost and any realistic revenue	<b>Deliverability</b> how practical it is to approve, build, run and maintain	<b>Market &amp; Social Licence</b> strength of outlets/ markets and community/ policy acceptance
Net Zero impact	CAPEX	Operability	Ease of outlet
Treatment process - Environmental impact	OPEX	Regulation Implications	Social & Governance Implications
	Revenue	Technology Maturity	Environmental Impact of Potential End Use

Not every criterion carries the same importance for the water sector. Weightings used reflect the priorities agreed on by the water utilities participating in the project. Items that strongly influence affordability and social licence, such as capital and operating costs, revenue potential, and social and governance factors, were given greater weight, while others were weighted more modestly. Applying these weightings made the trade-offs transparent; an option that is technically elegant but difficult to accept socially sat lower than one that is more acceptable and nearly as effective. Weighted scores were calculated as the product of the raw score and its weighting.

Once each option was scored and weighted across the four criteria, the results were brought together into a single total that could be compared across all options. The same approach was then used to explore different futures.

It is important to note that integrated combinations of different biosolids management approaches were not considered within the scope of this project. In practice, one or more approaches could be integrated in a single treatment facility, such as anaerobic digestion followed by a sludge lagoon. Integration could fundamentally change the overall energy balance, chemical demand and deployability of management options and would therefore require in-depth exploration on a case-specific basis.

All options were assessed against a common baseline, of a new facility co-located with an existing wastewater treatment plant, with access to electricity and return-liquid treatment. Location-specific factors such as land acquisition were excluded. Assessment against a common baseline enabled fair, decision-ready comparisons of the performance of each approach and avoided bias from local circumstances or scale effects.

## Consideration of representative facility size for each option

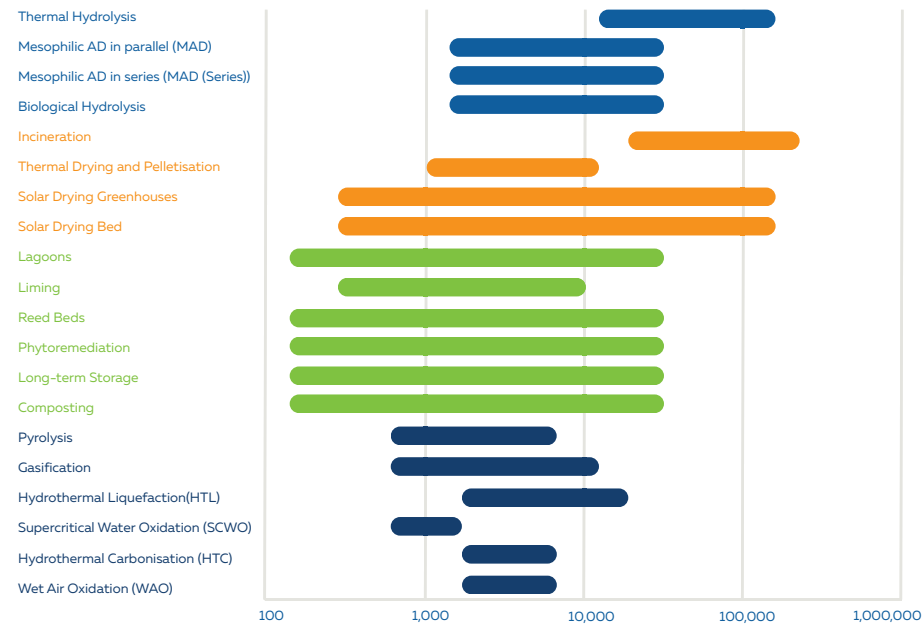
A solution which performs well at a metropolitan plant serving a large population may not be practical, affordable, or even approvable at a small regional site. To make comparisons fair and useful, options were considered against representative size bands that reflect how Australian and New Zealand utilities actually operate. Within each band, the assessment considered what a prudent utility would actually build and operate.

Facility size was treated as a practical context for decision-making. Table 1 details the assumed annual production throughput for each approach while Figure 6 gives an indication of the assumed range of throughput.

Table 1. Values of assumed annual throughput used in the assessment of the different biosolid approaches.

<b>Biosolid Management Approach</b>	<b>Assumed throughput value (Total Dry Solids per year – TDS/yr)</b>
Thermal Hydrolysis	30,000
Mesophilic AD in parallel (MAD)	10,000
Mesophilic AD in series (MAD (Series))	10,000
Biological Hydrolysis	15,000
Incineration	30,000
Thermal Drying and Pelletisation	5,000
Solar Drying Greenhouses	5,000
Solar Drying Bed	5,000
Lagoons	10,000
Liming	5,000
Reed Beds	550
Phytoremediation	550
Long-term Storage	10,000
Composting	1,500
Pyrolysis	2,000
Gasification	7,000
Hydrothermal Liquefaction (HTL)	3,500
Supercritical Water Oxidation (SCWO)	2,000
Hydrothermal Carbonisation (HTC)	5,000
Wet Air Oxidation (WAO)	5,000

Figure 6. An indication of the throughput ranges, in TDS/yr, for each of the biosolid approaches



## HOW TO USE THIS REPORT

This report provides a comprehensive, comparable assessment of 20 biosolids management approaches against plausible future scenarios. By applying the tool at a national scale across Australia and New Zealand, the analysis identifies broad trends, highlights areas of consistent performance, and surfaces the relative strengths and constraints of different approaches under changing conditions. The intent is to inform sector-wide understanding and facilitate more robust, scenario-informed planning by water utilities and policymakers.

**This report does not represent a formal strategy or prescriptive pathway, and should not be used as a direct input into site-specific business case assessments for biosolids management (see Figure 7).**

The analysis does not account for local regulatory, financial, or operational conditions; rather it explores how different management options perform under common assumptions, and indicates the potential advantages and disadvantages of implementing a particular option. As such, the findings are illustrative rather than definitive and should not be interpreted as site-specific guidance.

The report can be used to support an informed discussion of where different approaches may be most appropriate, in response to the evolving challenges and opportunities for the water sector.

### Use for options development



- General technology information
- Comparative costs
- Energy use and greenhouse gas emissions
- Environmental outcomes
- Deliverability
- Strength of outlets and markets
- National scale community, policy and regulatory acceptance

### Do not use for decision making



- Supplier specific technology information
- Site specific costs
- Site specific energy use and greenhouse gas emissions
- Site specific environmental outcomes
- Integration with existing infrastructure
- Local customer and community acceptance
- Site-specific policy and regulatory compliance

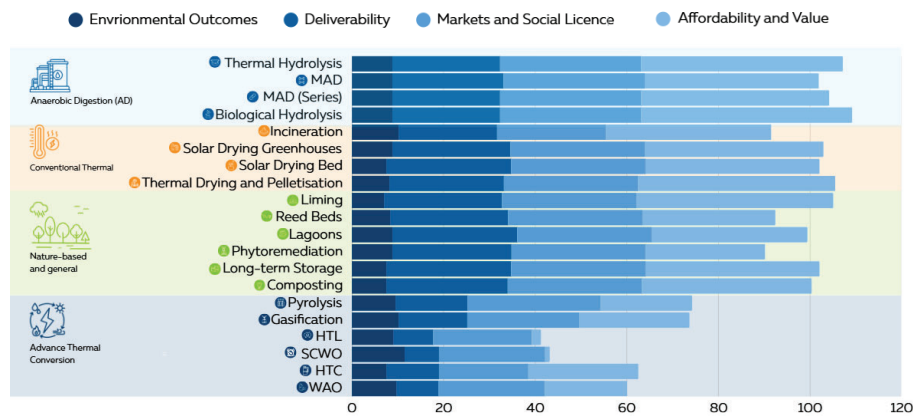


# WHERE WE STAND TODAY

## ASSESSING BIOSOLID OPTIONS UNDER EXISTING CONDITIONS

Where biosolids can be applied to land, these pathways gain strength from established outlets, predictable contracts and social licence built over many years. Thermal drying and pelletisation also rates highly in this context; while more capital intensive than simple digestion, it produces a consistent product that utilities and customers understand.

Figure 7. Biosolids management approaches assessed under current operating conditions



Technologies that rely on advanced thermal destruction generally sit lower in the base case. Their environmental performance inside the plant can be strong, but this is offset by higher capital and operating costs, tighter approvals pathways and greater scrutiny from communities. The financial certainty adjustment reinforces this effect: where cost and revenue evidence is thinner, the scores are prudently reduced, preventing speculative estimates from elevating rankings.

Market-facing considerations also matter. When land application is available, simpler outlets with known specifications and stable demand underpin higher off-take & market scores for digestion- and composting-type solutions. By contrast, options that produce novel products or require bespoke offtake agreements carry more commercial and policy risk and therefore lose ground once weightings are applied.

Rather unsurprisingly, utilities are favouring options that are operationally robust, cost-aware and supported by viable outlets today, while keeping an eye on technologies that may become more attractive as policies and markets evolve.

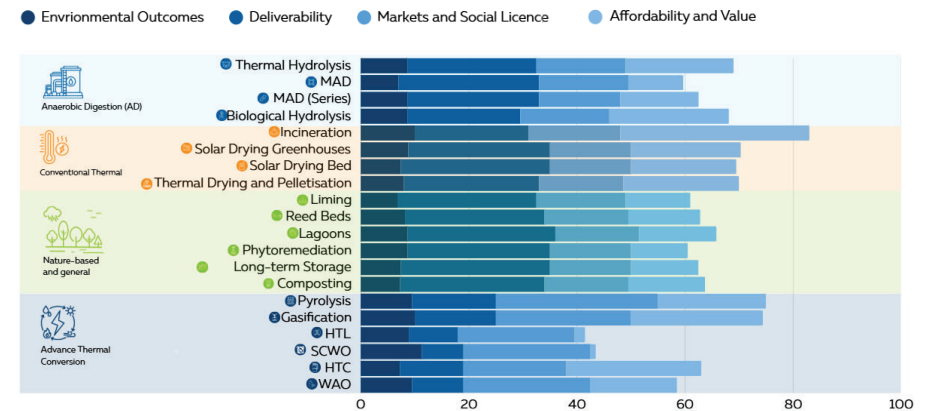
The main picture (Figure 8) is balance. Strong performers are not the most extreme in any single category, but the ones that carry solid scores across all four categories.

# CHANGE ON THE HORIZON

## COMPARING OPTIONS WITHOUT LAND APPLICATION

When the ability to apply biosolids to land is removed from the picture, the assessment deliberately tightens the assumptions that sit behind the scores (Figure 9). For each option the approved uses for biosolids are re-evaluated, leading to an increase in material directed to landfill and a stricter set of constraints on the environments where they can be utilised as a feedstock. Environmental impacts are re-balanced to account for hauling and disposal, and operating costs are adjusted for gate fees and logistics. The result is a “flatter” profile of totals and a noticeable change in the order of preference. Options designed to destroy or mineralise contaminants, rather than to create products for land, move up the rankings. Incineration and other thermal conversion pathways become comparatively stronger because their outlet is less exposed to shifting acceptability of land application, and their performance is less dependent on a willing agricultural market.

Figure 9. Biosolids management approaches assessed if biosolids no longer applied to land



Conversely, approaches whose value proposition relies on placing biosolids to land lose a key source of strength. Off-take scores fall as landfill replaces beneficial use, environmental benefits associated with soil application are no longer credited, and financial positions worsen as revenue is removed and disposal costs increase. Familiar digestion and stabilisation processes still retain advantages of operability and maturity, but their relative position drops when their preferred outlet is constrained. What emerges is a more even field in which resilience, through multiple viable outlets, robust regulatory pathways, and deliverable operations, matters more than incremental advantages on cost or emissions.

Portfolios that depend on a single outlet face concentrated risk; portfolios that keep options open through regional hubs, flexible contracting and staged upgrades are better placed. If land application tightens, programs that have already invested in odour control, dewatering performance, emissions management and quality assurance will adapt faster, whether that means shifting to thermal solutions, consolidating at regional facilities, or managing residues to landfill under strong environmental controls. The framework does not prescribe the next step, but it makes the trade-offs explicit: in a world without land application, technologies with secure end-points and proven delivery rise, while others will need clear enabling actions to remain viable.

# THE FINANCIAL REALITY

## LEVELISED COST COMPARISON

While the multi-criteria assessment considers affordability as a weighted score, understanding the absolute financial baseline is helpful to further inform decision-making. To support this, a preliminary levelised cost analysis was undertaken to provide comparable 'dollars per tonne' estimates (Figure 10). The options assessed have been limited by the data available to enable an effective comparison.

The Levelised Cost (LC) metric is the key financial tool used for this comparison. It is calculated by dividing the Present Value (PV) of the direct lifecycle costs by the PV of the total volume of biosolids processed over the asset's lifetime, expressed in A\$/t DS (Australian Dollars per tonne of Dry Solids).

This metric includes:

- **Capital Expenditure (CAPEX):** Upfront costs.
- **Operating Costs (OPEX):** Ongoing costs, including energy and maintenance.
- **Compliance and Decommissioning Costs.**
- **Excludes non-financial externalities.**

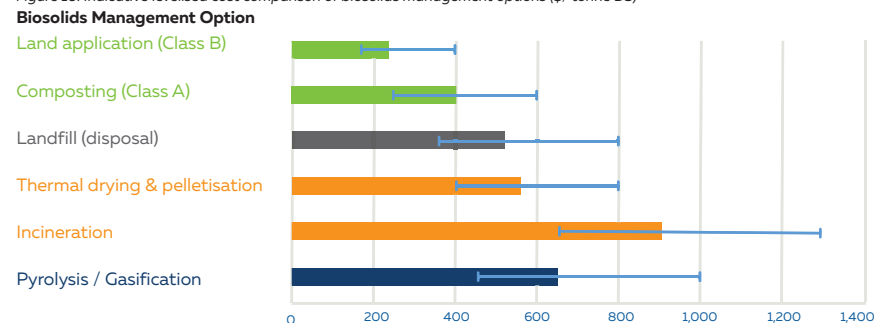
The analysis adheres to specific financial parameters to ensure consistency across all options:

- **Discount Rate:** A real discount rate of 4.5% (with a sensitivity range of 4–5%) was applied to calculate the Present Value (PV) of all costs and tonnes.
- **Currency & Timeframe:** All costs are expressed in constant 2025 Australian Dollars (AUD), removing inflationary effects to enable a stable comparison.
- **Asset Life:** Each option assumes a full, typical asset life (ranging from 15 to 30 years, depending on the technology)

It is critical to note the data's limitations when assessing its accuracy for specific projects:

- **National Placeholders:** The costs presented are national placeholders. They are derived from high-level, averaged inputs and do not account for critical local variables such as specific site logistics, haul distances, local energy tariffs, or regulatory differences.
- **Exclusion of Externalities:** The LC metric only includes direct financial costs. It excludes non-financial or societal externalities, such as the value of carbon sequestration, the cost of greenhouse gas emissions, or public acceptance risks.
- **Customisation Required:** For any final investment decision, water utilities must replace these placeholders with current contract data and site-specific financial assumptions.

Figure 10. Indicative levelised cost comparison of biosolids management options (\$/ tonne DS)



The levelised cost analysis positions Land Application (Class B) as the lowest national benchmark at a central estimate of A\$250/t DS, largely due to minimal processing infrastructure. This affordability, however, is highly sensitive to rising compliance requirements and transport logistics, particularly fuel price volatility, transport distances, and seasonal access, which can erode the apparent cost advantage in certain regions.

At the next tier, Composting (Class A) delivers a consistent, higher-quality product suitable for broader end uses, but at an increased central cost of A\$400/t DS. The uplift reflects the operational intensity of materials handling, controlled aeration, curing, and rigorous quality assurance. For utilities seeking reliable outlets into horticulture or land rehabilitation, composting offers value, albeit with a higher operating cost profile.

Intermediate solutions provide a balance between cost and product stability. Thermal Drying & Pelletisation sits at A\$575/t DS, commanding a moderate premium to secure product uniformity, reduce moisture content, and lower transport costs per tonne of dry solids. Notably, Landfilling—while often viewed as a straightforward disposal route—has a comparable central cost of A\$550/t DS once gate fees, transport, and compliance are accounted for. This parity highlights that disposal does not inherently deliver savings relative to beneficial reuse processing and may expose utilities to future price and regulatory risks.

At the premium end, Advanced Thermal Conversion (ATC) pathways offer maximum security through near-complete volume destruction, but at the highest capital and operating cost. Incineration (central A\$900/t DS) provides robust, high-assurance outlets suited to constrained markets or sensitive receiving environments. Emerging ATC technologies such as Pyrolysis (central A\$650/t DS) and Gasification (central A\$725/t DS) show comparatively lower central costs, reflecting their potential to recover value (e.g. biochar, syngas) and partially offset operating expenditure. Real-world performance, market development for recovered products, and regulatory clarity will determine the extent to which these technologies close the gap with established thermal solutions over time.

These assessments are general and indicative, intended to frame relative cost positions and practical trade-offs rather than prescribe a single "best" pathway. Actual outcomes will vary by site conditions, biosolids characteristics, haulage distances, contract rates, energy prices, market access for products, and regulatory requirements. Utilities should treat the figures as a guide to inform options screening and comparative risk, supported by sensitivity testing and locally verified inputs. Used in this way, the analysis provides useful context to an overall assessment of biosolid management options.





## BALANCING VIABILITY AND IMPLEMENTATION FOR THE BEST OUTCOMES

In delivering the assessment the challenge that utilities face for the future of biosolids management became clear. Utilities must weigh high capital outlays and operating costs against benefits such as energy and nutrient recovery, and carbon credits, while considering community concerns like odour, increased truck traffic, perceived health risks and environmental impacts.

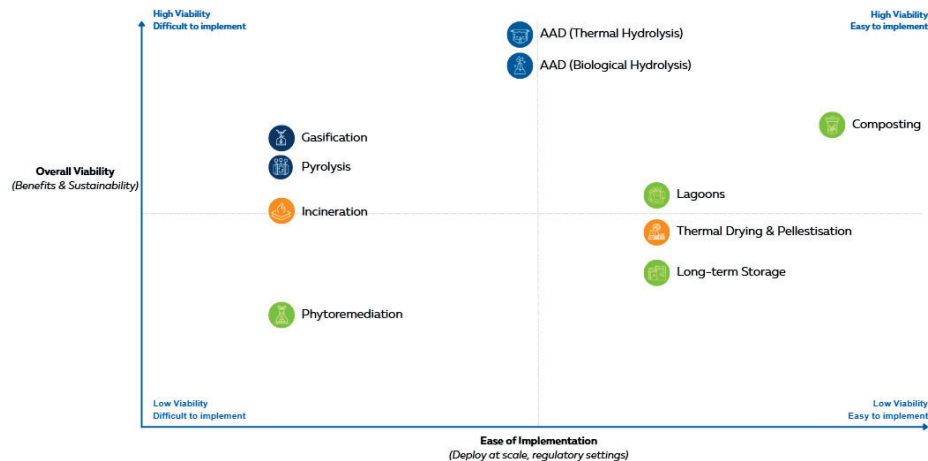
To complement this assessment and support easier communication of the results, a quadrant-based framework was applied that translates these multi-criteria findings into a two-axis strategic view: Ease of Implementation and Overall Viability.

This approach helps to visualise the change across both scenarios. To achieve the improved visualisation a sub-set of 10 of the 20 options across all categories are placed on the quadrant. The quadrant analysis builds directly on the original evaluation scores, distilling them into an intuitive format suitable for presentation and strategic dialogue (see Appendix 2).

The baseline graph (Figure 11) reflects the current biosolids management landscape. It shows that land-based reuse options (e.g. composting, thermal drying and pelletisation, advanced anaerobic digestion) are positioned in the top-right quadrant

—both highly viable and relatively easy to implement. These approaches are aligned with circular economy principles and supported by mature outlet markets, community familiarity, and existing infrastructure. In contrast, destruction-based technologies such as pyrolysis, gasification, and hydrothermal liquefaction are generally located in the top-left or bottom-left quadrants—technically complex and harder to deploy, despite offering long-term environmental advantages such as PFAS destruction or energy recovery.

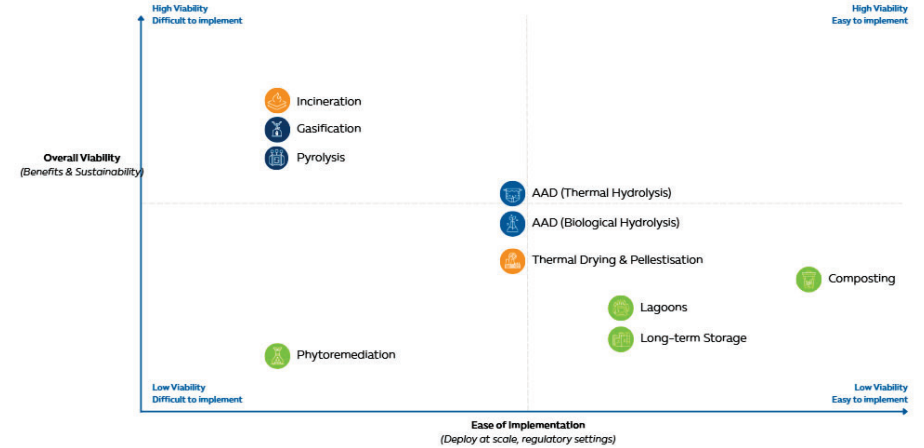
Figure 11. Quadrant-based framework for biosolids management approaches assessed under current operating conditions.



In the future scenario where beneficial land application of biosolids is no longer viable, the visual landscape shifts significantly (Figure 12):

- The viability of reuse-based options collapses, particularly for composting, liming, lagoon-based systems, and reed beds, which rely on soil application for value realisation.
- The overall viability of advanced anaerobic digestion approaches also declines, despite their energy generation benefits, because they still produce a biosolid requiring reuse or disposal.
- Technologies that avoid or destroy biosolids—incineration, pyrolysis, gasification, and advanced thermal conversions—rise in relative viability, as they provide pathways for PFAS destruction and eliminate reliance on reuse markets.

Figure 12. Quadrant-based framework for biosolids management approaches assessed if biosolids can no longer applied to land



However, even in this future scenario, many of the high-viability technologies remain in the bottom-left quadrant: viable but hard to implement. This reflects their high capital requirements, limited commercial maturity, regulatory ambiguity, and uncertain public acceptability.



### Implications for the sector

The shift from current state to future constrained scenarios reveals a pressing challenge: there is no fully deploy-ready alternative that combines high viability with easy implementation to replace land application if it becomes unviable within the short- to medium-term.

Significant implications in facilitating the required transition for managing biosolids include:

- **Readiness gap:** Technologies capable of filling the functional role of land application (e.g., nutrient recovery, energy generation, low-carbon disposal) are not yet mature or broadly deployable.
- **Investment need:** Targeted investment is needed to innovate, mature, de-risk, and scale promising technologies such as pyrolysis and gasification.
- **Market development:** Without strong outlets for alternative products (e.g. biochar, biocrude), economic viability remains uncertain, reducing the incentive for utilities to transition.
- **Regulatory alignment:** Clarification and streamlining of regulatory pathways for thermal processes, end-of-waste declarations, environmental controls and product standards are essential to unlock implementation.
- **Strategic planning:** Utilities will need to re-evaluate biosolids strategies under constrained reuse scenarios, identifying adaptive pathways, pivot points and contingency plans.

Bridging this gap will require a coordinated response, spanning innovation, regulation, market building, and cross-sector collaboration. The sector must act now to ensure resilient, circular, and community-aligned biosolids management strategies into the next decade and beyond.

## BIOSOLID MANAGEMENT OPTIONS

This section summarises the existing and emerging approaches for biosolids management considered within the assessment.



### Anaerobic Digestion (AD)

- AAD (Thermal Hydrolysis)
- Mesophilic AD in parallel (MAD)
- Mesophilic AD in series (MAD - series)
- AAD (Biological Hydrolysis)



### Conventional Thermal

- Solar Drying Greenhouses
- Solar Drying Bed
- Incineration
- Thermal Drying & Pelletisation



### Nature-based and General

- Phytoremediation
- Reed beds
- Liming
- Composting
- Lagoons (inc. Geobag Dewatering)
- Long-term Storage



### Advanced Thermal Conversion

- Pyrolysis
- Gasification
- Hydrothermal Liquefaction (HTL)
- Hydrothermal Carbonisation (HTC)
- Wet Air Oxidation (WAO)
- Supercritical Water Oxidation



## Mesophilic Anaerobic Digestion (parallel)



Thickened sludge (4-7%DS) is fed into an anaerobic digester with a residence time of 12-18 days at 36-38°C. Anaerobic bacteria break down volatile solids to generate **biogas** and the anaerobic conditions also reduce the pathogen count within the sludge. Following digestion, sludge is held in secondary storage for 7-12 days to enable further pathogen reduction. This can be conducted in a single secondary tank or across a series of sequential secondary tanks. Digestate is dewatered to 20-25%DS to recover **biosolids** which are rich in nitrogen and phosphorus.

### Energy Balance

Typically, biogas is combusted in combined heat and power (CHP) units. In most cases, this enables the digestion process to be self-sufficient in terms of energy and can generate surplus renewable electricity. Alternatively, biogas can be upgraded to remove CO<sub>2</sub> and generate biomethane as a natural gas substitute or a sustainable transport fuel.

### Chemical Demand

Low quantities of polyelectrolyte will be required for sludge dewatering and digestate dewatering processes. Antifoaming agents may be needed during digestion.

### Potential Carbon Impact

Typically, 40-50% of carbon in the sludge feed is present within the biosolids and will degrade to soil organic carbon over time if applied to land. The remainder will be converted to biogas and released as biogenic CO<sub>2</sub> if combusted onsite. Fugitive methane emissions can arise during secondary storage, which has historically been conducted in open tanks. This can be mitigated by covering secondary tanks and linking them to the biogas system.

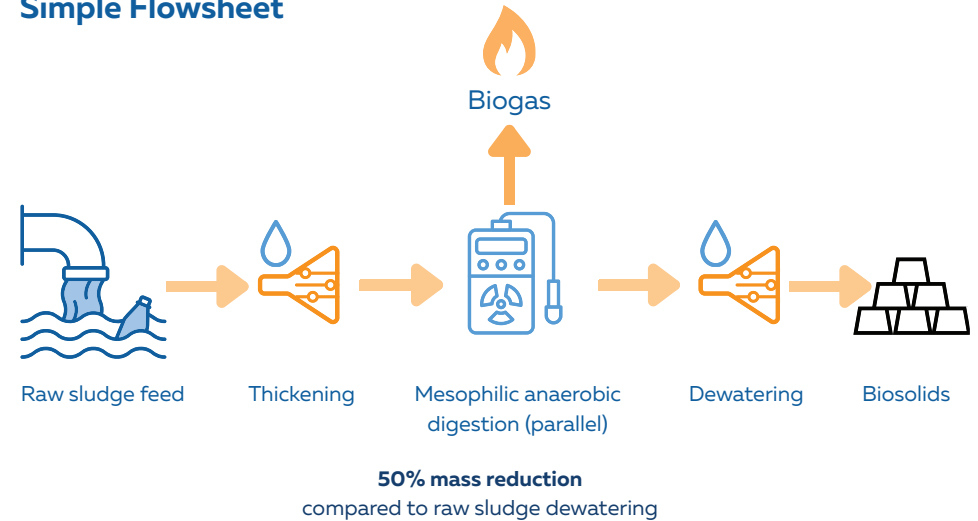
### Contaminants of Emerging Concern

Existing evidence indicates that PFAS and microplastics are not reduced during the anaerobic digestion process. These compounds will be transferred into the biosolids and the digestate dewatering liquors.

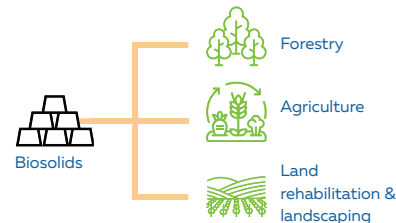
### NET ENERGY PRODUCER

TYPICAL OPERATING CONDITIONS	37°C, 6%DS (digester feed), 16d HRT
TYPICAL ENERGY CONSUMPTION	1.0-1.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	2.0-2.5 MWh/tDS (biogas)

## Simple Flowsheet

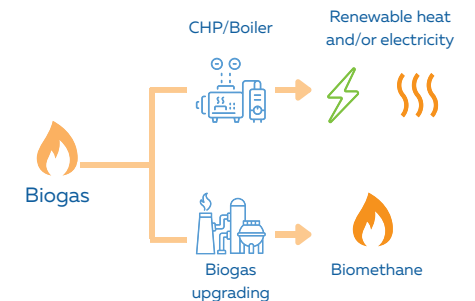


## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class B)

**Biogas** is a flexible, carbon neutral energy source comprising approximately 60% methane / 40% CO<sub>2</sub>





## Mesophilic Anaerobic Digestion (series)



Thickened sludge (4–7%DS) is held in anaerobic digesters at 36–38°C. In this variation, the sludge flows through multiple digesters in series (or a single vessel with baffles/walls). This is a cost-effective approach to extend the effective residence time during digestion by eliminating short-circuiting risks and creates the ideal conditions for different anaerobic bacteria at each stage. This increases **biogas** yields (by 10–15% based on limited evidence to date), solids destruction and pathogen reduction of the sludge relative to conventional digestion processes. Secondary storage (7–12 days) is typically required to enable further pathogen reduction. Digestate is dewatered to 20–25%DS to recover nutrient-rich **biosolids**.

### Energy Balance

The energy demand is comparable to conventional anaerobic digestion but with increased biogas yields. In most cases, combustion of biogas in CHPs enables the process to be self-sufficient in terms of energy and can generate surplus renewable electricity. Alternatively, biogas can be upgraded to remove CO<sub>2</sub> and generate biomethane as a natural gas substitute or a sustainable transport fuel.

### Chemical Demand

Low quantities of polyelectrolyte will be required for the sludge thickening and dewatering processes. Antifoaming agents may be needed during digestion.

### Potential Carbon Impact

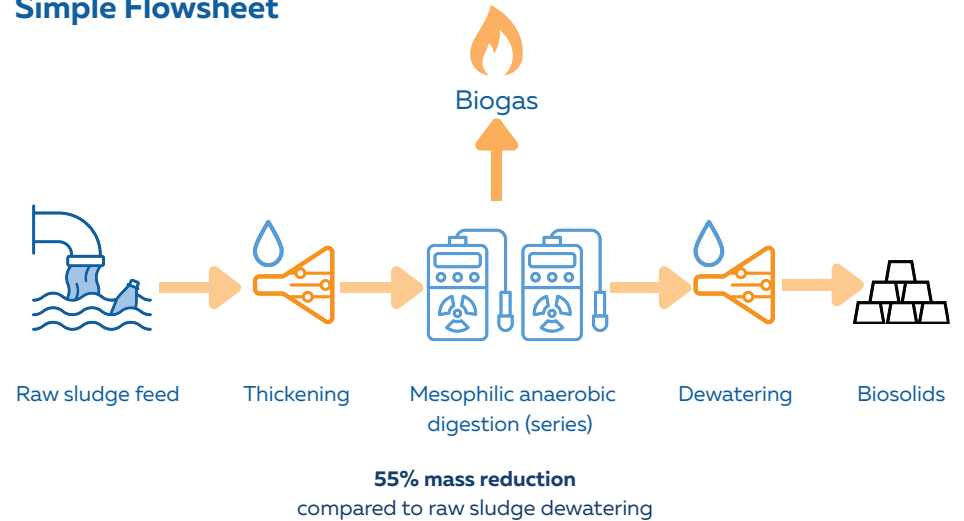
Typically, 30–40% of carbon in the sludge feed is present within the biosolids and will degrade to soil organic carbon over time if applied to land. The remainder will be converted to biogas and released as biogenic CO<sub>2</sub> if combusted onsite. Due to increased biogas recovery during digestion, the risk of fugitive methane from digestate is reduced.

### Contaminants of Emerging Concern

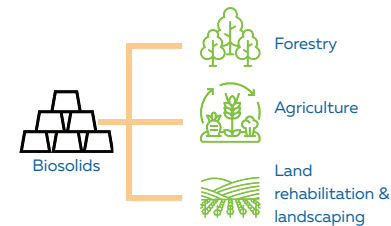
Existing evidence indicates that PFAS and microplastics are not reduced during the advanced anaerobic digestion process. These compounds will be transferred into the biosolids and the digestate dewatering liquors.

NET ENERGY PRODUCER	
TYPICAL OPERATING CONDITIONS	37°C, 6%DS (digester feed), 16d HRT
TYPICAL ENERGY CONSUMPTION	1.0–1.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	2.0–2.5 MWh/tDS (biogas)

## Simple Flowsheet

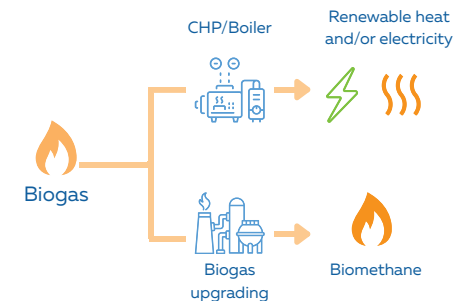


## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class B).

**Biogas** is a flexible, carbon neutral energy source comprising approximately 60% methane/40% CO<sub>2</sub>.





## Advanced Anaerobic Digestion (Thermal hydrolysis)



Dewatered sludge (~14-16%DS) is pre-treated in a thermal hydrolysis stage. This exposes sludge to raised temperatures and pressures (~165°C, 6 bar) to lyse cells and promote organic matter breakdown by increasing its bio-availability. Hydrolysed sludge is fed into anaerobic digesters with a residence time of 10-16 days at 36-38°C. Anaerobic bacteria degrade volatile solids to generate increased **biogas** yields and greater reductions in the dry solids and pathogen count of the sludge, relative to mesophilic anaerobic digestion alone. Digestate can be dewatered up to 30-35%DS to recover **biosolids** which are rich in nitrogen and phosphorus.



### Energy Balance

The energy demand is greater than mesophilic anaerobic digestion alone due to steam required for thermal hydrolysis, but the process also yields more biogas. In most cases, combustion of biogas in CHPs and/or steam boilers enables the process to be self-sufficient in terms of energy and can generate surplus renewable electricity. Alternatively, biogas can be upgraded to remove CO<sub>2</sub> and generate biomethane as a natural gas substitute.



### Chemical Demand

Low quantities of polyelectrolyte will be required for dewatering processes, alongside higher requirements for anti-foaming agents than other digestion types.



### Potential Carbon Impact

Typically, 20-30% of carbon in the sludge feed is present within the biosolids and will degrade to soil organic carbon over time if applied to land. The remainder will be converted to biogas and released as biogenic CO<sub>2</sub> if combusted on-site. Due to increased biogas recovery during digestion, the risk of fugitive methane from digestate is reduced.



### Contaminants of Emerging Concern

Existing evidence indicates that PFAS and microplastics are not reduced during the advanced anaerobic digestion process. These compounds will be transferred into the biosolids and the digestate dewatering liquors.

### NET ENERGY PRODUCER

TYPICAL OPERATING CONDITIONS

37°C, 12%DS (hydrolysis feed), 14d HRT

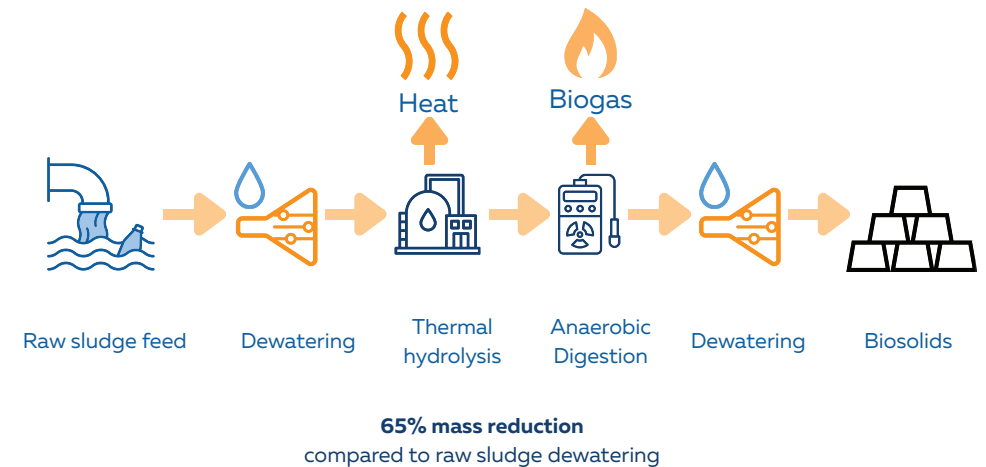
TYPICAL ENERGY CONSUMPTION

2.0-2.5 MWh/tDS

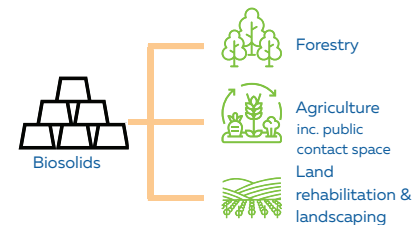
POTENTIAL ENERGY PRODUCTION

2.5-3.0 MWh/tDS (biogas)

## Simple Flowsheet

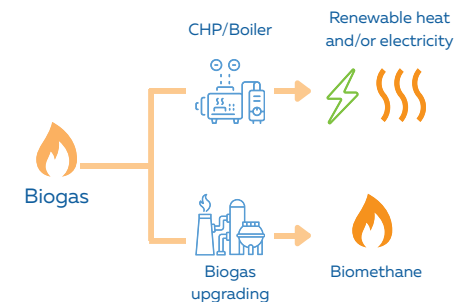


## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class A).

**Biogas** is a flexible, carbon neutral energy source comprising approximately 60% methane / 40% CO<sub>2</sub>.





## (AAD) Biological hydrolysis



Thickened sludge (~8%DS) is pre-treated by biological hydrolysis at moderate temperatures (40-55°C) in a sequence which includes heating, pasteurisation and hydrolysis. This increases the availability of digestible carbon whilst also providing pathogen reduction. Hydrolysed sludge is fed into anaerobic digesters with a residence time of 10-16 days at 36-38°C. Anaerobic bacteria degrade volatile solids to generate increased **biogas** yields and greater reductions in the dry solids and pathogen count of the sludge, relative to mesophilic anaerobic digestion alone. Digestate is dewatered up to 25-30%DS to recover nutrient-rich **biosolids**.

### Energy Balance

The energy demand is greater than mesophilic anaerobic digestion alone but less intensive than thermal hydrolysis processes. Due to the moderate temperatures required for the pre-treatment, this could be supplemented by sustainable heating sources (e.g. heat pumps). In most cases, combustion of biogas in CHPs and/or boilers enables the process to be self-sufficient in terms of energy and can generate surplus renewable electricity. Alternatively, biogas can be upgraded to remove CO<sub>2</sub> and generate biomethane as a natural gas substitute.

### Chemical Demand

Low quantities of polyelectrolyte will be required for dewatering processes. Antifoaming agents are likely to be needed during digestion.

### Potential Carbon Impact

Typically, 20-30% of carbon in the sludge feed is present within the biosolids and will degrade to soil organic carbon over time if applied to land. The remainder will be converted to biogas and released as biogenic CO<sub>2</sub> if combusted on-site. Due to increased biogas recovery during digestion, the risk of fugitive methane from digestate is reduced.

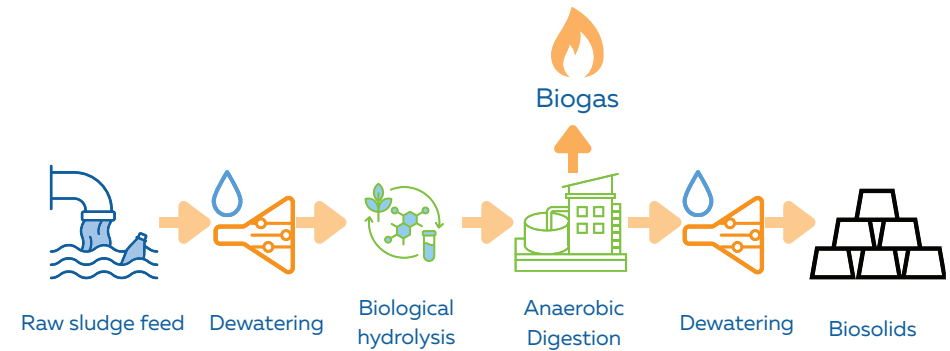
### Contaminants of Emerging Concern

Existing evidence indicates that PFAS and microplastics are not reduced during the advanced anaerobic digestion process. These compounds will be transferred into the biosolids and the digestate dewatering liquors.

### NET ENERGY PRODUCER

TYPICAL OPERATING CONDITIONS	37°C, 12%DS (hydrolysis feed), 14d HRT
TYPICAL ENERGY CONSUMPTION	1.5-2.0 MWh/tDS
POTENTIAL ENERGY PRODUCTION	2.5-3.0 MWh/tDS (biogas)

## Simple Flowsheet



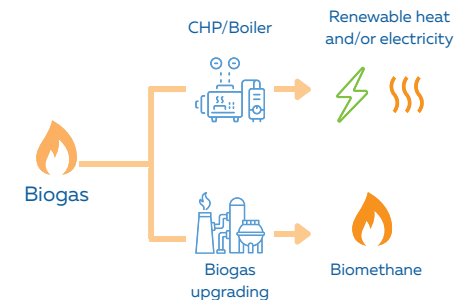
**60% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class A).

**Biogas** is a flexible, carbon neutral energy source comprising approximately 60% methane / 40% CO<sub>2</sub>.





## Phytoremediation



This process involves growing specific plants species, known as hyperaccumulators, in dewatered sludge. The addition of bulking agents such as wood chips, straw, or green waste can support plant growth and enhance biodegradability. Stabilisation of sludge can be achieved over time, and plant roots may absorb and accumulate contaminants from the sludge. Periodic removal of plant growth could enable these contaminants to be removed from the sludge pile. Over time, a peaty **biosolids** blend of up to 40%DS can be recovered. Notably, this process could also be conducted by planting grasses and can be termed phyto-conditioning.

### Energy Balance

The energy consumption for phytoremediation is negligible and is associated with dewatering and blending the sludge feed alongside planting, maintaining, and harvesting the plants. If grass is used, desludging and screening will be required after the growing season.

### Chemical Demand

Small amounts of polyelectrolyte are needed for sludge dewatering. Amendments (natural, chemical or microbial) can be used as aids to promote plant growth, with biosolids often containing only low levels of potassium (an essential plant macro-nutrient).

### Potential Carbon Impact

There is a paucity of data available for phytoremediation, and so it is assumed to perform similarly to composting. Based on this, 70-80% of carbon in the sludge feed may be present in the biosolids and degrade to soil organic carbon over time if applied to land. The remainder will be released to atmosphere as biogenic CO<sub>2</sub>.

### Contaminants of Emerging Concern

There is emerging evidence that specific plant species could absorb organic pollutants and heavy metals into their tissue or degrade contaminants through metabolic activity. This is an area of ongoing research.

### ENERGY NEUTRAL

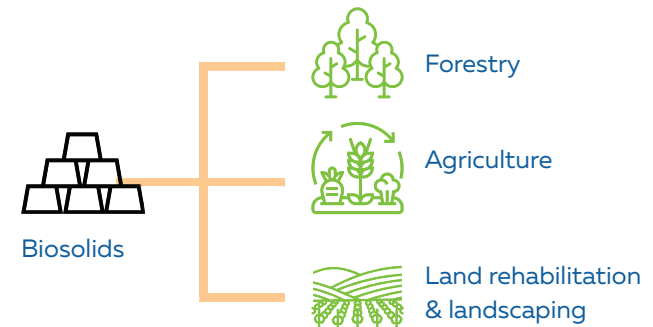
TYPICAL OPERATING CONDITIONS	Ambient, 20%DS
TYPICAL ENERGY CONSUMPTION	< 0.1 MWh/tDS(dewatering only)
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**50% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class B).



## Sludge Treatment Reed Beds



Reed beds are a nature-based treatment approach, comprising of an excavated area with a gravel and sand base in which the growth of reeds is encouraged. They work on a fill-hold-empty cycle. Batches of raw sludge are applied every 2-4 weeks once the reeds are established. Prior screening is recommended to remove debris. Sludge solids settle and are dewatered over time, whilst the water is evaporated or percolates through the base layer to produce a low-solids liquor which may require further treatment. Sludge is stored in the hold-phase for multiple years and undergoes breakdown by microorganisms - reducing the dry mass and deactivating pathogens. Reed beds are typically operated on 5-10-year cycles, after which sludge is dredged in the form of stable, dewatered **biosolids** (20-40%DS) and the reed bed needs to be replanted and recommissioned.

### Energy Balance

Reed beds are a passive process with negligible energy requirements during normal operation. It should be noted that the periodic dredging and recommissioning cycles will require heavy plant equipment with associated energy and fuel usage.

### Chemical Demand

None

### Potential Carbon Impact

Typically, 80-90% of carbon in the sludge feed will be recovered in the biosolids and will degrade to soil organic carbon over time if applied to land. The remaining carbon will be emitted as biogenic CO<sub>2</sub>. Overloading the reed bed can result in anaerobic conditions and the release of fugitive methane emissions. Notably, carbon may be taken up by the reeds but will be released to the atmosphere when the plant matter is degraded.

### Contaminants of Emerging Concern

Anaerobic microbes will break down complex organic compounds and absorb nutrients from the sludge over time. However, there is no evidence for the removal of microplastics and PFAS, so these are expected to be present in the outputs.

ENERGY NEUTRAL	
TYPICAL OPERATING CONDITIONS	Ambient, < 5%DS
TYPICAL ENERGY CONSUMPTION	None
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**50% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser (typically EPA Class B).

Biosolids from reed beds can accumulate raised concentrations of heavy metals over 5-10-year operating cycles, which can limit applicability.



## Liming



The involves blending liquid or powdered lime (calcium oxide or calcium hydroxide) into sludge. Lime can be dosed in-line during sludge pumping or within a blending vessel. Lime addition will raise sludge pH (>12) and temperature (>50°C) sufficient to achieve microbial destruction and chemical stabilisation during a specified storage duration. This produces **lime-stabilised biosolids**. Liming dewatered sludge can lead to ineffective mixing and poor uniformity of the final output. In contrast, liming sludge prior to dewatering supports a controlled mixing process which can enable a more resilient process and greater degree of biosolids stabilisation. Unlike most other management practices, this process will increase the solid content of sludge. Notably, **lime-stabilised biosolids** can be associated with increased odour potential and ammonia emissions relative to digested biosolids, due to the raised pH.

### Energy Balance

Lime dosing has minimal energy demands. Whilst excess low-grade heat is generated during the exothermic liming reaction, this is not typically recovered.

### Chemical Demand

Liming requires substantial addition of calcium oxide or calcium hydroxide to achieve the desired pH balance. Typically, these chemicals are added in doses equivalent to 10-30%wt of the sludge dry solids content (0.1-0.3 kg/kg dry solids). For this reason, the lime-stabilised biosolids will have an increased dry solids mass compared with the raw sludge.

### Potential Carbon Impact

Almost all carbon within the sludge feed will be transferred into the lime-stabilised biosolids. The high pH environment limits downstream microbial activity, minimising the potential for fugitive methane emissions and helping to retain carbon within the biosolids. However, the carbon will eventually degrade to soil organic carbon if applied to land.

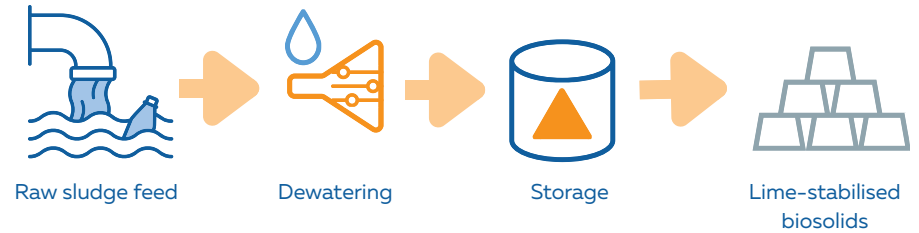
### Contaminants of Emerging Concern

Evidence indicates that PFAS and microplastics are not reduced during the liming process. However, pH manipulation can affect partitioning of some acidic PFAS and cause them to accumulate within the dewatering liquors rather than the biosolids.

## ENERGY NEUTRAL

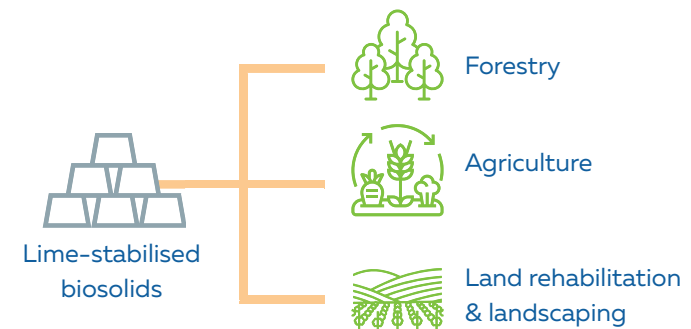
TYPICAL OPERATING CONDITIONS	Ambient, <5%DS
TYPICAL ENERGY CONSUMPTION	< 0.1 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**20% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Lime-stabilised biosolids** are rich in nitrogen and phosphorus and could be applied as a soil amendment and fertiliser. They can achieve EPA Class A, depending on pH, duration and temperature.

The high pH means these are favourable for use on acidic soils, or those with moderate/high inorganic fertiliser application.



## Composting



Dewatered sludge can be subjected to composting, which is an aerobic digestion process that kills pathogens and breaks down organic matter through the activity of microorganisms. Typically, sludge is combined with bulking agents such as wood chips, straw, or green waste to enhance air flow in the windrow and provide the supplementary nitrogen required for the reaction. Composting will generate humus-like biosolids which are rich in nitrogen and phosphorus. Most commonly, composting is conducted outdoors in piles (termed "windrows") which are typically 2 metres high, 4 metres wide and require periodic turning using plant equipment.



### Energy Balance

Windrow composting is a passive process with negligible energy requirements during normal operation. Energy or fuel will be required to turn the piles periodically, and a compressed air supply can be included to promote mixing and ensure adequate contact with air.



### Chemical Demand

Small amounts of polyelectrolyte are needed for sludge thickening or dewatering.



### Potential Carbon Impact

Typically, 70–80% of carbon in the sludge feed will be present in the composted biosolids and will degrade to soil organic carbon over time if applied to land. The remainder will be released to atmosphere as biogenic CO<sub>2</sub>. Poor mixing or aeration during composting can lead to anaerobic conditions and the release of fugitive methane emissions. Careful management is therefore required to maintain ideal conditions.



### Contaminants of Emerging Concern

There is no evidence to suggest that composting reduces emerging contaminants such as PFAS and microplastics. Contaminant levels may increase if co-composting is conducted with food waste. These compounds are expected to be present in the final biosolids output.

## ENERGY NEUTRAL

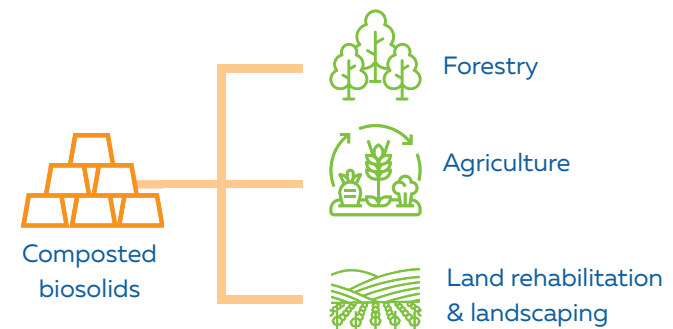
TYPICAL OPERATING CONDITIONS	Ambient, 35%DS (composting feed)
TYPICAL ENERGY CONSUMPTION	< 0.1 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**5% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Composted biosolids** are a humus-like, nutrient-rich output and could be applied to land as a soil amendment and fertiliser. They can achieve EPA Class A, depending on duration, turning frequency and temperature.



## Sludge lagoons (inc. Geobag Dewatering)



Sludge lagoons are a passive treatment solution. They consist of shallow reservoirs with linings to prevent sludge liquors leaching into the environment. Raw or digested sludge is deposited in the lagoon and left to settle for extended periods (>6 months). Prior screening is recommended to remove debris. It will undergo breakdown by microorganisms, which reduce the dry matter and deactivate pathogens. Over time, the water content evaporates in ambient conditions, and **biosolids** can be recovered. The biosolids can undergo further dewatering. Typically, passive, semi-permeable geotextile dewatering bags can be applied which allow liquors to drain away to increase the final biosolids dry solids content up to 25-40%DS. Alternatively, recovered sludge could be further dewatered in a drying pan.

### Energy Balance

Sludge lagoons are a passive process with negligible energy requirements during normal operation. As with sludge treatment reed beds, it should be noted that the periodic sludge removal and recommissioning cycles will require heavy plant equipment with associated energy and fuel usage.

### Potential Carbon Impact

Typically, 80-90% of carbon in the sludge feed will be recovered in the biosolids and will degrade to soil organic carbon over time if applied to land. This process can be associated with significant fugitive methane emissions due to the uncontrolled anaerobic conditions within the lagoon.

### Chemical Demand

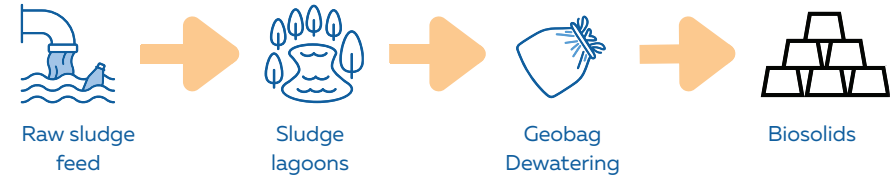
Unlike mechanical dewatering processes, the use of Geobags will not require polymer addition.

### Contaminants of Emerging Concern

Existing evidence indicates that PFAS and microplastics are not reduced during the anaerobic sludge breakdown in lagoons. These compounds will be transferred into the biosolids.

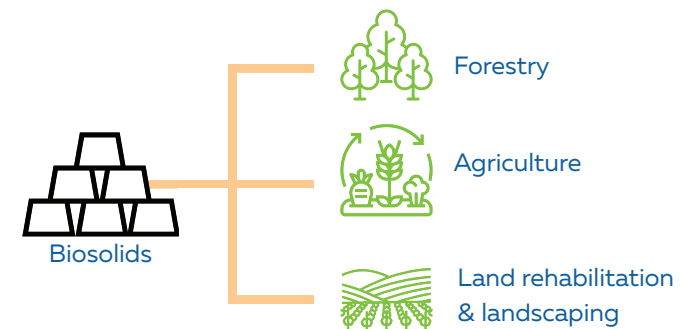
<b>ENERGY NEUTRAL</b>	
TYPICAL OPERATING CONDITIONS	Ambient, < 5%DS
TYPICAL ENERGY CONSUMPTION	None
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**60% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biosolids** are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser. They are typically EPA Class B but can qualify as Class A for pre-digested sludges depending on DS% and duration.



## Long-term Storage



In this approach, raw or digested sewage sludge could be dewatered and then stored in open air for extended periods. Prior screening is recommended to remove debris. Sludge may be configured in windrows to aid open-air drying, which are typically 2 metres high, 4 metres wide, and require periodic turning using plant equipment. During this storage period, stabilisation can occur passively, and **dried biosolids** can be recovered. The stabilisation duration is typically 3-years, but it should be noted that utilities can work with their regulator in site-specific assessments which may allow for a reduction in the duration. The final quality grade of the biosolids will be influenced by any upstream processing of the sludge (e.g., anaerobic digestion, lagoon evaporation).

### Energy Balance

This approach requires minimal energy demands. These will be associated with the initial dewatering processes and the periodic use of plant equipment during the management of windrows.

### Potential Carbon Impact

It is expected that 80-90% of carbon in the sludge feed will be recovered in the biosolids and will degrade to soil organic carbon over time if applied to land. The remaining carbon will be emitted as biogenic CO<sub>2</sub> due to the breakdown of organic matter during storage. Substantial fugitive methane emissions and strong odours can arise from the open air drying and storage of sludge.

### Chemical Demand

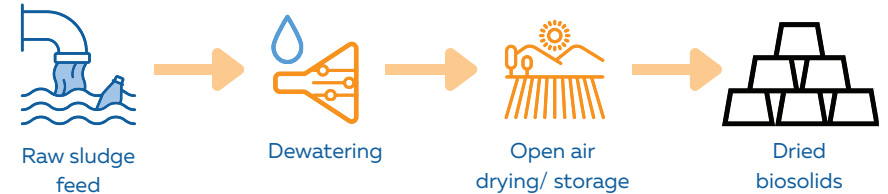
Small amounts of polyelectrolyte are needed for sludge dewatering.

### Contaminants of Emerging Concern

There is no evidence to suggest that long-term storage will reduce emerging contaminants such as PFAS and microplastics. These compounds are expected to be present in the final biosolids output.

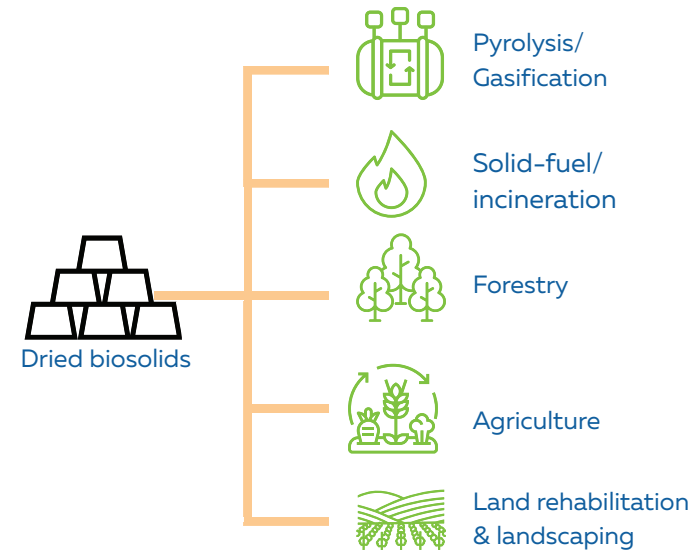
<b>ENERGY NEUTRAL</b>	
TYPICAL OPERATING CONDITIONS	Ambient, 20-25%DS (to drying/storage)
TYPICAL ENERGY CONSUMPTION	< 0.1 MWh/tDS (dewatering only)
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**75% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Dried biosolids** from long-term stabilisation are a nutrient-rich output and could be applied to land as a soil amendment and fertiliser. They are typically EPA Class B but can qualify as Class A for pre-digested sludges depending on DS% and duration.



## Solar Drying Beds



Solar drying harnesses heat from the sun to evaporate moisture from sludge, making it an energy-efficient treatment approach. Solar drying can be conducted in open air beds. Open air systems can utilise manual turning of sludge to promote even drying. **Dried biosolids** are recovered, which are a low volume and nutrient-rich output.

### Energy Balance

Solar drying is predominantly passive, unlike heat intensive thermal drying systems. Energy usage will be associated with the initial dewatering processes and the periodic use of plant equipment during the management of sludge.

### Potential Carbon Impact

Almost all carbon within the sludge feed will be transferred into the dried biosolids. This will degrade to soil organic carbon if applied to land, released as biogenic CO<sub>2</sub> if used as solid fuel or has the potential to be sequestered within char if utilised in pyrolysis/gasification processes.

### Chemical Demand

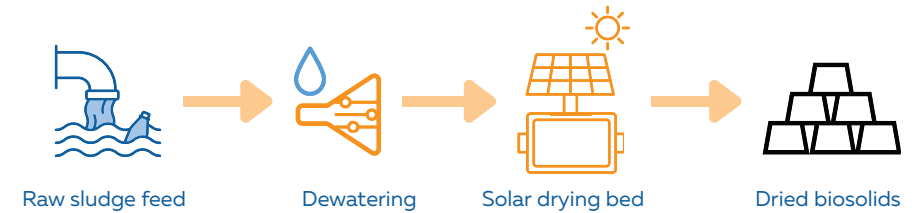
Low quantities of polyelectrolyte are required for sludge dewatering. Pre-treatment (lime/ferric chloride) may be required to further reduce pathogens and improve drying efficiency.

### Contaminants of Emerging Concern

There is no evidence to suggest that thermal drying reduces emerging contaminants such as PFAS and microplastics, so these are expected to be present in the evaporated water fraction and the dried biosolids.

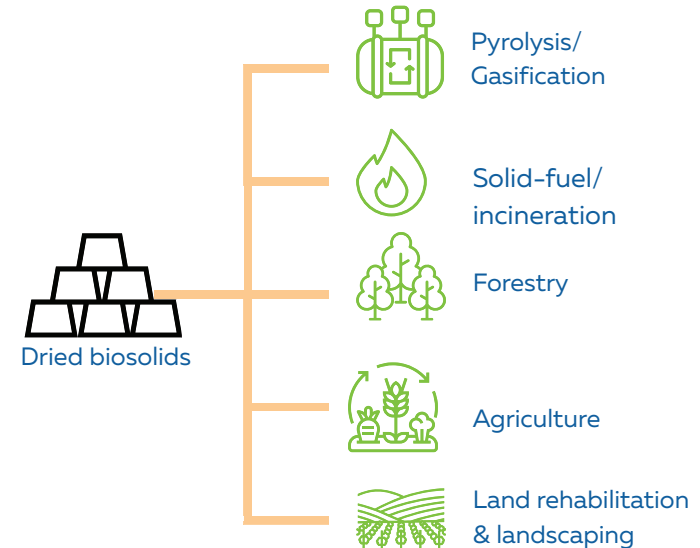
<b>ENERGY NEUTRAL</b>	
TYPICAL OPERATING CONDITIONS	Ambient, 20-25%DS (dryer feed)
TYPICAL ENERGY CONSUMPTION	< 0.1 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**75% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Dried biosolids** are a low volume, nutrient-rich output which could be used as a feedstock for a pyrolysis or gasification facility, combusted as a solid-fuel, or applied to land as a soil amendment.

They are typically EPA Class B but can qualify as Class A for pre-digested sludges.



## Solar Drying Greenhouses



Solar drying harnesses heat from the sun to evaporate moisture from sludge, making it an energy-efficient treatment approach. This can be conducted in automated greenhouse facilities which trap solar heat. Greenhouses enable process intensification (and therefore reduced footprint) compared to open air drying beds, greater control of the drying process and treatment of process emissions prior to release. Sludge movement can be automated and optimised by mechanical agitation. **Dried biosolids** are recovered, which are a low volume and nutrient-rich output.

### Energy Balance

Solar drying is predominantly passive, unlike heat intensive thermal drying systems. If utilising automated mechanical agitators, it will have a relatively low ancillary power demand. In some cases, indoor drying systems may require supplementary heating to maintain an effective drying rate which could be provided by waste heat sources if available.

### Chemical Demand

Low quantities of polyelectrolyte are required for sludge dewatering. Pre-treatment (lime/ferric chloride) may be required to further reduce pathogens and improve drying efficiency. In ventilated systems, acid/alkali may be required for scrubbing particulates from the exhaust vapours.

### Potential Carbon Impact

Almost all carbon within the sludge feed will be transferred into the dried biosolids. This will degrade to soil organic carbon if applied to land, released as biogenic CO<sub>2</sub> if used as solid fuel or has the potential to be sequestered within char if utilised in pyrolysis/gasification processes.

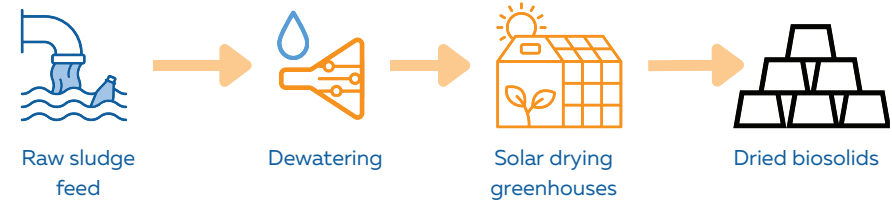
### Contaminants of Emerging Concern

There is no evidence to suggest that thermal drying reduces emerging contaminants such as PFAS and microplastics, so these are expected to be present in the evaporated water fraction and the dried biosolids.

### ENERGY NEUTRAL

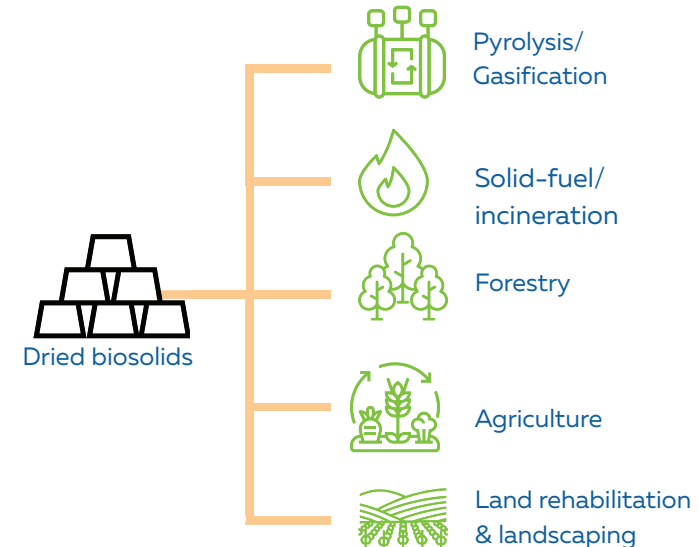
TYPICAL OPERATING CONDITIONS	Ambient, 20-25%DS (dryer feed)
TYPICAL ENERGY CONSUMPTION	0 - 0.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**75% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Dried biosolids** are a low volume, nutrient-rich output which could be used as a feedstock for a pyrolysis or gasification facility, combusted as a solid-fuel, or applied to land as a soil amendment.

They are typically EPA Class B but can qualify as Class A for pre-digested sludges.



## Thermal Drying & Pelletisation



Sludge is mechanically dewatered and then thermally dried up to 85-90%DS. Typical dryer designs include drying belts and rotating drums with hot air convection, or electrically heated screw conveyors. Dried sludge then enters a pelletiser and is cooled and compressed to generate uniform **biosolids pellets**, which can be readily stored, transported, and use in a range of applications.



### Energy Balance

Thermal drying is energy intensive and typically requires the direct combustion of fossil fuels (e.g. natural gas) or the use of steam or electrical heating to drive the evaporation process. The pelletisation process will require power for the dried sludge blending and compression.



### Chemical Demand

Low quantities of polyelectrolyte will be required for sludge dewatering. Acid/alkali may be required for scrubbing particulates from the exhaust vapours. Pre-treatment with lime or ferric chloride may be required to reduce pathogens and improve drying efficiency. Furthermore, binding agents (e.g. cellulose and starch) may be used to enhance pellet formation and help them maintain shape and integrity.



### Potential Carbon Impact

Almost all carbon within the sludge feed will be transferred into dried biosolids. This will degrade to soil organic carbon if applied to land, released as biogenic CO<sub>2</sub> if used as solid fuel or could be sequestered within chars if utilised in pyrolysis/gasification processes. Fossil fuel usage during thermal drying will result in high carbon emissions.



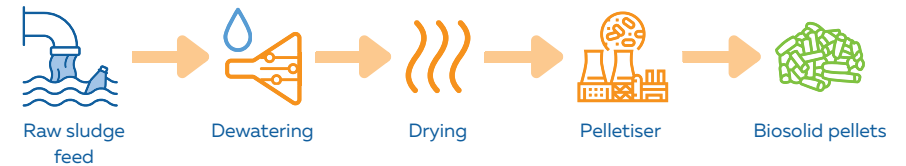
### Contaminants of Emerging Concern

There is no evidence to suggest that thermal drying reduces emerging contaminants such as PFAS and microplastics, so these are expected to be present in the evaporated water fraction and the dried biosolids.

### NET ENERGY CONSUMER

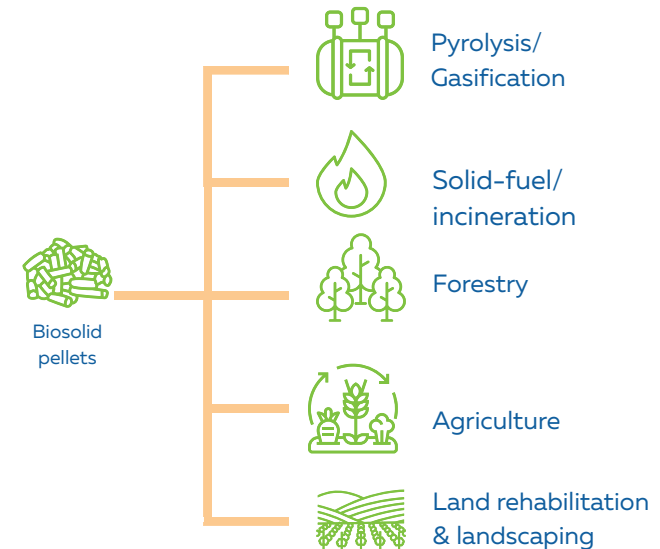
TYPICAL OPERATING CONDITIONS	120°C, 20-25%DS (dryer feed)
TYPICAL ENERGY CONSUMPTION	2.5-3.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None

## Simple Flowsheet



**75% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biosolids pellets** are a condensed output which could be used as a feedstock for a pyrolysis or gasification facility, combusted as a sustainable solid-fuel, or applied to land as a soil amendment.

Can achieve EPA Class A depending on dryer temperature and upstream processing (e.g., digestion).



## Incineration



Incineration involves combustion of organic matter within dewatered sludge to dramatically reduce its volume at approx. 1,000°C. An initial drying stage (typically incorporated within the incinerator) increases the dry solids content above approximately 35–40%DS (depending upon energy content) prior to combustion. The combustion process can use multiple hearths, fluidised beds, or electric infrared incinerators and converts sludge to ash and CO<sub>2</sub>.

### Energy Balance

If the dry solids content of the feed is above 35–40%DS, incineration of the sludge may generate sufficient heat to cover all heating demands for the process. Support fuel (e.g., natural gas) will be required on start-up. Typically, sludge incineration will generate surplus heat which is used to produce steam and drive a turbine for power generation.

### Chemical Demand

Low quantities of polyelectrolyte will be required for sludge dewatering. Acid/alkali is typically required for scrubbing particulates and pollutants from flue gases (e.g., SO<sub>x</sub>, NO<sub>x</sub>). Additional flue gas scrubbing or carbon filtration is required for volatilised metals.

### CO<sub>2</sub> Potential Carbon Impact

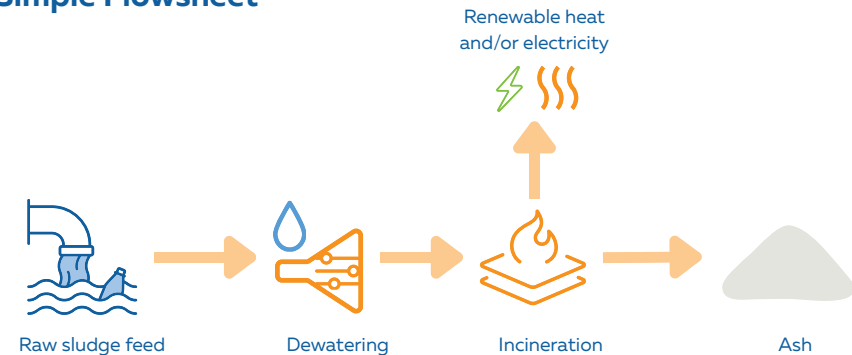
Up to 90% of carbon in the sludge feed will be converted to biogenic CO<sub>2</sub> and released to the atmosphere. The remainder will be present as fixed carbon in the ash. The flue gases can also contain nitrous oxide (N<sub>2</sub>O) which is a potent greenhouse gas. Greenhouse emissions arising from the use of support fuel and N<sub>2</sub>O production during incineration can be mitigated by ensuring stable feed conditions.

### Contaminants of Emerging Concern

There is evidence that the high temperature operation can degrade microplastics and PFAS compounds from the solid-phase. However, PFAS breakdown products may persist in flue gases. More research is required to measure pollutant concentrations within the flue gas combustion products and support their management.

NET ENERGY PRODUCER	
TYPICAL OPERATING CONDITIONS	1000°C, 40%DS (incinerator feed)
TYPICAL ENERGY CONSUMPTION	4.0–4.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	5.5–6.0 MWh/tDS (heat, power)

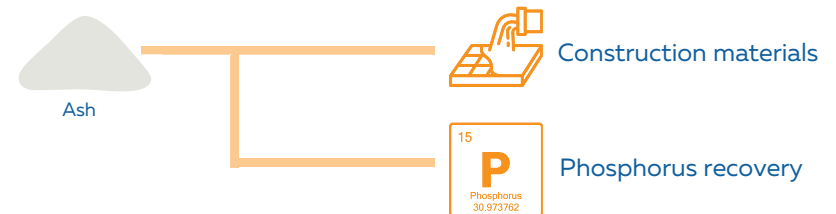
## Simple Flowsheet



**75% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation

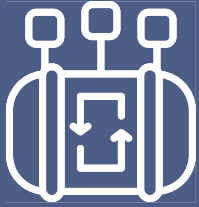
Ash could be used in construction materials (depending on quality) or processed to extract phosphorus for agricultural use.



Excess heat from the incineration process can be utilised within a steam turbine to generate **renewable electricity**.

Renewable heat and/or electricity





## Pyrolysis



Dewatered sludge undergoes thermal drying to reach 80-90%DS prior to pyrolysis. Dried sludge enters the pyrolysis reactor and is processed at high temperatures (600-700°C) in a zero-oxygen environment. This converts the sludge to **pyrolysis gas** and **biochar**.



### Energy Balance

Typically, pyrolysis gases are combusted within a thermal oxidiser to provide heat for the pyrolysis and drying stages. Additional heat input may be needed for the drying process, particularly if feeding with sludges below 30%DS content. Auxiliary fuel will also be required on start up. Pyrolysis gases can be treated to separate them into pyrolysis-oil and syngas, although examples of pyrolysis-oil recovery are extremely limited in practice due to processing complexity and trace contaminants.



### Potential Carbon Impact

Typically, 50-60% of carbon in the sludge feed is sequestered within highly stable biochar. The remaining carbon in sludge is converted to pyrolysis gases and will be released as biogenic CO<sub>2</sub> if these are combusted within the process.



### Chemical Demand

Low quantities of polyelectrolyte will be required for sludge dewatering. Acid/alkali is typically required for scrubbing particulates and pollutants from the flue gases.

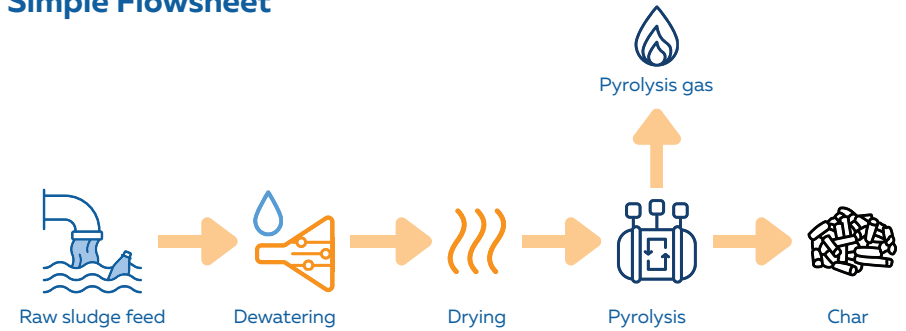


### Contaminants of Emerging Concern

There is strong evidence that PFAS and microplastics are removed from the solid-phase and are below detection limits in the biochar output. However, more research is required to measure PFAS concentrations in the flue gas from pyrolysis gas combustion.

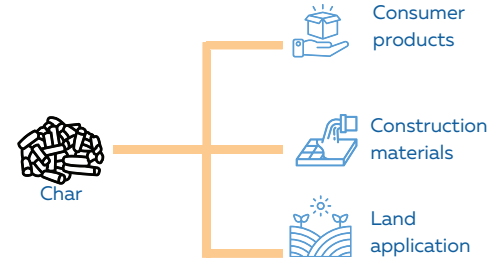
NET ENERGY CONSUMER	
TYPICAL OPERATING CONDITIONS	600-700°C, 25%DS (dryer feed)
TYPICAL ENERGY CONSUMPTION	3.5-4.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	3.0-3.5 MWh/tDS (pyrolysis gas)

## Simple Flowsheet



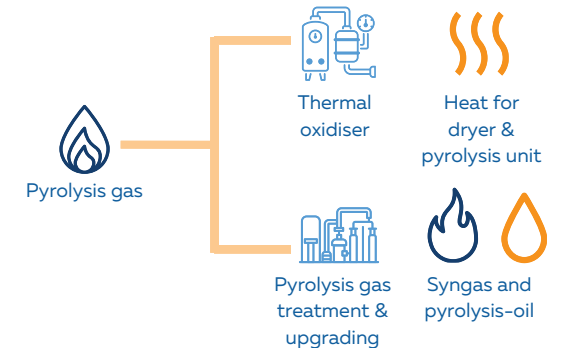
**90% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Biochar** is a highly stable form of sequestered carbon which contains phosphorus and may have nutrient value for land application (depending on quality grade).

**Pyrolysis gas** is a complex blend of hydrogen, hydrocarbons, tars and condensable oils. It is typically combusted for heat onsite.





## Gasification



Dewatered sludge undergoes thermal drying to reach 80-90%DS prior to gasification (800-1,200°C). Drying can occur in a separate unit or as part of an integrated system with gasification. During gasification, dried sludge is heated within a partial oxygen environment. It undergoes partial combustion to generate heat, whilst decomposing the remaining organic material to **syngas** and **char/ash**. The yield of these outputs can be adjusted by varying the amount of oxygen entering the gasifier.

### Energy Balance

In most cases, heat recovered from the gasification reaction and combustion of the syngas in a CHP unit allows the process to be self-sufficient in terms of energy. However, auxiliary fuel will be required on start up. There is typically excess energy in the form of syngas or renewable electricity from a syngas CHP. Syngas could be also upgraded to recover H<sub>2</sub>.

### Chemical Demand

Low quantities of polyelectrolyte will be required for sludge dewatering. Acid/alkali is typically required for syngas scrubbing prior to combustion (removal of particulates, SO<sub>x</sub>, NO<sub>x</sub> etc.).

### Potential Carbon Impact

Approximately, 10% of carbon in the sludge feed will be sequestered within a stable char/ash output. This is due to partial combustion of the solid-phase for heat and transfer of carbon into the syngas. If combusted, carbon within the syngas will be released to atmosphere as biogenic CO<sub>2</sub>.

### Contaminants of Emerging Concern

Evidence suggests that high levels of microplastics and PFAS are removed and/or converted within the reactor when operating above approximately 800°C. However, more research is required to measure PFAS concentrations within the syngas and its combustion products.

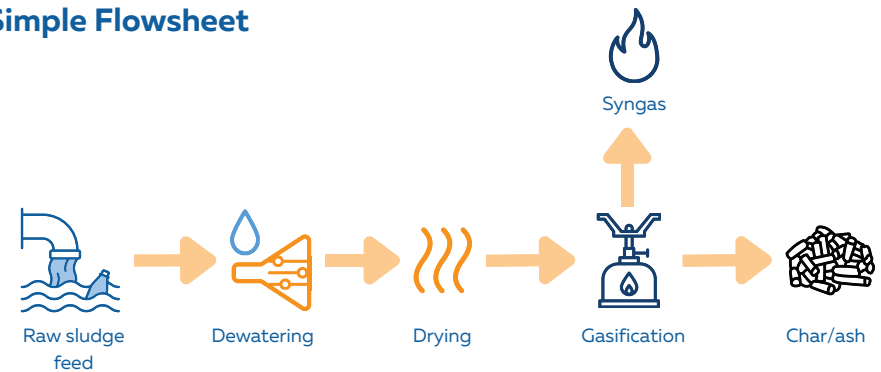
## NET ENERGY PRODUCER

TYPICAL OPERATING CONDITIONS	800-1,200°C, 25%DS (dryer feed)
TYPICAL ENERGY CONSUMPTION	3.0-3.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	4.0-4.5 MWh/tDS (syngas, heat)

## WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

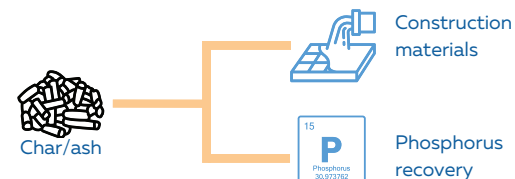
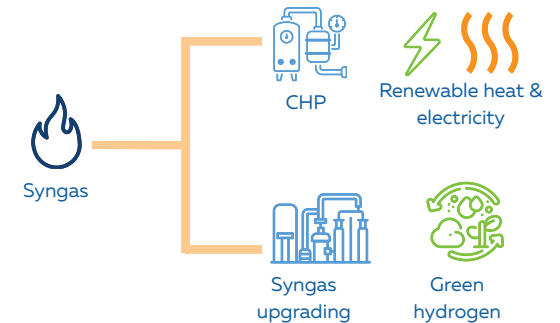
## Simple Flowsheet



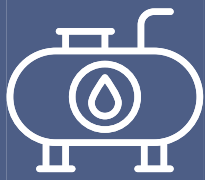
**95% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation

**Syngas** is an energy dense gas that can be utilised within a combined heat and power (CHP) engine to produce heat and electricity. It could also be upgraded and cracked to recover hydrogen.



**Char/ash** could be utilised within construction aggregates or undergo processing for phosphorus recovery.



## Hydrothermal Liquefaction (HTL)



Hydrothermal liquefaction (HTL) treats dewatered sludge (5-20% dry solids) at high temperatures (250-400°C) and high pressures (100-350 bar) without oxygen. This process can convert up to 30-40% of the dry solids into a liquid **biocrude oil**. The remaining material is converted to solid precipitate (**ash**), dissolved within an aqueous **concentrated effluent** (which will require further treatment) and released as process gases (mainly CO<sub>2</sub>).



### Energy Balance

The feed requires heating to high temperatures (via natural gas/ steam) and requires pumping to high pressures. Increasing the dry solids content of the feed within the 5-20%DS range will reduce its volume and therefore reduce the heat and power demand for the process. Biogas could be recovered from the concentrated effluent in a downstream process due to the presence of biologically available dissolved carbon sources.



### Potential Carbon Impact

Typically, 50-60% of carbon in the sludge feed is transferred into biocrude oil. The remaining carbon is converted into process gas emissions, dissolved into the aqueous stream or present in the precipitate (ash). Dissolved carbon can be used for downstream digestion and biogas generation and will be ultimately released as biogenic CO<sub>2</sub>.



### Chemical Demand

Small amounts of polyelectrolyte are needed for sludge dewatering.



### Contaminants of Emerging Concern

Evidence suggests that microplastics and some PFAS are removed and/or converted from the sludge feedstock when operating at temperatures above 350°C. Some of the contaminants are therefore expected to be present in the solid and liquid outputs from the process.

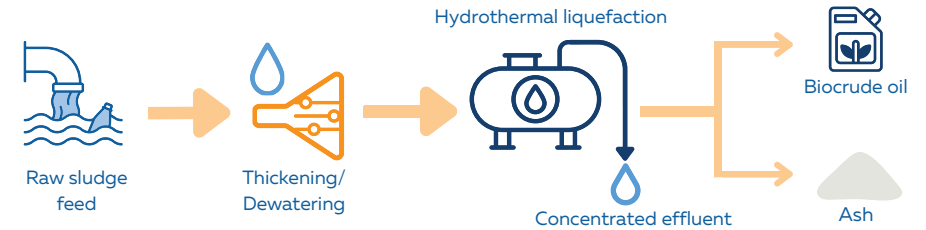
### NET ENERGY CONSUMER

TYPICAL OPERATING CONDITIONS	250-400°C, 200 bar, 15%DS (HTL feed)
TYPICAL ENERGY CONSUMPTION	1.0-1.5 MWh/tDS
POTENTIAL ENERGY PRODUCTION	None (excl. effluent)

## WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

### Simple Flowsheet



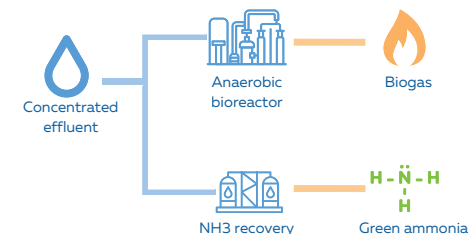
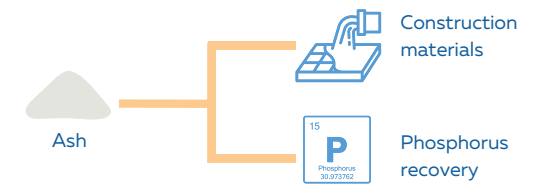
**87% mass reduction**  
compared to raw sludge dewatering

### Potential Output Utilisation



**Biocrude oil** can be further refined into valuable outputs, such as sustainable aviation fuel (SAF).

**Ash** could be used in construction or processed to extract phosphorus for agricultural use (depending on quality).



The **concentrated effluent** contains dissolved carbon sources which may be biologically available for biogas generation, and may contain raised ammonia levels which could be recovered by thermal stripping.



## Hydrothermal Carbonisation (HTC)



Hydrothermal carbonisation (HTC) can treat thickened or dewatered sludge (5-20%DS) at high temperatures (180-300°C) and high pressures (20-60 bar) in the absence of oxygen. This process converts up to 30-40% of dry solids into a solid output called **hydrochar**. Hydrochar can be recovered using a filter press. The residual liquid fraction is a **concentrated effluent** which will require further treatment. The reactor produces process gases (mainly CO<sub>2</sub>).



### Energy Balance

The feed requires heating to high temperatures (via natural gas / steam) and requires pumping to high pressures. Increasing the dry solids content of the feed within the 5-20%DS range will reduce its volume and therefore reduce the heat and power demand for the process. Biogas could be recovered from the concentrated effluent in a downstream process due to the presence of biologically available dissolved carbon sources.



### Potential Carbon Impact

Typically, 70-90% of the carbon in the sludge feed is captured within the hydrochar. The remaining carbon is released as process gases or dissolved within the effluent (available for biogas recovery or biological oxidation) and will ultimately be released as biogenic CO<sub>2</sub>.



### Chemical Demand

Small amounts of polyelectrolyte may be required for sludge dewatering. Sulfuric acid is commonly used as a catalyst to speed up the breakdown of organic matter, improve dewaterability, and increase hydrochar yields.



### Contaminants of Emerging Concern

Evidence suggests that there is limited microplastics and PFAS degradation when operating at 250-300°C, and potential new-PFAS formation from precursor molecules. Therefore, it is expected that these contaminants will still be present within the hydrochar and concentrated effluent.

### NET ENERGY CONSUMER

TYPICAL OPERATING CONDITIONS

180-300°C, 40 bar, 15%DS (HTC feed)

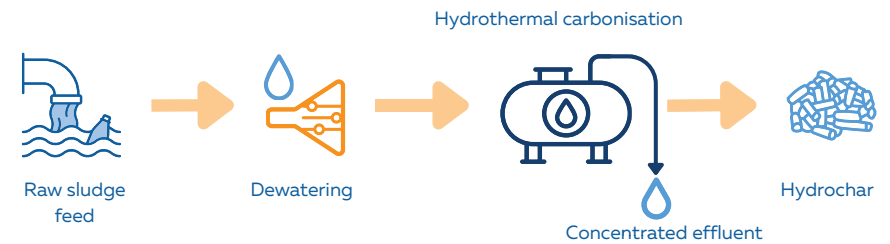
TYPICAL ENERGY CONSUMPTION

0.5-1.0 MWh/tDS

POTENTIAL ENERGY PRODUCTION

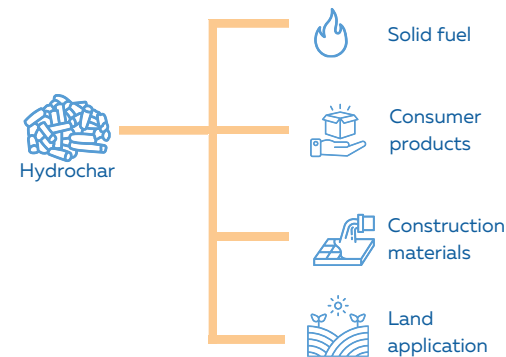
None (excl. effluent)

## Simple Flowsheet



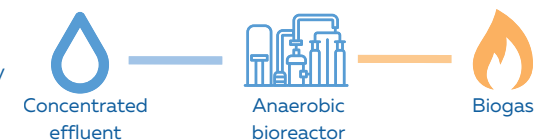
**80% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Hydrochar** is a solid fuel which can replace coal use in heavy industries. It could also be used in construction materials, applied as a soil amendment or incorporated into consumer products (depending on quality grade).

The **concentrated effluent** contains dissolved carbon sources which may be biologically available for biogas recovery.





## Wet Air Oxidation (WAO)



Wet Air Oxidation (WAO) involves the treatment of thickened or dewatered sludge (5-20%DS) at high temperatures (150-320°C) and high pressures (50-150 bar) in an oxygenated reactor. It is operated below the “critical point” of water, which is the key differentiator between this process and super-critical water oxidation. Under these conditions, organic solids are broken down to generate a **concentrated effluent** which will require further treatment, a solid precipitate (**ash**) and process gases (mainly N<sub>2</sub> and CO<sub>2</sub>).



### Energy Balance

The partial oxidation of organic matter will release heat energy. Depending on the sludge and its dry solids content, this process can be autothermal (self-sufficient for its heating requirements). Increasing the feed dry solids content will reduce the power demand and increase the heat output. Biogas could be recovered from the concentrated effluent in a downstream process due to the presence of biologically available dissolved carbon sources.



### Chemical Demand

Polyelectrolyte is needed for sludge thickening or dewatering. An oxygen source (pressurised air or pure oxygen) will be required for the oxidation reactor.



### Potential Carbon Impact

All carbon in the sludge feed is either oxidised in the reactor and released in the process gases or is dissolved within the concentrated effluent for downstream digestion/treatment. Ultimately, all carbon will be released to the atmosphere as biogenic CO<sub>2</sub> unless captured in downstream processes.



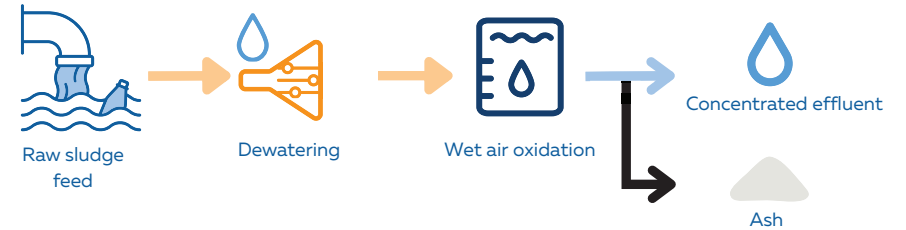
### Contaminants of Emerging Concern

Evidence suggests that this process can partially degrade microplastics when operated above 220°C. However, there is limited evidence to show that this process can effectively remove or convert PFAS and so this is expected to be present in the effluent. Further research is required into approaches for PFAS removal from the effluent.

### NET ENERGY CONSUMER

TYPICAL OPERATING CONDITIONS	150-320°C, 80 bar, 10%DS (WAO feed)
TYPICAL ENERGY CONSUMPTION	0.5-1.0 MWh/tDS
POTENTIAL ENERGY PRODUCTION	< 0.5 MWh/tDS (heat, excl. effluent)

## Simple Flowsheet

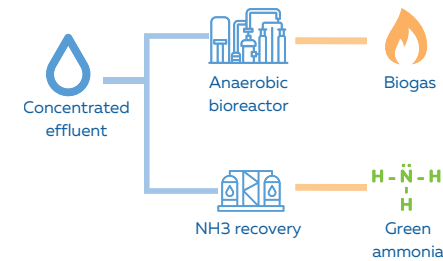


**95% mass reduction**  
compared to raw sludge dewatering

## Potential Output Utilisation



**Ash** could be used in construction or processed to extract phosphorus for agricultural use (depending on quality).



**The concentrated effluent** contains dissolved carbon sources which may be biologically available for biogas generation, and may contain raised ammonia levels which could be recovered by thermal stripping.



## Super-critical Water Oxidation (SCWO)



Super-critical Water Oxidation (SCWO) could treat thickened or dewatered sludge (5–20%DS) at high temperatures (>400°C) and high pressures (>240 bar) in an oxygenated reactor. These conditions are above the “critical point” of water, which is the key differentiator between this process and Wet Air Oxidation. Under these extreme conditions, all organic matter (solid and dissolved) is fully oxidised to recover **dilute effluent** with minimal treatment requirements, a solid precipitate (**ash**) and process gases (mainly N<sub>2</sub> and CO<sub>2</sub>).



### Energy Balance

The total oxidation of organic matter will release enough heat energy for the process to be autothermal (self-sufficient for its heating requirements). There will be excess thermal energy within the pressurised process gases which can be used to generate electricity in an expansion turbine. Increasing the feed dry solids content will reduce the power demand for pumping and increase the energy recovery potential.



### Potential Carbon Impact

Up to 95% of carbon in the sludge feed will be released as biogenic CO<sub>2</sub> within the process gases, with the remainder present within the ash.

2



### Chemical Demand

Small amounts of polyelectrolyte are needed for sludge thickening or dewatering. An oxygen source (pressurised air or pure oxygen) will be required for the oxidation reactor.



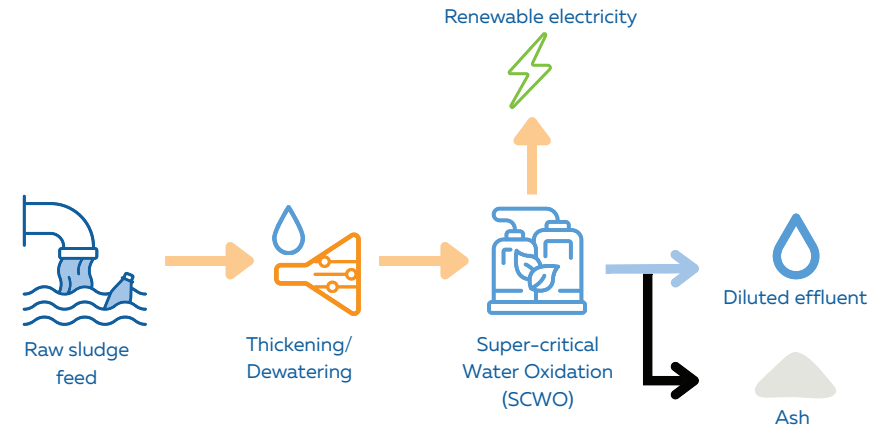
### Contaminants of Emerging Concern

Evidence suggests that high levels of microplastics are degraded within the sludge at approximately 400°C. There is also strong evidence that significant PFAS degradation occurs when operating above 600°C. Further research on the composition of the dilute effluent is required to support this.

### NET ENERGY PRODUCER

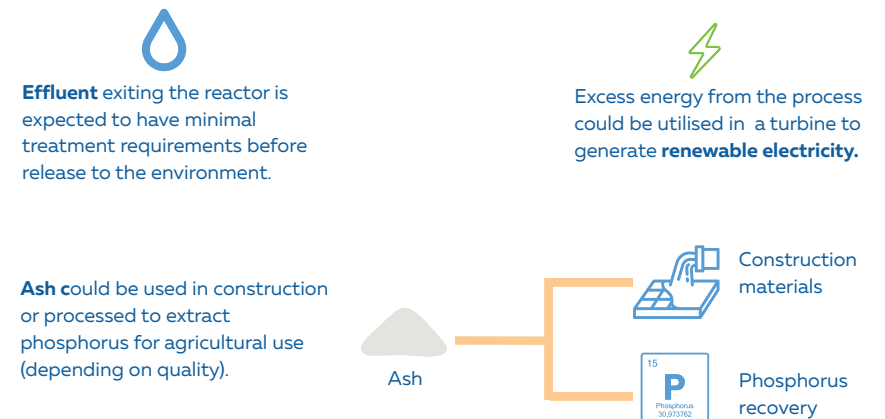
TYPICAL OPERATING CONDITIONS	>400°C, >240 bar, 10%DS (SCWO feed)
TYPICAL ENERGY CONSUMPTION	0.5-1.0 MWh/tDS
POTENTIAL ENERGY PRODUCTION	3.0-3.5 MWh/tDS (heat, power)

## Simple Flowsheet



**95% mass reduction** compared to raw sludge dewatering

## Potential Output Utilisation



## CASE STUDY 01

### WEIGHING UP THE OPTIONS

Sustainable biosolids management across Australia & New Zealand

## WESTERN TREATMENT PLANT LAGOONS & DRYING PANS (VIC)

MELBOURNE WATER



Lagoons



Melbourne Water's Western Treatment Plant (WTP) at Werribee treats approximately half of Melbourne's sewage through a modern hybrid system that combines mechanised nutrient removal plants (NRPs) with lagoon treatment and extensive resource recovery operations. Located on a 10,500-hectare site, also home to internationally recognised Ramsar wetlands, WTP is one of the largest advanced wastewater facilities in Australia.

As Melbourne's population has grown, WTP has transitioned from a largely lagoon-based process to a more highly mechanised and controlled, energy-efficient treatment system. The upgraded treatment trains support public health, protect Port Phillip Bay, and underpin Melbourne Water's circular economy objectives.

### BENEFITS

- Advanced nutrient removal and modern treatment capacity through multiple NRPs, including the 5 West NRP designed to process up to 150 megalitres per day (ML/d).
- Partial energy self-sufficiency (76.7%) achieved through biogas capture from covered anaerobic lagoons with capability for full energy self-sufficiency expected to return after current renewal project.
- Large-scale biosolids reuse program, with 30,273 tonnes of biosolids tonnes applied to farms in the last year, improving soil productivity.

### How it works

Most sewage flow is treated via modern activated sludge and nutrient removal plants (NRPs) using advanced aeration, bioreactor control systems, shortcut nitrogen removal and secondary clarification. Lagoons continue to play an important but secondary role, largely acting as polishing stages downstream of mechanised treatment. Sludge from the mechanised plants is transferred to solar drying pans, where it dries over extended periods. Once meeting EPA Victoria's quality requirements, biosolids can be supplied for agricultural reuse.

### Status & what's next

The biosolids reuse program continues to operate each year at scale, with modern compliance controls in place. Upgrades to strengthen mechanised treatment capacity are ongoing, ensuring WTP can meet future population growth and tighter environmental performance requirements. Melbourne Water continues to work with EPA Victoria, the water industry, customers and community to implement measures aligned with best-practice approaches and meet its General Environmental Duty.

## CASE STUDY 02

## INCINERATION WITH AGRI-ASH REUSE (ACT)

ICON WATER



Incineration



Icon Water's Lower Molonglo Water Quality Control Centre (LMWQCC) operates two furnaces that convert biosolids into Agri-Ash, a calcium-rich mineral product supplied to regional farms under the NSW EPA Resource Recovery Order (Agri-Ash) 2020. This process effectively eliminates pathogens and volatile organic compounds, producing a stable, sterile product that continues to serve as a valuable agricultural purpose.

### BENEFITS

- Safe reuse solution – provides a regulated solution that avoids biosolids stockpiling and minimises transport while delivering proven agronomic value.
- Consistent production – generates around 16 tonnes of Agri-Ash per day, enabling consistent supply to farms.
- Nutrient rich composition – contains around 60% calcium-based compounds and 6% phosphorus, making it suitable as a liming or nutrient input under the approved Resource Recovery Order.

### How it works

Biosolids are treated at high temperatures, producing mineral ash that is collected and supplied to farms under contract roughly three days per week. Use of the ash is governed by the Resource Recover Order, which sets out strict conditions on quality, record-keeping, and application limits. This framework gives landholders confidence in its safe and compliant use.

Incineration is a well-established technology, and in this configuration it has delivered reliable solids management, and a stable, consistent product over time.

### Status & what's next

While the current incineration and Agri-Ash pathway remains effective, the furnaces are nearing the end of their operational life. Icon Water is preparing to replace the furnaces and, through a multi-criteria assessment, identified gasification as its preferred modernisation pathway, closely followed by fluidised bed combustion, based on emissions performance, energy efficiency, and circular economy outcomes. As new information becomes available during detailed design, heat treatment technologies will continue to be validated to ensure the best long-term outcome is achieved.

In the meantime, Agri-Ash distribution will continue under existing approvals, ensuring continuity for regional farms. Independent fertiliser trials conducted by the NSW South East Local Land Services over six years showed that Agri-Ash performs comparably to superphosphate in both productivity and cost-effectiveness.

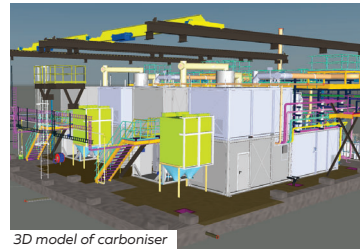


**RIVERSTONE CARBONISATION  
(PYREG) (NSW)**

SYDNEY WATER



Within the North West Treatment Hub (NWTB) program, Sydney Water is installing two PYREG PX1500-SH carbonisation units at Riverstone WRRF to ensure ongoing usage of biosolids with imminent guidelines on PFAS levels. The technology heats dewatered biosolids to approximately 500–700 °C in limited oxygen, and a flameless oxidation (FLOX) step polishes the off-gas. The North West Hub Alliance (John Holland, Stantec and KBR) is delivering upgrades across Riverstone and Rouse Hill. A market expression of interest (EOI) has been used to explore offtake partners for the biochar so reuse can begin from day one.



3D model of carboniser

**BENEFITS**

- Management of contaminants such as PFAS.
- Approximately 90% reduction in solids volume for transport, with associated reductions in truck movements, transportation costs and handling risk.
- Design throughput of around 10.5 t/d dry solids, producing more than 400 kg/h of biochar at maximum production.

**How it works**

Dewatered biosolids are carbonised for several minutes at high temperatures under controlled oxygen. The resulting off-gas is treated in a FLOX chamber designed to ensure complete oxidation and temperature uniformity, before it is released through standard air pollution controls. The resulting product is a high-carbon biochar with potential uses under NSW rules (e.g. soil applications and materials development), subject to receiving environment and product quality specifications.

Air emissions are predicted to be within the NSW Clean Air Regulation limits in the project's assessment.

**Status & what's next**

Procurement and construction are underway at Riverstone WRRF. Equipment deliveries are expected in late 2025, with commissioning targeted for April 2027 (EOI). Licence variation and routine monitoring will accompany the ramp-up. Sydney Water is progressing biochar offtake planning to secure beneficial reuse pathways.



**PYROCO PILOT  
PYROLYSIS (VIC)  
SOUTH EAST WATER  
& PARTNERS**



South East Water (SEW), RMIT, Intelligent Water Networks (IWN) and Greater Western Water have partnered to develop and pilot PYROCO, a compact, heat efficient pyrolysis technology that converts biosolids into biochar. The collaboration began as a 'plan B' response to tightening expectations around PFAS in biosolids and the potential constraints on land application under evolving national guidance. PYROCO emphasises high internal heat transfer efficiency and a reactor train with few moving parts, aiming to simplify maintenance and enable modular deployment at utility scale.

**BENEFITS**

- Indicative PFAS destruction – through the samples taken and analysed, PFAS levels in all biochar samples were below detection limits.
- Compact footprint (pilot plant ~3 × 4 m) and increased automation, including continuous char removal and cooling.

**How it works**

In the PYROCO configuration, dried biosolids are heated at about 550–600 °C in a near oxygen free fluidised bed pyrolyser supported by a gas producer. Off gas passes to a vertical thermal oxidiser (~850–900 °C, ~2 s residence time) for final polishing and then subbed before release. PYROCO's internal heat transfer is designed to be 'hyper efficient', supporting an aim of largely autothermal running once at temperature (actual energy balance depends on feed solids and calorific value). Pilot scale capacities were ~20 kg/h (Mark 1) and ~25 kg/h (Mark 2).

**Status & what's next**

Planning is underway for a larger scale fully integrated demonstration plant with the support of an Australian Government CRC-P grant to validate operability, emissions and financial viability at a commercial scale. South East Water's commercial arm, Iota, is in the planning phase to establish a delivery model and partners to further explore opportunities for PYROCO's future availability in the Australian water sector. The planned fully integrated and automated demonstrated plant will include scale-up guidelines for larger facilities. The integrated Jumbo Dryer has a range of standard sizes to support expansion. The fluid bed design's ability to scale to the required throughput is seen as a key benefit of the solution.



**BIOSOLIDS GASIFICATION FACILITY (QLD)**

LOGAN CITY COUNCIL



Logan City Council has moved from long-distance trucking of dewatered biosolids for land application to an onsite thermal conversion pathway at Loganholme WWTP. The full-scale facility, now commissioned and being optimised, integrates belt drying with a rotary hearth gasifier, followed by a thermal oxidiser and wet-end emissions polishing. The goal is to cut logistics, stabilise contaminants of concern, and produce a consistent biochar while tightly integrating heat within the process. The change was driven by escalating haulage costs, exposure to fuel and electricity prices, and community expectations around pollutants such as PFAS and microplastics. Historically, the plant generated about 34,000 t/yr of dewatered biosolids (≈90 t/d), requiring ~300 km road transport (≈ 6 trucks/day) and contributing roughly A\$5M/year to operating costs (≈30% of WWTP OPEX).



**BENEFITS**

- ~90% reduction in biosolids volume, meaning far fewer truck movements.
- Demonstration program indicated ~80% heat energy neutrality; full-scale optimisation is ongoing.
- PFAS destruction detected in the exhaust stream (test data); microplastics reduced by ~82% across the process (demonstration result).
- Indicative climate and cost signals: about 4,800 tCO<sub>2</sub>e/yr lower emissions and ~A\$1.4 M/yr OPEX savings (based on only 44% of site solids being processed via gasification) versus the former haul and land apply model.

**How it works**

Centrifuges deliver sludge at ~22% DS to thermal belt dryers, which raise solids to ~90% DS using recovered process heat. Dried pellets enter the gasifier (~600 °C, low oxygen) to produce a combustible gas that is fully oxidised in a thermal oxidiser. Recovered heat goes back to the dryers to minimise net energy draw. Downstream, a wet scrubber (including Mg(OH)<sub>2</sub> for SO<sub>2</sub> control) and wet electrostatic precipitator polish emissions, with continuous monitoring on the stack. Site electricity is supported by an onsite ~1.1 MW solar array.

**Status & what's next**

The plant predominantly meets licence conditions; Logan is working with the regulator on optimisation to achieve consistent compliance under all operating states. The biochar is positioned as a potential GradeA product with prospective uses in potting mixes and as a soil conditioner (market development is active and jurisdiction-specific). Efforts are focused on optimising processes to improve equipment utilisation and deliver greater operational expenditure benefits.



**RECOMMENDATIONS AND NEXT STEPS**

**Maintain viable land application while planning for constraint**

Support the continued use of land application where PFAS NEMP 3.0 limits and other contaminant controls can be met, while developing adaptive transition plans for constrained or lost land application scenarios.

**Primary responsible stakeholders**

- **Lead:** Environment regulators
- **With:** Water utilities, WSA and ANZBP (coordination and knowledge-sharing)

**Key actions**

- Coordinate a national program of field trials to generate consistent, locally relevant data on PFAS mobility and accumulation in soils and crops under different biosolids applications.
- Develop a standardised framework for designing, monitoring and reporting these trials, enabling jurisdictional, national (Australia and New Zealand) and international comparability.
- Use this evidence base to inform environmental regulators' margin-of-safety decisions under PFAS NEMP 3.0 and any future revisions, with transparent alignment to food safety and community risk outcomes.

## Strategic transition and adaptive pathway planning for biosolids

Develop a coordinated, sector-wide transition program that

- 1 embeds adaptive and scenario-based biosolids planning across all utilities,
- 2 builds robust and sustained markets for current and emerging biosolids-derived products, and
- 3 establishes a national resource recovery and biorefinery roadmap to guide long-term circular economy outcomes and investment decisions.

### Key actions

- Support utilities to incorporate constrained reuse scenarios—such as tightening PFAS limits or loss of land access—into all biosolids strategies, clearly identifying pivot points that trigger movement from land application to advanced thermal conversion (ATC) or other non-biosolids-generating pathways.
- Develop a coordinated strategy for biochar, biocrude, mineral residues, energy products and fertiliser alternatives, ensuring strong market pull to support investment in high carbon value and circular products.
- Establish product specifications, certification schemes and end-of-waste criteria in collaboration with regulators, standards bodies and industry partners to reduce uncertainty and build customer confidence.
- Identify and engage priority sectors (agriculture, construction, fuels, energy, carbon markets) to secure demand, create term offtake agreements and define viable value chains.

### Primary responsible stakeholders

- **Lead:** WSAA
- **With:** Water utilities, WaterRA, ANZBP, local and state planning agencies, state/territory environmental regulators, related sector association bodies (ANZBIG, Bioenergy Australia, ACOR); standards bodies



## Align policy and regulation for non-biosolids-generating approaches

Clarify and streamline regulatory pathways for ATC and incineration, including licensing of treatment processes, end-of-waste determinations for outputs, and consistent environmental controls, to reduce uncertainty and unlock investment.

### Primary responsible stakeholders

- **Lead:** State/territory and national environmental regulators, with relevant environment/energy departments
- **With:** WSAA, ANZBP (sector input); water utilities (pilots and evidence); standards bodies

### Key actions

- Develop nationally consistent guidance where possible on how thermal processes are classified, licensed and assessed, including alignment of waste-to-energy policies, thermal treatment definitions, and PFAS destruction requirements.
- Establish clear criteria and processes for end-of-waste and product approvals for biosolids-derived char, fuels and residues, harmonising expectations across jurisdictions to avoid fragmented markets.
- Provide regulatory guidance on monitoring, emissions limits and operational controls for ATC and incineration, drawing on EU IED and other international best practice, while aligning with circular economy policy and avoiding lock-in to pure disposal pathways.

## Coordinate innovation and knowledge-sharing across the sector

Establish an ongoing, sector-wide innovation and knowledge program on biosolids and ATC, to systematically track technology maturity, reference sites, regulatory experience and market developments, and to close the readiness gap identified in the report.

### Primary responsible stakeholders

- **Lead:** WSAA, WaterRA and ANZBP
- **With:** Utilities; research organisations; regulators; technology providers

### Key actions

- Maintain and periodically update the evaluation framework as new data on costs, environmental performance, deployment experience and markets becomes available, including new reference facilities in Australia, New Zealand and overseas.
- Form international alliances (e.g. via Global Water Research Commission) to share learnings across international jurisdictions that may be further advanced in ATC deployment and sustainable aviation fuel (SAF) markets.
- Document case studies of pilots, regulatory pathways and market arrangements (e.g. SAF initiatives, biochar trials) to accelerate learning and avoid duplication.



## GLOSSARY

### A–B

**Aqueous Liquors:** Liquid streams generated from biosolids processing (e.g., dewatering liquors, condensate, or effluent from thermal processes). These typically contain elevated ammonia, COD and solids, and are usually returned to the wastewater treatment plant for further treatment.

**Anaerobic Digestion (AD):** A biological process that breaks down organic material in the absence of oxygen, producing biogas and stabilised biosolids.

**ANZBP – Australia & New Zealand Biosolids Partnership:** A collaboration supporting research, guidance and sector knowledge-sharing on biosolids management.

**ATC – Advanced Thermal Conversion:** Thermal processes such as pyrolysis, gasification and hydrothermal liquefaction that convert biosolids into energy products and stable residues. **Beneficial Use:** The reuse of biosolids or derived products in ways that improve soil quality, support agriculture, or deliver other environmental or economic benefits.

**Biochar:** A stable, carbon-rich solid produced from pyrolysis of biosolids, used as a soil amendment or construction input.

**Biocrude:** A liquid fuel precursor produced via hydrothermal liquefaction, potentially refinable into sustainable aviation fuel.

**Biosolids:** Treated sewage sludge stabilised to reduce pathogens and odour, suitable for beneficial reuse.

**Biogas:** Methane-rich gas produced through anaerobic digestion, used for heat and electricity generation.

**Biomethane:** Upgraded biogas that meets gas-grid quality requirements.

### C–O

**Capital Expenditure (CAPEX):** Upfront investment required to construct or upgrade biosolids treatment infrastructure.

**Circular Economy:** An economic model focused on keeping resources in use and minimising waste.

**Composting:** A biological process producing a stable soil conditioner from biosolids mixed with organic carbon sources.

**Contaminants of Emerging Concern (CECs):** Substances such as PFAS or microplastics requiring evolving monitoring or regulatory oversight.

**Drying (Thermal Drying & Pelletisation):** Processes that reduce moisture to create transportable products or solid fuels.

**End-of-Waste Determination (EoW):** A regulatory decision defining when a processed material is no longer considered waste.

**Environmental Outcomes:** The environmental impacts, positive or negative, associated with a biosolids management approach.

**Gasification:** A high-temperature conversion of biosolids into syngas and mineral residues.

**Hydrochar:** A solid product created through hydrothermal carbonisation.

**Hydrothermal Carbonisation (HTC):** A wet-thermal process producing hydrochar and aqueous liquors.

**Hydrothermal Liquefaction (HTL):** A process that converts biosolids into biocrude, aqueous liquors and solid residues.

**Incineration:** Complete combustion of biosolids, producing heat and ash.

**Lagoons:** Basins for long-term stabilisation and dewatering of sludge.

**Land Application:** Applying biosolids to agricultural land or rehabilitation sites.

**Mesophilic Digestion (MAD):** Anaerobic digestion operated at moderate temperatures (~35°C).

**Microplastics:** Small plastic particles (<5 mm) present as residual contaminants in biosolids.

**Monofill:** A landfill accepting only biosolids or similar sludges.

**Net Zero Alignment:** The contribution of an option to emissions reduction, carbon sequestration or renewable energy.

**Off-take / Off-take Market:** End-users or markets accepting biosolids-derived products.

**Operational Expenditure (OPEX):** Ongoing operational and maintenance costs.

## P-W

**Pathogen Reduction:** Treatment processes that reduce disease-causing organisms to meet regulatory standards.

**PFAS – Per- and Polyfluoroalkyl Substances:** A persistent group of synthetic chemicals monitored under PFAS NEMP 3.0.

**PFAS NEMP 3.0:** Australia's national guidance setting PFAS limits and requirements for biosolids.

**Phytoremediation:** Use of plants to stabilise or transform contaminants.

**Pyrolysis:** Thermal decomposition of biosolids without oxygen, producing biochar, syngas and oils.

**Quadrant Analysis:** A two-axis visual tool showing relative viability and ease of implementation.

**Reed Beds:** Passive systems where planted wetland cells dewater and stabilise sludge.

**SCWO – Supercritical Water Oxidation:** A process using supercritical water to oxidise organic matter.

**Social Licence:** Community acceptance enabling a project or activity to operate with trust and support.

**Solar Drying Beds / Greenhouses:** Low-energy systems using heat and airflow to dry biosolids.

**Stabilisation:** Processes reducing pathogens, odour and vector attraction.

**Syngas:** Combustible gas produced via pyrolysis or gasification.

**Thermal Conversion:** High-temperature processes transforming biosolids into energy and residues.

**Thermal Hydrolysis:** A high-temperature pre-treatment enhancing digestibility.

**Viability (Overall Viability):** A combined measure of environmental, market, financial and social performance.

**WAO – Wet Air Oxidation:** Oxidation of biosolids at elevated temperatures and pressure.

**Weighted Outcomes:** Combined scores reflecting relative importance of evaluation criteria.

**WWTP – Wastewater Treatment Plant:** A facility treating sewage to produce effluent and biosolids.



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## Appendix 1

# Market potential for products derived from biosolid management approaches

The biosolids management approaches assessed in this report produce a variety of outputs, including solids, liquids, and gases. This section provides a brief overview of the current market situation in Australia and New Zealand and outlines important factors for each type of output. While it is not a full market analysis, the section considers the main steps needed to support the proposed uses of these residuals.

## Biosolids

### Market position and forms

Biosolids are produced in a range of qualities and formats, which strongly influences market appetite. Stabilised, higher-quality products—especially those processed to be user-friendly (e.g. pellets)—are more desirable for off-takers and support sustained land application where quality requirements are met.

### Alternative outlet (solid fuel)

Thermal drying and pelletisation can enable use as a biogenic fuel (e.g. cement kilns), but this market is not yet well developed in Australia. Viability depends on proximity to appropriate industrial off-takers, willingness to accept waste-derived fuels, and consistent product quality (often requiring pelletisation). Off-taker decarbonisation drivers are the main determinant of interest, so identifying target sectors and sites is the critical first step.

### Regulatory uncertainty (PFAS NEMP 3.0)

The introduction of PFAS NEMP 3.0 organics limits has created jurisdiction-level uncertainty. Impacts will vary depending on each regulator's risk judgment and the size and flexibility of a utility's available landbank. Continued research on PFAS mobility and materiality is central to regulator decisions on risk levels and, therefore to the ongoing viability of land application.

### Market maturity

Overall, biosolids land application is a mature route but will require ongoing research and adaptive management to remain viable under evolving regulatory settings.

## Biogas (and biomethane)

### On-site energy generation (mature)

Biogas produced from digestion is commonly used for combined heat and power (CHP), generating heat and electricity for on-site use, with export contingent on grid capacity. This is a mature pathway across Australia and New Zealand.

### Local off-take by pipeline

Supplying adjacent off-takers by pipeline can be viable where distances are short, as proposed (e.g. Wodonga WWTP hydrogen plant concept). Success depends on co-location and shared resource exchange.

## Biogas (and biomethane)

### Primary use-cases

- *Soil amendment (closest to deployment)*. Widely adopted internationally; in Australia, regulatory frameworks are maturing rapidly and are expected to improve deployability as they crystallise. Benefits include soil carbon, water retention and slow-release nutrients.
- *Aggregates/concrete (fast-developing)*. Research and industry activity align the sequestration value of biochar with aggregates decarbonisation needs. Queensland's end-of-waste code signals fewer regulatory hurdles compared with direct land application, but commercialisation requires proving no adverse effects on material performance and building off-taker confidence through co-developed blends.

### Other pathways (early-stage)

Adsorbents, activated carbon, AD additives and battery materials hold potential but remain undeveloped for sewage-sludge biochar in Australia and New Zealand; further primary research and regulator/off-taker collaboration are needed.

## Syngas and pyrolysis oils/tars

### On-site use is primary (mature internally)

In pyrolysis/gasification systems, syngas and volatilised oils are typically combusted to supply process/drying heat, with any surplus used in CHP to generate electricity. This internal energy integration is common and considered a mature off-take—but chiefly for internal use.

### Efficiency note

Electrical efficiency of syngas in CHP is lower than biogas, but it provides a flexible outlet after process heat needs are met.

### Upgrading to biomethane (under development)

Upgrading is established internationally but deploys widely only where grid injection is permitted. A New Zealand example is planned at Manawātū WWTP; in Australia, grid injection is not yet permissible, though projects such as Malabar (Jemena) are advancing the pathway. Accordingly, the market is under development.

### Key enabler

Continued engagement with gas network operators on biomethane injection, supported by agreed gas quality protocols aligned to international practice, is pivotal to unlock larger markets. WSAA supporting Bioenergy Australia in the development of the first National Bioenergy Feedstock Strategy in recognising biomethane as a low-carbon, renewable gas.

### Base-case assumption for evaluation

Biochar applied to land as a soil amendment; unit value is uncertain and reflected accordingly in scoring.

### External off-take (undeveloped)

Tanker off-take is not practiced for biosolids-fed ATC facilities; given dryer energy demands and modest surplus, an external syngas market is unlikely to be material for utilities.

### Base-case assumption for evaluation

All syngas/volatilised oils are combusted on-site; any excess electricity offsets on-site wastewater assets rather than being exported.

## Ash and mineral residues

### Landfill disposal (mature)

Incinerator ash is commonly landfilled and can attract lower gate fees where it serves capping/mixing functions. This route is mature in many Australian jurisdictions and in New Zealand (for existing facilities).

### Land application (maturing, jurisdiction-specific)

Some facilities (e.g. ICON Water's Lower Molonglo) have progressed agri-ash application; however, wider deployment would require further regulatory and market development, extensive characterisation and case-by-case risk assessment due to ash composition.

### Base-case assumption for evaluation

Landfill disposal for incinerator ash and ATC mineral residues, noting limited precedent for other uses domestically.

### Aggregates (precedents exist, but volumes limited)

Ash incorporation in concrete/blocking has more precedent than for biochar, yet volumes often fall short of total production and may incur gate fees as ash lacks the carbon sequestration value that incentivises biochar uptake. With few sewage-sludge incinerators in Australia, this remains undeveloped; any future facility would need firm off-take commitments that beat landfill economics.

## Hydrochar (from hydrothermal carbonisation)

### Solid fuel route (potential, but undeveloped locally)

Hydrochar retains much of the feedstock's chemical energy and can serve as a solid fuel, offering an alternative to dried biosolids pellets. Viability depends on proximity and an off-taker willing to accept waste-derived fuel. The route exists at small scale in Europe but is undeveloped in Australia.

### Soil application (challenging)

Hydrochar differs materially from biochar in stability, adsorption and ion-exchange characteristics; combined with limited evidence of PFAS/microplastics risk reduction, this pathway has gained less traction and remains undeveloped in Australia and New Zealand.

### Base-case assumption for evaluation

Hydrochar is modelled as a solid fuel outlet with the revenue question treated via confidence grading (recognising potential lower barriers than land application with respect to contaminants).

## Biocrude (from hydrothermal liquefaction, HTL)

### Strategic context

HTL has attracted significant interest as a potential feedstock for Sustainable Aviation Fuel (SAF) and other refinery products. While the global and Australian SAF feedstock markets are developing, the value chain (collection, transport, refining capacity, certification) must align for deployment at utility scale. The UK's progress is notable, but Australian/NZ replication faces logistical and feedstock differences (e.g. reliance on digestate in proof-of-concepts and shorter UK distances).

### Base-case assumption for evaluation

Biocrude is assumed to be sold to a refinery and upgraded into SAF given its higher value-add and the global shortage of suitable feedstocks.

### Aqueous liquors (cross-cutting output)

Most approaches generate aqueous-phase liquors (e.g. dewatering liquors, dryer condensate, effluent from wet-processing ATC). Compositions vary, but typically feature elevated ammonia, COD and suspended solids. The base assumption is return to the co-located WWTP for treatment (with or without dedicated pre-treatment, depending on risk to the WWTP), and this has been reflected in the quantitative assessments.

### Regulatory pathway

Standards for biofuels made from other feedstocks provide reference points; for utility-grade deployment, biocrude must be refined to meet fuel performance criteria and secure laboratory certification for end-use approval. Direct combustion as a waste-oil remains undeveloped locally and will require use-case development and clarification of applicable regulatory regimes.



**Appendix 2**  
**Quadrant development, rationale and conversion**

The quadrant graphic is based on two key dimensions:

- **X-Axis: Ease of Implementation**
- **Y-Axis: Overall Viability**

These axes were derived by synthesising and re-weighting the original evaluation framework into two practical, strategic categories that resonate with utility executives and planners.

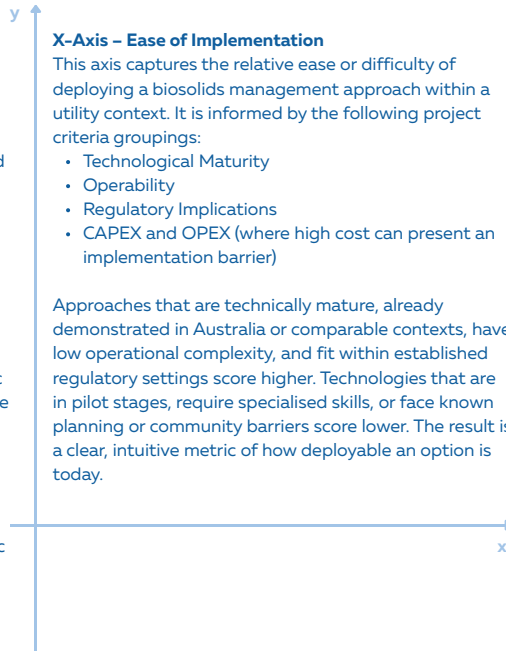
**Y-Axis – Overall Viability**

This axis reflects the long-term sustainability, value and benefit of each option. It consolidates multiple project evaluation groups:

- Environmental Impact (Treatment and Use Case)
- Net Zero Alignment
- Revenue Generation Potential
- Social and Governance Implications
- Ease of Market Outlet

A high score indicates a solution with strong environmental outcomes, favourable carbon implications, economic returns or cost-effectiveness, and positive market and community alignment. Lower scores reflect options with minimal benefit, uncertain markets, or high environmental and financial burdens.

This axis therefore reflects both economic and societal value and the solution's ability to contribute to the circular economy, net zero goals, and long-term resilience.



**X-Axis – Ease of Implementation**

This axis captures the relative ease or difficulty of deploying a biosolids management approach within a utility context. It is informed by the following project criteria groupings:

- Technological Maturity
- Operability
- Regulatory Implications
- CAPEX and OPEX (where high cost can present an implementation barrier)

Approaches that are technically mature, already demonstrated in Australia or comparable contexts, have low operational complexity, and fit within established regulatory settings score higher. Technologies that are in pilot stages, require specialised skills, or face known planning or community barriers score lower. The result is a clear, intuitive metric of how deployable an option is today.

**Score Conversion Process**

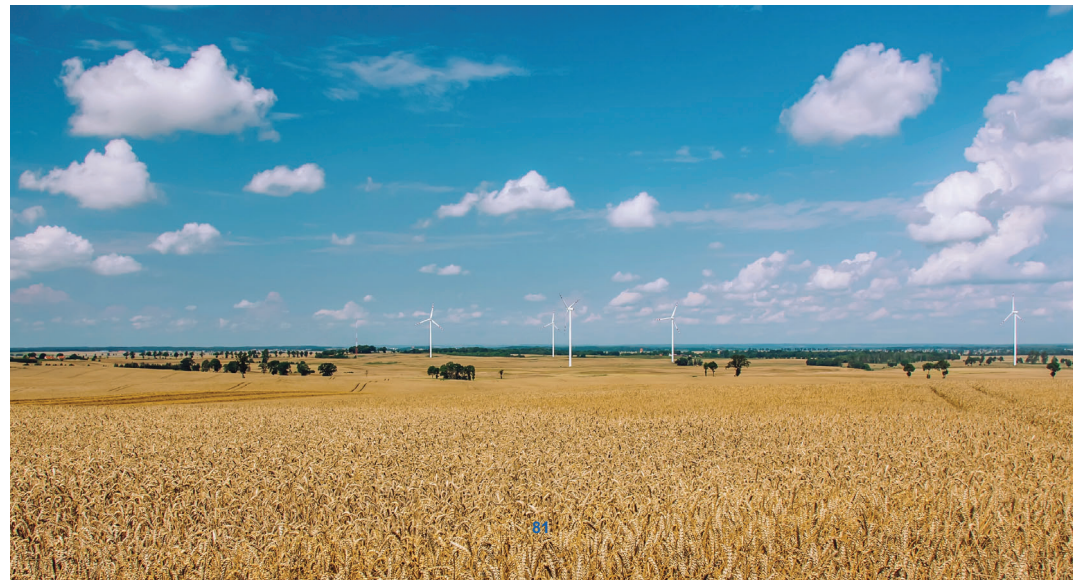
Each of the 20 biosolids management options evaluated in the project report was assessed against the original weighted criteria, and qualitative and quantitative insights were drawn from the evaluation results, including:

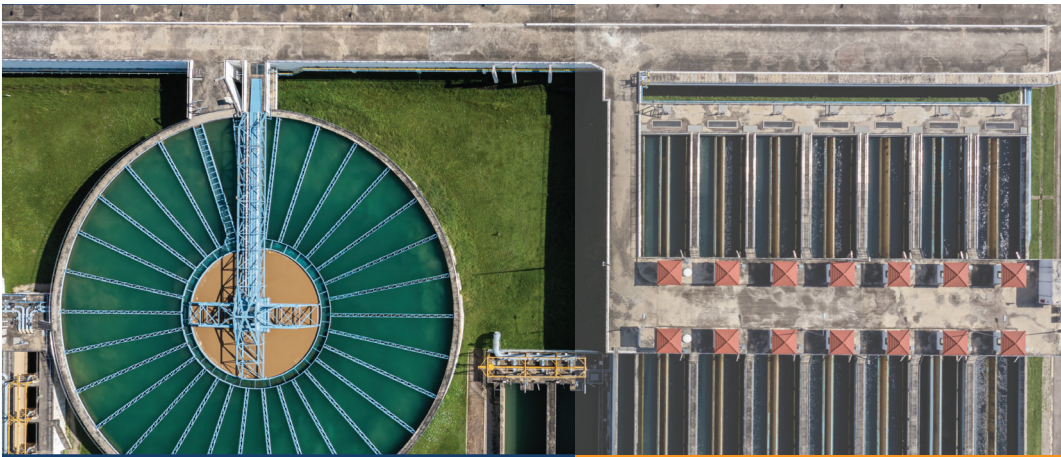
- Commentary on technological readiness
- Market maturity of outputs (e.g., biochar, dried pellets)
- CAPEX/OPEX sensitivity analyses
- Environmental sustainability narratives

These insights were translated into a simplified **1 to 5 scale** for both axes:

Score	Ease of Implementation	Overall Viability
5	Proven, ready to deploy with minimal hurdles	Strong benefits, market-ready, net zero-aligned
3	Moderate complexity, partial maturity	Mixed benefits, moderate or uncertain returns
1	Experimental, complex or faces major barriers	Low value, high cost, unclear outcomes

This scoring approach allowed for visual mapping of 10 options across the four strategic quadrants: high/low viability versus easy/hard to implement for the two scenarios as shown in Figures 11 and 12 of the report.





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