WEIGHING UP THE OPTIONS: ADDRESSING UNCERTAINTY FOR THE SUSTAINABLE MANAGEMENT OF BIOSOLIDS

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ABSTRACT

In this collaborative study, established and emerging biosolids management solutions were explored. Utilities are increasingly required to navigate complex and shifting conditions, from evolving regulations and public expectations to market volatility and emerging contaminants. To support robust decision making, this project developed a Sustainable Biosolids Management Assessment Framework, enabling utilities to weigh up management options across plausible futures. The framework empowers utilities to build resilience and maximise the long-term value of biosolids in supporting a circular, low-carbon future.

INTRODUCTION

The Australian and New Zealand water sectors face regulatory uncertainties surrounding contaminants of emerging concern that may be present within sewage sludge. These include the broad family of Per- and Polyfluoroalkyl Substances (PFAS) which do not degrade in the environment, alongside other organic pollutants and microplastics. This is driving the need for a strategic review of the future of biosolids management, which also needs to consider societal concerns, climate variability, capital constraints and rising operational costs. These challenges have led to considerable innovation in biosolids management, which could unlock a variety of sustainable processes and novel outputs.

Recognising the importance of sustainable biosolids management, the Water Services Association of Australia (WSAA), in consultation with the Australian New Zealand Biosolids Partnership (ANZBP), proposed the development of a Sustainable Biosolids Management Assessment framework. The aim of this framework is to support decision making relating to the future of biosolids management.

The scope of this project was to review and document a range of established and emerging biosolids management approaches, and to develop an evaluation framework which enables a comparative assessment of each approach.

The overarching goal of this project was to empower stakeholders to make informed decisions that address the challenges faced by the Australian and New Zealand water sectors, individual utilities and their communities, whilst maximising the sustainable benefits from biosolids. The work undertaken in this project has been developed to aid decision making and provide strategic level insights and guidance for the Australian and New Zealand water sectors.

AtkinsRéalis were engaged by WSAA to lead the development of this framework, and followed a highly collaborative process involving utilities, regulators and other stakeholders from across Australia and New Zealand. Thirteen water utilities participated as project stakeholders, with each providing a representative for the Project Advisory Group (PAG). The PAG met frequently throughout the project to ensure that water utilities were able to influence the outcome of the project and that the framework remained aligned with water sector priorities.

The resulting framework developed via this project identifies preferential approaches for both the near- and long-term, balancing the potential to adapt to the challenges of the future against the practicalities of deployment for WSAA and ANZBP's member utilities.

METHODOLOGY

This highly collaborative project was delivered across six tasks, each of which is described in the sub-sections below.

Task 1 – Situational Awareness

Ensuring that water utilities participating in the project were brought along for the journey as the evaluation framework was developed was crucial for successful outcomes. As such, a strong emphasis was placed on collaboration and co-creation with WSAA and other stakeholders throughout the project. A Project Advisory Group was set up by WSAA to provide leadership and support with engagement activities.

Task 1 focussed on interactive workshops and water utility 1-1 interviews to enable the development of situational awareness specific to the Australian and New Zealand context and to ensure strong alignment across all stakeholders.

Through these 1-1 interviews and the initial stakeholder workshop, the biosolids management approaches for evaluation during the project were collaboratively selected. Recurring themes that were raised across the interviews and in the workshop are illustrated in the word-cloud shown in Figure 1.

Task 2 – Options Review and Best Practice Analysis

Based on insights from Task 1, a comprehensive list of biosolids management approaches was developed. This was refined following feedback from WSAA and the Project Advisory Group to produce a finalised list of 20 biosolids management approaches to be explored as part of this project. These are shown in Figure 2.

The AtkinsRéalis team developed one-page summaries for each of the 20 collaboratively selected approaches (see Figure 3). These were designed to enable a high-level comparative assessment of each approach during the evaluation stage. Their development draw on global technological, market and regulatory insights, and focussed not only on the technical details of each biosolids management approach, but importantly on the fate of biosolids and the main outputs recovered via each approach. This task also included a deep-dive regulatory review to identify current and emerging compliance requirements.

Task 3 – Evaluation Criteria Development

A second workshop was held with participating utilities, where drivers were collaboratively defined. These drivers were used to develop the evaluation criteria for the framework.

A wide range of criteria were developed to enable a comparison and evaluation of the biosolids management approaches documented in Task 2. The 11 criteria selected were categorised into four groups: Environment, Cost & Value, Deployment and Off-Take Market. Each of the finalised 11 criteria were comprised of detailed sub-criteria which were used for scoring. The groupings, criteria and sub-criteria are shown in Figure 4.

With the criteria defined, weightings were applied to each. The weightings used are a critical component of the evaluation framework, enabling the outcomes to be tailored to the unique drivers, priorities and ambitions of water utilities and stakeholders across Australia and New Zealand. To ensure these were reflected in the outputs of this project, the weightings were developed through multiple iterations and refined with feedback from the Project Advisory Group to ensure they were fit for purpose.

Task 4 – Initial Evaluation

Each of the 20 biosolids management approaches selected in Task 2 were evaluated against the criteria developed in Task 3. The initial results from this evaluation were discussed at a workshop with project stakeholders and feedback was used to refine the evaluation outputs.

In order to develop an overall score for each of the management approaches, each of the sub-criteria were scored on a 1-5 scale, with clearly-defined scoring definitions for each sub-criterion. These scores were rolled up into an overall score for each criterion, and the weightings were then applied for each of the criteria in order to generate an overall, aggregate score for each management approach. The outcome of this assessment was tested with project stakeholders such that feedback could be incorporated into the final output.

Furthermore, to offer a forward-looking perspective and highlight potential future developments, sensitivity analysis was performed to present a high-level forecast of emerging issues and opportunities.

Task 5 – Final Report Drafting

A final report summarising the collaborative approach, case studies, one-page summaries, methodology, evaluation outcomes and scenario analysis was produced.

Throughout the course of the project delivery, technical memoranda were submitted to WSAA and provided to the Project Advisory Group members, summarising key tasks (1, 2 and 3). As a result, the draft version of the final report contained no surprises to WSAA or the participating utilities. Stakeholder feedback on the draft version of the report was provided and addressed in the final version of the report.

Task 6 – Industry Dissemination Webinar

The key outcomes of the project were presented to the wider industry via a webinar to close out the project, enabling both dissemination of the results but also an opportunity for engagement with wider industry stakeholders and consideration of next steps and application of the findings.

DISCUSSION AND RESULTS ANALYSIS

Following the methodology outlined in the previous section, an overall scoring profile was developed as shown in Figure 5. This figure shows a clear tier-break between the more established management approaches used in Australia and across the world, and emerging Advanced Thermal Conversion (ATC) processes.

The key premise for these overall scores is that biosolids application to land is still manageable within the PFAS National Environmental Management Plan (NEMP) Version 3.0, Australia's nationally agreed guidance on the management of PFAS contamination in the environment, which was the cautious view provided in many participating utility 1-to-1 interviews at the commencement of the project. The outcomes of this assessment consequently show that where the NEMP 3.0 limits can be complied with, the generation of biosolids for land application is still the best approach most strongly aligned with utilities' overall objectives. However, the view that NEMP 3.0 is compatible with continued biosolids application to land was by no means a unanimous consensus when discussed in 1-to-1 interviews, meaning alternative approaches require investigation and scrutiny.

When filtering the rankings to include only the management approaches capable of either degrading PFAS or generating outputs that do not require land application, this throws the relative ATC rankings into sharper focus (Figure 6).

The resulting filtered list is understandably smaller, and whilst incineration scores the highest, its applicability to the Australian and New Zealand context is doubtful for many utilities. Incinerators require a significant feedstock quantity to be viable (ideally over 30,000 tonnes of dry solids per year (TDS/y)), a policy framework that promotes energy-from-waste solutions, and an acceptance of disposal outlets for the ash as a worst case position. This has meant in practice that global uptake of incineration has been mixed, with whole countries either embracing or rejecting this approach previously, and only facilities serving larger urban centres are likely to be economically viable.

Consequently, the next-highest scoring alternatives such as gasification and pyrolysis are therefore priorities for developing a viable alternative to land application. Both score lower due to uncertainties around the outlet for the chars they produce, and resolving these uncertainties is essential for utilities' ability to deploy them in the future at full-scale. Other ATC solutions such as Hydrothermal Liquefaction (HTL) produce a biocrude output that have unknown downstream fate implications for contaminants such as PFAS. Further investigation into these fate pathways is needed to develop these options further. It is of note that HTL scores lower than char-forming ATC technologies largely due to the substantial downstream infrastructure and value-chain that is required to develop a market-ready output. This is currently in development in the UK but its absence in Australia and New Zealand is reflected in the scores generated.

Overall, the scoring reflects the current position of biosolids in Australia and New Zealand: where PFAS limits can be complied with biosolids generation and land application is still preferable. However, when this causes landbank constraints or market pinch points, the char-forming ATC solutions are preferable for the majority of utilities' scale of sites.

Beyond the filtering of the initial output as described above, further sensitivity analysis was conducted to test the results under potential futures. One of the scenarios tested was the possible near-term scenario for utilities where there is a loss of access to agricultural land for biosolids application, without the sufficient lead-time to construct the infrastructure assets required for an alternative management approach. In such cases, the biosolids produced would require an immediate disposal outlet, such as landfill.

Figure 7 illustrates the impact this scenario has on the scoring and ranking of the 20 assessed biosolids managemnet approaches. This shows the consequences of all biosolids production incurring landfill disposal fees at the same rate per tonne as incinerator ash and the 'Environmental' and 'Off-Take and Market' scoring reflecting the use of landfill. Landfilling of biosolids presents several challenges that make it impractical for many of these Management Approaches. This includes issues such as the relationship between the acceptable water content and ignition risks in feedstocks. Additionally, disposing of organics in landfills is widely regarded as undesirable from a sustainability perspective because of the loss of valuable nutrients that could otherwise be recovered and which conflicts with circular economy objectives.

The scores in Figure 7 show a flatter overall profile than in Figure 5, with the viability of approaches that generate biosolids reduced to a similar level to those for ATC technologies. It is notable that the three high Technology Readiness Level (TRL) solutions from Figure 6 (Incineration, Pyrolysis and Gasification) are also the top three in this scenario.

When considered alongside the potential for ATC technologies and markets for outputs to evolve and improve their overall performance and hence scoring, this illustrates why a biosolids-to-landfill approach is unlikely to be the most effective or optimal strategy to pursue. The technologies that produce smaller residual masses are favoured in this scenario, and so these would be the most viable in the event a utility is forced into utilising landfilling at short notice whilst still implementing an alternative approach. Among the approaches that produce treated biosolids, this resilience makes those approaches that result in a lower mass residual more desirable for implementation in the near-term.

CONCLUSION

The results show a clear picture of where the water industry stands today, under current conditions. However, it is also clear that there is no one-size-fits-all solution and the sector is facing a landscape of trade-offs that will change materially with regulatory and market conditions.

Under current conditions, the best performing ways to manage biosolids are those that convert them to safe products to use on land. These management approaches include 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 (e.g. pyrolysis and gasification), 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 (e.g. biochar etc.).

However, shifts in the regulatory environment significantly impact the outcome. 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 increase.

In addition to the key conclusions noted above, a number of other conclusions, recommendations and proposed next steps are summarised below.

- Biosolids are intrinsically valuable and play an important role in enabling a circular economy.
- Emerging technologies offer the potential to generate even more valuable resources from biosolids.
- Regulatory, technological and market challenges exist, and in order to address these challenges, collaboration and policy development are needed.
- There is a need to understand the actual risks associated with contaminants of concern on a more granular, local level, to help inform selection of the appropriate approach at a utility level.
- The optics and policy alignment of incinerators limit its practical deployability. This is also of concern for other thermal processes.
- Early engagement with a representative group of local, state and national government agencies on the preferred “Plan B” should biosolids no longer be applicable to land needs to be conducted.
- The scientific evidence for biochar use-cases is extensive; however, the market appetite is still unclear. If biochar markets don’t develop, utilities may be left with a high-cost technological solution paired with a high-cost outlet.
- Biochar market development and industrial off-taker engagement at a sector level is required nationally to help utilities target their local efforts.
- The development of ATC technologies beyond pyrolysis and gasification (e.g., HTL, Super-Critical Water Oxidation etc.) could be accelerated by national R&D funding.

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REFERENCES

2025. Weighing up the Options: Sustainable Biosolids Management Across Australia & New Zealand, Water Services Association of Australia, VIC, Australia.

Figure 1: Word-Cloud Representing Key Themes Raised During the Situational Awareness Phase

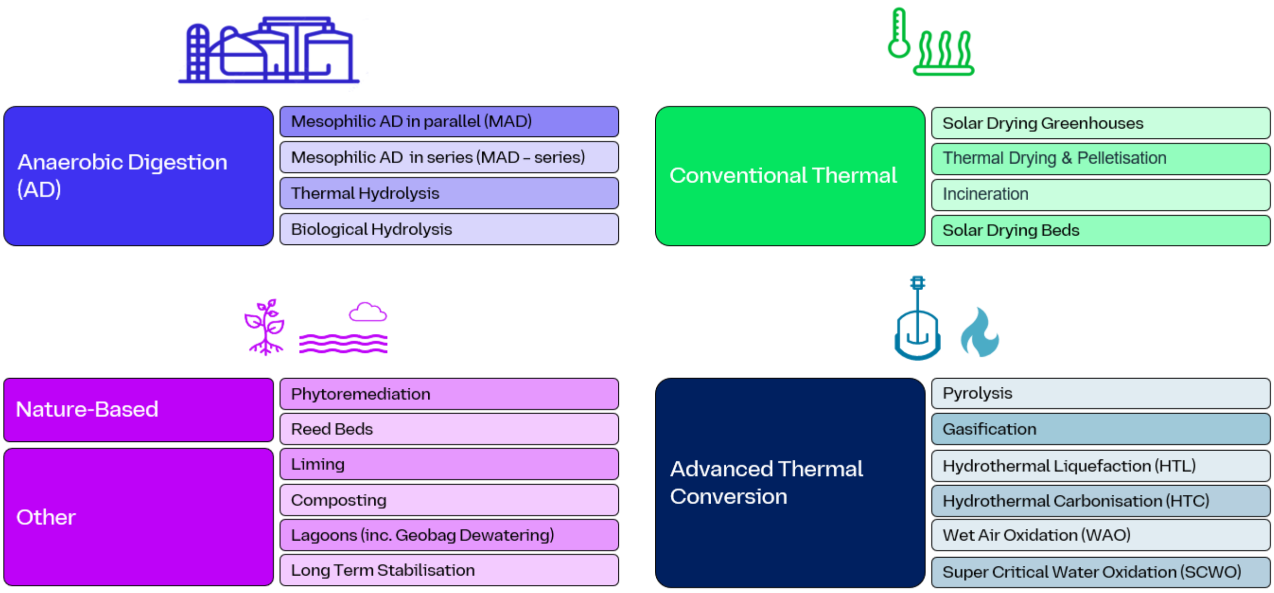

Figure 2: The 20 Biosolids Management Approaches Assessed throughout the Project

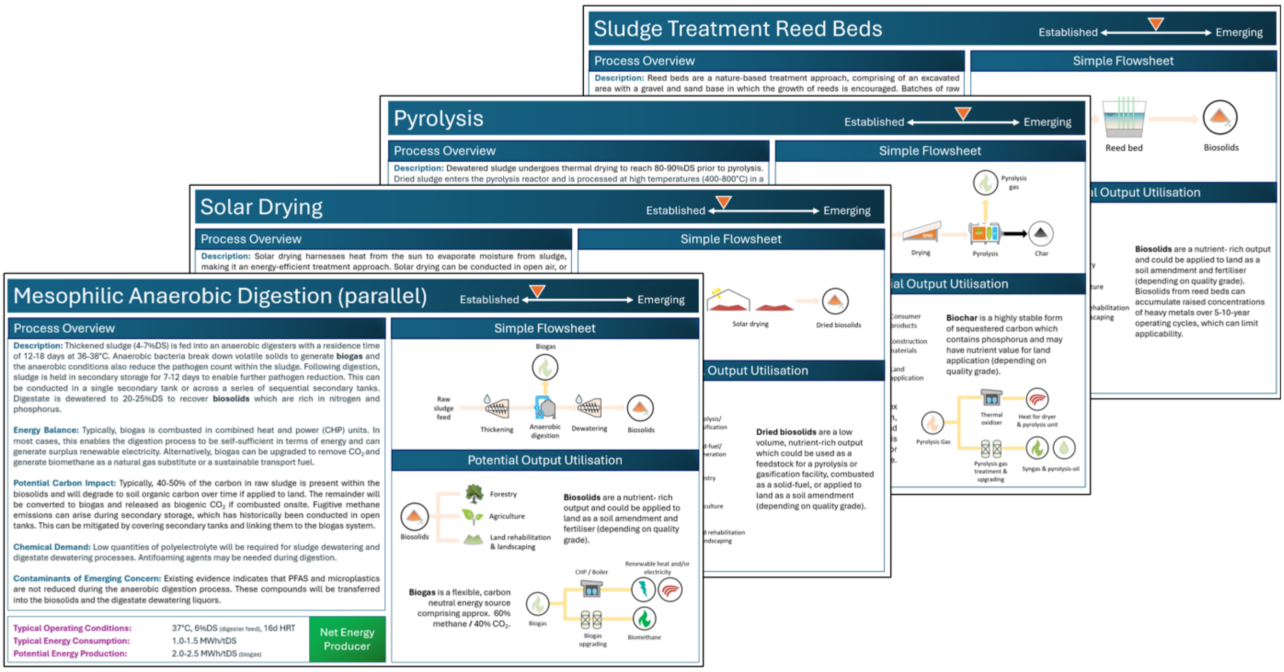

Figure 3: Examples of the One-Page Summaries Produced for each of the Evaluated Biosolids Management Processes

Net Zero Impact	Scope 1	Scope 2	Scope 3	
Treatment Process – Environmental Impact	PFAS Fate/destruction Impact Sub-Criteria	Air Quality Emissions	Aqueous Emissions	Land/Soil Impact
CAPEX	Value	Certainty		
OPEX	Value	Certainty		
Revenue	Value	Certainty		
Operability	Feedstock Flexibility	Technological Complexity	Operable & Reliable at the Inputted Scale	Complexity of Process Safety
Regulatory Implications	Current Reg Coverage Level	Regulatory Stringency		
Technological Maturity	TRL	IRL		
Ease of Outlet	Size of Market vs Production	Reliable Outlet (Low Vulnerability to Disruption)	Ability to Accept Waste Inputs	
Social & Governance Implications	Traditional / Historic Usage Alignment	Policy Alignment	Social Licence Impacts	
Environmental Impact of Potential Use Case	Impact on water quality / diffuse pollution	Impact on air quality / pollution	Impact on land/soil	System Emissions

Figure 4: Evaluation Criteria (Left-Hand Column) and Associated Sub-Criteria

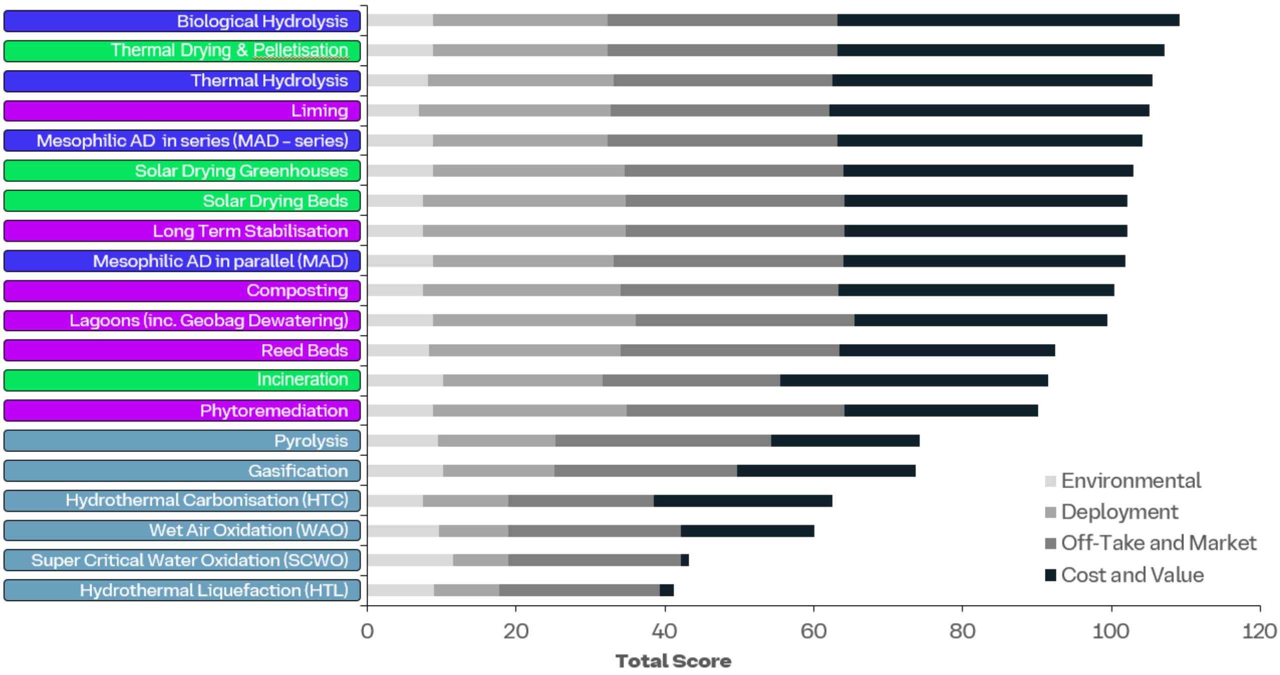

Figure 5: Evaluation Results for the 20 Biosolids Management Approaches under the Base Case Future State Scenario

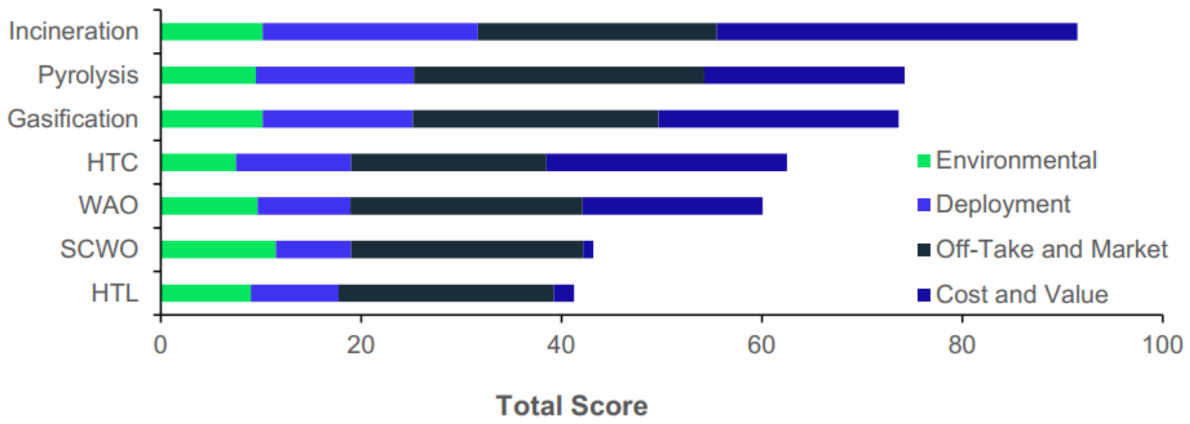

Figure 6: Evaluation Results Filtered for only Biosolids Management Approaches that Degrade PFAS or Non-Land-Applied Outputs

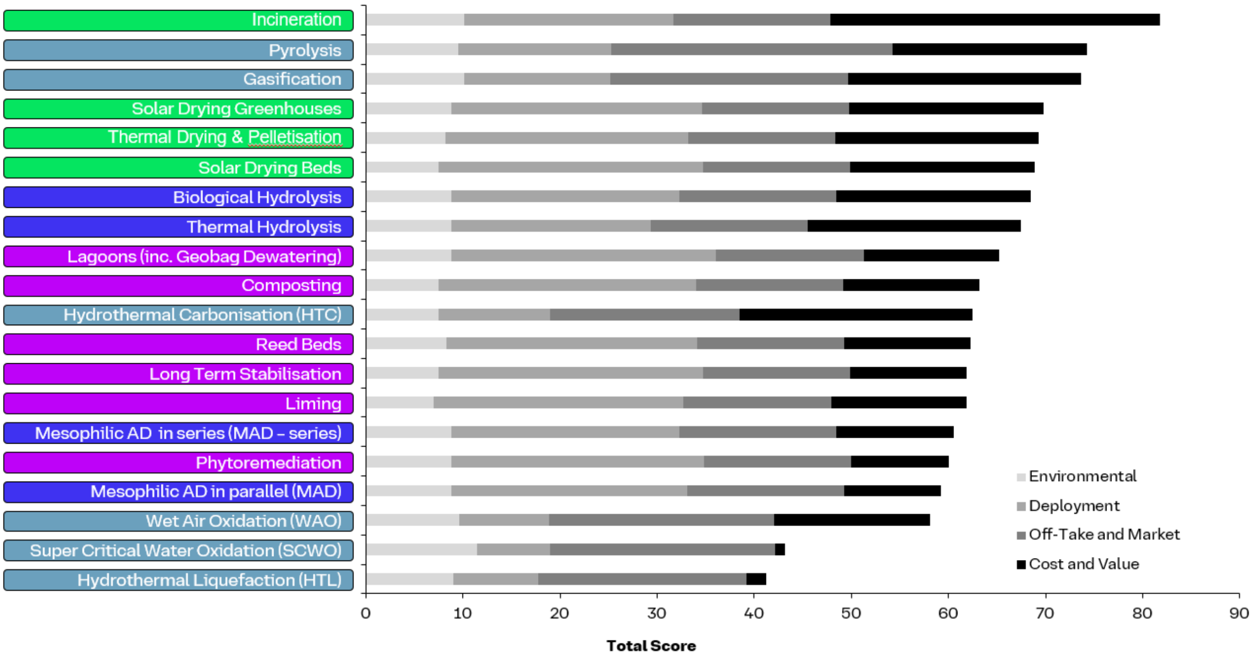

Figure 7: Evaluation Results for the 20 Biosolids Management Approaches under a Scenario where Biosolids Application to Land is Not Permitted