Waste-to-Energy Technologies:
Applications and Implications for Tāmaki Makaurau

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Executive Summary

Waste-to-Energy (WtE, or energy from waste, EfW) is a broad term used to describe processes that treat waste materials to generate heat, fuel, gas, chemicals, and/or electricity. The purpose of this report is to help guide Auckland Council and its communities with decision-making on the use of WtE technologies, to support the principles and objectives of the council's Waste Management and Minimisation Plan.

The report presents an overview of thermal and non-thermal WtE processes and technologies (co-processing, incineration, pyrolysis, gasification, anaerobic digestion and landfill gas utilisation) and assesses their positioning within established waste minimisation and te ao Māori frameworks. A review of recent literature assists in examining critical aspects of WtE technologies, framed by four key principles as recommended by the Ministry for the Environment in its 2020 waste-to-energy guide[1]. Findings from published literature are also used to consider the applications and implications of using WtE technologies within the context of Auckland's complex waste management system and existing national energy and waste policy. The report's findings reinforce and provide an update to earlier advice provided in council's previous Waste Assessments in 2011 and 2017. Key insights and recommendations are summarized below.

Waste Hierarchy and Circular Economy:

While the Auckland region currently relies on several WtE technologies to process specific waste streams that helps decarbonize the economy and reduce waste disposed to landfill, all WtE applications are limited in enabling actions at the top of the 'waste hierarchy' (avoid, reduce, reuse), given all WtE technologies depend on accessing waste materials to meet ongoing energy demands. Although certain WtE technologies offer stronger alignment with waste hierarchy and circular economy principles than others, this report emphasizes the need to prioritise investment and action that develop the top-tiers of the waste hierarchy, given those are best placed to achieve a "low-waste, low-emission circular economy"[2].

Greenhouse Gas Emissions and Environmental Impacts:

Greenhouse gas emissions generated from any WtE process are intricately linked to the composition of waste feedstocks, as well as the complex interplay of temporal factors, technology design, plant operations, and local contexts. Beyond carbon emissions, and for thermal WtE operations (co-processing, incineration, pyrolysis and gasification) in particular, the two most important environmental impacts are: i) ensuring air quality standards are met to mitigate health and environmental concerns, and ii) having robust residual waste management treatment/disposal solutions for by-products generated. The need for thorough assessment and monitoring to ensure safe and environmentally responsible WtE operations is acknowledged, especially for technologies that are less mature and less commercially proven.

Commercial Viability:

Large-scale ventures necessitate substantial financial commitment as well as securing waste supply and output agreements. High ongoing operating costs are also critical considerations, with significant expense required to control air emissions and discharges for thermal WtE operations. Commercial viability of WtE facilities hinges on capital investment, operational costs, feedstock availability, and contractual agreements – and these factors vary across technology types, scale, composition of waste feedstock, as well as access to markets for products/energy produced. In the

[1] https://environment.govt.nz/assets/Publications/Files/waste-to-energy-guide-for-new-zealand.pdf
[2] Te Rautaki Para – NZ Waste Strategy https://environment.govt.nz/publications/te-rautaki-para-waste-strategy/

Auckland context, this viability is heavily influenced by existing waste infrastructure and market conditions.

Treaty Partner and Community Support:

Pivotal to the success of using WtE technologies to manage wastes in Tāmaki Makaurau is the acknowledgement of indigenous rights and perspectives represented through genuine decision-making input and iwi/Māori engagement. It is common for large scale thermal WtE proposals to receive strong community opposition, as has been the experience in other parts of Aotearoa and overseas. Obtaining community acceptance for proposed projects and operations requires addressing key concerns relating to decision-making processes, plant location, health risks, and economic and environmental impacts.

In summary:

- The degree to which a particular WtE application gains implementation success depends on the local context – in particular, the presence of supportive partners, stakeholders, and enabling infrastructure/services, institutions, and policies. The Ministry for the Environment's 2020 WtE guide, and associated four key principles, provides a useful framework to evaluate waste-to-energy proposals.

- Using specific wastes as fuels in industrial co-processing plants is expected to remain a viable option for Auckland, provided these applications continue to support the four key WtE principles listed above. Such technologies support diversion pathways for specific wastes generated across the region, including end-of-life timber, tyres and used engine oils.

- Despite improvements in air quality emission controls over the years, the establishment of a conventional incineration plant in Tāmaki Makaurau to process mixed wastes is not expected to receive strong political or community support. Large scale thermal incineration of mixed wastes is therefore not a recommended approach, with a proposal in this regard requiring a thorough feasibility study to determine the level of community support and overall viability.

- Alternative thermal technologies, such as pyrolysis or gasification, may be favoured over combustion technologies, however the level of support will be dependent on the types of feedstocks processed and key outputs, along with a thorough evaluation against the MfE's four key principles on a case-by-case basis.

- Capturing landfill gas and maximising extraction/destruction rates are deemed necessary requirements to reduce greenhouse gas emissions at landfill sites. Utilising the gas for energy is a secondary priority, while supporting Auckland's energy decarbonisation. Alongside these efforts, reducing the generation and disposal of organic materials to landfill (including timber, paper/cardboard, garden and food wastes) is necessary to avoid and reduce bio-genic methane emissions.

- Anaerobic digestion (AD) is a non-thermal technology that recovers energy from specific organic wastes. It aligns well with national and regional policy direction and local context and is typically positioned higher on the waste hierarchy compared to other thermal WtE technologies (according to the NZ Waste Strategy). Relative to other WtE technologies, AD can prove cost-effective with fewer environmental and social risks. Notably, other initiatives across the Auckland region exist which focus on reclaiming nutritional value and benefits from specific organic wastes for people, animals, and/or soils, albeit without involving energy recovery.

1 Introduction

1. The purpose of this report is to contribute to informed decision-making on the role that Waste to Energy (WtE) technologies (or energy from waste, EfW) can have to minimise and manage solid wastes generated within Tāmaki Makaurau, as part of the development of Auckland Council's next Waste Minimisation and Management Plan.

2. This report provides an overview of key environmental, economic, social, and cultural considerations relating to different WtE processes and applications, within the context of national waste and energy policy and the region's existing waste management systems.

2 Waste to energy (WtE) processes

3. Waste to energy is a broad term used to describe processes that treat waste materials to generate heat, fuel, gas, chemicals, and/or electricity. WtE processes can be broadly categorised into those that produce heat (thermal), and those that are non-thermal.

4. The most common WtE processes discussed in this report, and their respective forms of energy, are listed in Table 1 based on guidance from the Ministry for the Environment (MfE, 2020)[3].

Table 1: Thermal and Non-thermal waste to energy processes

Process	Energy Output	Description
Thermal processes		
Co-processing	Heat	Uses feedstocks derived from wastes to replace natural mineral resources and/or fossil fuels (coal, fuel oil, natural gas) in industrial processes. Most common uses are in the cement industry, thermal power plants, or in industrial boilers/kilns. A separate initial mechanical or thermal/chemical process may first be required (e.g. torrefaction, transesterification etc) to first transform a waste material into the appropriate form for co-processing.
Incineration (with energy recovery)	Heat and/or electricity	Burns combustible materials within waste materials by heating to high ignition temperatures in the presence of air. 'Bottom ash' is generated which comprises incombustible materials and requires disposal or secondary uses. Exhaust gases (including greenhouse gases) and fly ash are also produced. Flue gas treatments are designed to capture and minimise the release of a range of hazardous inorganic and organic substances (such as heavy metals and dioxins) contained in release gases and fly ash. Fly ash requires safe treatment/disposal. Heat generated from the combustion process is captured in a boiler and can be used to raise steam for a steam turbine to produce electricity.
Pyrolysis	Heat, gas, fuel	Heats waste to a moderate-high temperature, without oxygen, to create a partial combustion process. Depending on the temperature reached, it can produce a mixture of gaseous, liquid, and solid residues. Solid residues from pyrolysis of organic materials are often referred to as bio-char, which is a carbon-rich by-product that, depending on the feedstocks and quality, can be used as a soil amendment. Syngas is the gaseous output which is typically a mixture of hydrogen, carbon monoxide, and methane. Syngas can be used to generate power and heat or further processed to produce chemicals. The liquid pyrolysis

[3] https://environment.govt.nz/publications/waste-to-energy-guide-for-new-zealand/

Process	Energy Output	Description
		product is an oil that can be used as a fuel or further processed and refined into other chemicals.
Gasification	Heat, gas, fuel	Heats waste materials (typically homogenous, carbon-rich materials) at high temperature, in a limited amount of oxygen, to produce combustible syngas, tar and ash residue. Additional processes are used to convert the syngas to other chemicals, or to use as a fuel for generating electricity or steam.
Non-thermal processes		
Anaerobic digestion	Gas	A controlled biological process where organic matter decomposes via the influence of microorganisms, in the absence of oxygen to produce a bio-gas (made up of predominately methane). A liquid/solid by-product referred to as digestate is also produced.
Landfill gas utilisation	Gas	Landfill gas (a mixture of predominately methane and carbon dioxide) is generated through the uncontrolled decomposition of organic materials within an oxygen-poor landfill environment. Gas is collected through buried vertical and horizontal piping which can be processed and treated for use as an energy source. Landfill gas continues to be produced beyond the operating life of a landfill. Landfill gas not captured/converted via a gas collection system, releases greenhouse gases to the environment.

5. Other processes or technologies exist that support the transformation of wastes/materials into forms of energy but are not listed in Table 1 or discussed in this report. This is because such technologies may have low commercial/technology readiness, target niche applications or specific feedstocks, or are variations of or complimentary to the main processes presented in the table above. Examples include *torrefaction* (converts woody biomass into a solid bio coal fuel by removing water content under heat and pressure), *transesterification* (used to convert plant-based fats and oils into biodiesel), mechanical processes to generate ‘refuse-derived-fuels’, or other processes such as thermal hydrolysis, Fischer–Tropsch technology and carbon capture and storage technologies.

2.1 Thermal WtE

6. Globally, incineration of municipal solid wastes (MSW)[4] together with energy recovery, (hereafter referred to as incineration) is the most widely applied thermal WtE technology[5]. Incineration requires oxygen to operate and is designed to burn mixed wastes at high temperatures (typically 850 to 1200°C).

7. In locations where incineration is used as primary waste management infrastructure, it offers the benefits of reducing waste volumes while also generating heat and/or electricity.

8. Table 1 lists co-processing, pyrolysis and gasification as further examples of thermal WtE technologies which, like incineration, generate heat and require heat to operate. These thermal processes may process mixed wastes, however typically target more homogenous

4 Definitions of municipal solid waste (MSW) vary, however in general MSW must include waste items collected from households from municipalities (OECD, 2023). In high-income and more affluent countries, MSW typically has higher proportions of inorganic materials (including plastics, glass, metals) compared to organic materials (Negi et al., 2019).
5 There are over 1,700 incineration WtE plants worldwide, of which 85 per cent are in developed countries, such as in Japan, France, Germany, Italy and the US (Levaggi et al, 2022).

materials and/or specific types of waste materials (e.g. end-of-life tyres, timber, biomass, plastics, or waste oil) and are generally smaller scale than incineration operations.

9. Incineration is typically carried out in a more oxygen-rich environment and at higher temperatures than other thermal processes, and all thermal processes involve different reactions and product yields.

10. In general, the more moderate temperatures in pyrolysis, with faster heating rates, yield liquid and solid products. Gasification with high temperatures and heating rates, promotes the generation of gas products.

11. Pyrolysis and gasification can be referred to as Alternative Thermal Treatments (ATT), which is a broad and somewhat ambiguous term commonly used in the UK to refer to thermal WtE processes that are not conventional incineration.

12. Co-processing is the only thermal waste to energy process applied at scale in Aotearoa New Zealand. Examples include the use of end-of-life tyres and wood wastes as combustion fuels (to substitute the use of coal) in the operation of the cement kiln at Fletcher Ltd's Golden Bay Cement plant in Whangarei[6], or waste engine oil and biomass forestry waste in industrial boilers and kilns for process heat applications[7].

13. There have been several attempts over the past couple of decades to introduce large scale incineration/WtE in NZ[8], as well as proposals and pilot projects for small scale pyrolysis plants[9]. Several proposals have since been abandoned, or continue to be at investigative stages, or are continuing through resource consenting processes.

2.2 Non-thermal WtE

14. Anaerobic digestion (AD) and landfill gas capture (with energy recovery) are the two examples of non-thermal WtE processes discussed in this report. In both processes, biogas[10] is captured and burned to generate CO_2, heat and/or electricity. In some cases, excess heat and CO_2 generated from burning the gas at an AD facility or a landfill site is used by nearby horticultural or agricultural facilities[11].

15. Both AD and landfill gas capture target the decomposition of biomass within an oxygen-deprived environment in which anaerobic bacteria generate a combustible 'biogas', predominately comprised of methane (CH_4). The gas is referred to as biogas because it is derived from renewable, plant-based materials, with CO_2 released when burned.

[6] https://www.goldenbay.co.nz/sustainability/
[7] https://www.eeca.govt.nz/insights/eeca-insights/biomass-boilers-for-industrial-process-heat/; https://rosenz.co.nz/
[8] Examples include: a proposal by Global Olivine in late 1990s to covert the Meremere Power Station in Huntly (https://www.nzherald.co.nz/nz/plan-junked-for-power-plant-fired-by-rubbish/6JJFFIZ36CACCLOVSIXYUI5FCM/), and other more recent WtE proposals in Hokitika, Kaipara, and Waimate by South Island SIRRL, in Manawatu proposed by Bio Plant Ltd, and Te Awamutu proposed by Global Contracting Ltd.
[9] For example, TyreGone, a pyrolysis plant for tyres in Glendene, Auckland which received central government funding and operated for about 5 years; a timber pyrolysis plant proposal in Blenheim which did not proceed but the technology was set up in Timaru and has since ceased; and a research pyrolysis plant in Otaki.
[10] Biogas can be refined to produce biomethane (concentrated methane) and is referred to as renewable natural gas. Chemically, it is undistinguishable from 'natural gas' (extracted from fossil-fuel gas fields), and so is a direct substitute in reticulated natural gas systems, provided it meets the AS/NZS 5442 specifications (Beca, 2021).
[11] https://www.beca.com/getmedia/4294a6b9-3ed3-48ce-8997-a16729aff608/Biogas-and-Biomethane-in-NZ-Unlocking-New-Zealand-s-Renewable-Natural-Gas-Potential.pdf

16. There are approximately 40 active Class 1 landfills in NZ[12], and more than 1000 closed landfills[13], the majority of which have no landfill gas capture systems. Of the landfills in Aotearoa that do have infrastructure to capture landfill gas, there are 14 that utilise captured landfill gas to generate energy/electricity (Eunomia, 2023). Some other sites may collect landfill gas but only flare off the gas without using it as an energy source.

17. Flaring or burning landfill gas to convert to CO_2 avoids the release of methane gas – a greenhouse gas that is 28 times more potent than carbon dioxide over a 100-year timeframe[14], and is the main gas attributable to greenhouse gas emissions associated with the waste sector.

18. Where landfill gas is not captured, where fugitive emissions emit into the atmosphere (which happens at all active and closed landfill sites), or when landfill gas collection systems are under-performing, methane gas emissions are released. Therefore, those landfill sites that do not have gas capture systems generate significantly higher GHG emissions overall compared to those sites that capture gas and convert it to CO_2 by flaring or energy conversion.

19. Anaerobic digestion (AD) plants are specifically designed to process only biomass feedstocks to maximise the capture and use of biogas and increase yield. Anaerobic digestion plants are common overseas, and in New Zealand are most often established at wastewater treatment plants or at farms/specific industrial sites to manage effluents[15].

20. While biogas plants are an established industry in NZ, Beca (2021) reports only 3.5 PJ of biogas is collected and utilised annually from landfills, wastewater treatment facilities and industrial manufacturing sites across the country, compared to an estimated 12.6 – 16.9 PJ of energy from potentially available feedstocks. Biogas energy sources provide less than 1% of NZ's total energy supply[16].

21. Aotearoa New Zealand's first large-scale anaerobic digestion plant was commissioned by Ecogas Ltd in 2022 and is specifically designed to generate biogas and digestate from food scraps. The plant is located in Reporoa and processes food waste from Auckland (including Auckland Council's food scraps collection service for households) as well as other feedstocks from central North Island. The plant has capacity to process 75,000 tonnes per year[17] and is expected to generate around 0.3 PJ of biogas (Beca, 2022).

22. Collecting gas from within a landfill (during both the operating and closure phases) is generally a passive process which relies on the functioning of a series of gas extraction wells and pipes installed within the landfill. Wastes contained within a landfill environment are highly variable and do not all produce gaseous byproducts compared to the organic wastes processed by AD plants. For these reasons, biogas from an AD plant is captured more efficiently and is a higher quality than biogas captured from within a landfill.

[12] https://environment.govt.nz/facts-and-science/waste/waste-facilities-and-disposal/
[13] https://environment.govt.nz/assets/Publications/Files/closed-landfills-guide-may01_0.pdf
[14] https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane
[15] There are 13 AD plants associated with wastewater treatment plants in New Zealand and 6 other operational anaerobic digestion facilities (Eunomia, 2023).
[16] https://www.energymix.co.nz/our-consumption/new-zealands-consumption/#where-does-our-energy-come-from-ff8ed
[17] https://www.ecogas.co.nz/reporoa

3 Positioning of WtE within waste policy frameworks

3.1 Te Ao Māori perspectives on waste

23. How government waste policy reflects te ao Māori is an essential consideration in Aotearoa New Zealand, given Māori indigenous rights and interests under Te Tiriti o Waitangi. As explored in recent research by Karaitiana and Maya (2022) however, the incorporation of te ao Māori principles and values into national waste management policy has not been strongly represented over the decades. This is despite mention in NZ's first national Waste Strategy stating, over two decades ago, that "*Maori have a unique perspective and role in waste minimisation and management. …As New Zealand moves towards zero waste Maori are expected to become more active in waste management planning and waste prevention. Decision-making must allow for direct Maori input into policy, standards and guidelines, monitoring and evaluation*" (MfE, 2002).

24. Iwi policy statements and iwi management plans (or IMPs) offer some insight into Māori perspectives relating to waste. IMPs express iwi/hapū priorities regarding kaitiakitanga, and are specifically relevant to local government resource management decision-making and planning processes.

25. IMPs can address a single issue or feature of the natural environment such as freshwater, Māori heritage, or provide a regional assessment of issues of significance, such as waste management. For example, a statement relating to resource use made in Te Pou o Kāhu Pōkere Iwi Management Plan for Ngāti Whātua Ōrākei 2018 states, *"Efficient use of resources is at the heart of kaitiakitanga – the guiding principle is that we should not take more from Papatuānuku than we need. Waste is inherently abhorrent.*"

26. A respected, contemporary Māori environmental framework with relevance to resource management, including waste management, is known as the Mauri Model (Figure 1). It was developed by Dr. Kepa Morgan in 2002 and refers to and is based on the Māori environmental concept of mauri[18].

27. Within a resource management framework, the Mauri Model seeks Māori values to be effectively included in planning, policy and decision-making processes. It was developed as a framework, assessment method, and decision-making tool, by integrating economic, social, cultural dimensions as part of the wider natural ecosystem. The Mauri Model was also designed to help understand how different activities impact on the intrinsic values of ecosystems, and to show the interrelatedness between sustainability dimensions (Morgan, 2003; Morgan & Fa'aui, 2018).

28. For a specific WtE process or technology to be assessed using the Mauri Model, it would involve determining whether the process/application results in the enhancement or depletion of mauri within each dimension (whānau, community, hapū, and ecosystem).

29. Of note, Para Kore, a predominant Māori-kaupapa zero waste organization, is vocal in its opposition to several recent incineration proposals in parts of the country. While Para Kore is not representative of any specific iwi/hapū, and does not claim to provide pan-Māori views, it

[18] Mauri: **1. (noun)** life principle, life force, vital essence, special nature, a material symbol of a life principle, source of emotions - the essential quality and vitality of a being or entity. Also used for a physical object, individual, ecosystem or social group in which this essence is located. https://maoridictionary.co.nz/; Mauri is listed as one of several key Māori environmental concepts which form the basis for Māori perspectives when seeking to assess and understand ecosystems (Harmsworth & Awatere, 2013).

offers a clear position statement that asserts that waste to energy (incineration) is inconsistent with Māori tikanga[19].

30. As with any issue of significance to iwi/Māori there will be differing perspectives. Tools such as the Mauri Model can be helpful to systematically evaluate values of importance to those people and systems connected to a specific proposal.

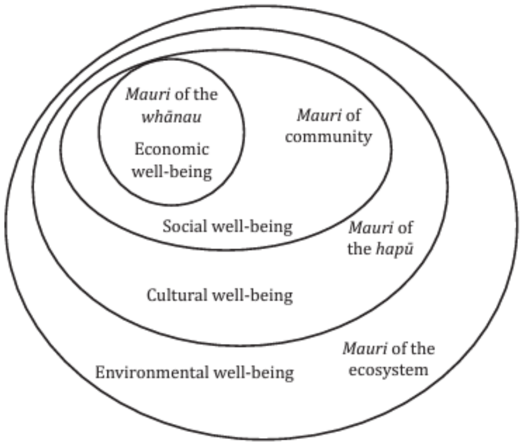

Figure 1: Mauri Model – a decision-making tool for assessing the important cultural concept of mauri (Morgan, 2003)

3.2 Waste Hierarchy

31. The 'Waste Hierarchy' is a framework commonly referred to in waste minimisation and management policy across many developed countries, including Aotearoa New Zealand.

32. Elements of the waste hierarchy concept were first introduced into European waste policy in 1975, and while there are many versions, most have in common the order of preference for action to minimise and manage waste – from prevention to disposal. More recently the waste hierarchy has also been applied to specific wastes/materials, for example food and plastic[20].

33. The waste hierarchy can be presented diagrammatically in the form of an inverted pyramid. Figure 2 presents an example from the recently published Te Rautaki Para – Aotearoa NZ Waste Strategy (MfE, 2023).

34. WtE processes used to manage mixed or residual wastes (including incineration and landfill gas capture) can fit within the 'recovery' or 'disposal' tiers of the hierarchy and, within the 'recycle' tier in the case of anaerobic digestion of biomass, as per Figure 2.

35. Debate regarding WtE is often viewed by proponents regarding its potential benefits versus landfill disposal, and conversely by its detractors in terms of its shortcomings compared with waste prevention and waste minimisation measures that lie further up the waste hierarchy.

[19] https://www.parakore.maori.nz/waste-to-energy/
[20] https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy; https://wrap.org.uk/resources/report/plastics-waste-hierarchy#download-file

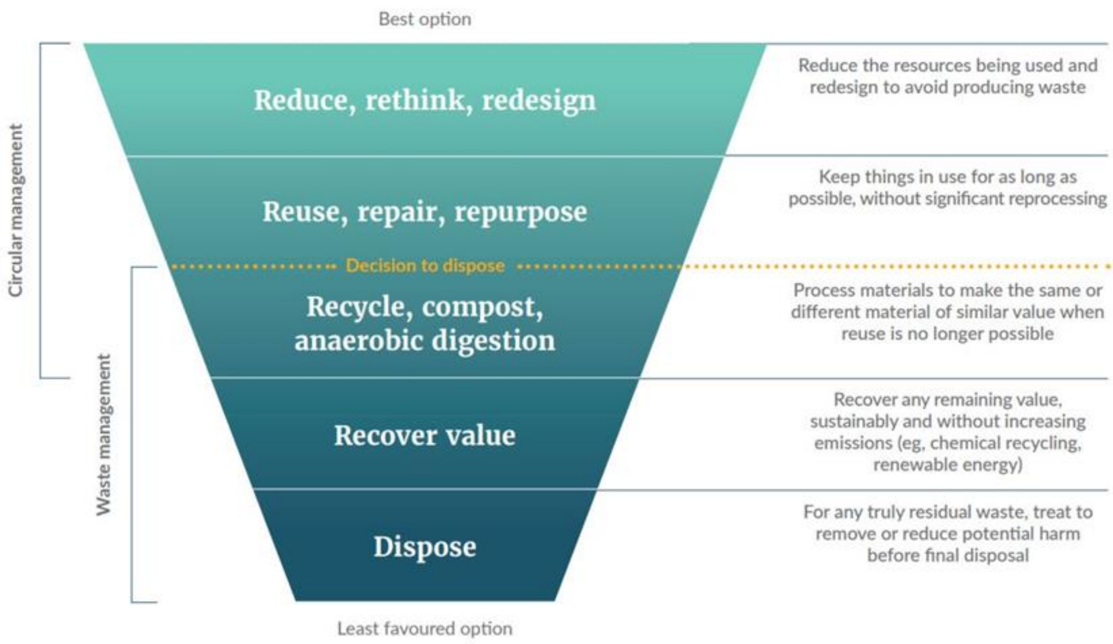

Figure 2: Waste Hierarchy from Aotearoa NZ Waste Strategy (MfE, 2023, page 25)

36. As Gertsakis and Lewis (2003) comment, the waste hierarchy provides a similar message to one promoted within the health sector which offers a logic hard to oppose - that is *"it is more effective to avoid problems from the outset, than to invest in reactive solutions once the problem has presented".*

37. Once waste is produced however (i.e. crosses the yellow line as shown in Figure 2), decisions are made as to whether the waste is to be recycled, recovered, or disposed. The waste hierarchy is a guide not a rule book, and the choice as to how a material is managed is influenced by the surrounding context, including legislative, infrastructural, and economic systems that exist. Seadon (2010) suggests *"waste is the result of inadequate thinking"*, and given NZ has one of the highest waste per capita rates across the OECD[21], this may indicate there has been a significant lack of creative thought given to the top two tiers of the waste hierarchy in NZ over the past few decades.

38. The order of the waste hierarchy has not been without critique, however. In Rethinking the Waste Hierarchy (Environment Assessment Institute, 2005) the positioning of incineration in particular above disposal, is questioned. Recognizing both waste practices are capable of resulting in negative environmental, economic, social, and cultural outcomes, authors argue that the net social cost of incineration by far exceeds the net social cost of landfill (by comparing the financial costs of incineration with landfill, and assigning approximate equivalent environmental costs to both).

39. Further, the limitations of the waste hierarchy in its ability to achieve wider sustainable outcomes, including a reduction in consumption and extraction of resources, are well documented[22]. For many, the waste hierarchy is recognised as effective in avoiding waste disposal to landfill but lacks in its ability to reduce extraction and consumption of natural

[21] OECD – 756 kg per person in 2018 compared to OECD total 535 kg per persons; https://data.oecd.org/waste/municipal-waste.htm
[22] Refer to reference list - Schall, 1992; Price and Joseph, 2000; Boyle, 2000; Gertsakis and Lewis, 2003; Gharfalkar et al., 2015; Van Ewijk and Stegemann, 2016; Taelman et al, 2018; Nilsen, 2022; Diprose et al., 2022.

resources (including energy and emissions) and associated impacts on the society and the environment.

40. In order to be effective, as acknowledged in 1992 by Yale University waste scholar Schall, the waste hierarchy needs to address both the waste management system and the production system, that is *"decisions about what to produce, how much to produce, and what to use in terms of raw material inputs into those production processes*."

3.3 Integrated Sustainable Waste Management (ISWM)

41. Integrated Sustainable Waste Management (ISWM) is a waste management framework and assessment tool that extends the waste hierarchy by placing it within a wider socio-technical system. The ISWM concept was refined in the early 2000s[23] and recognises three important dimensions of waste management: 1) stakeholders; 2) waste system elements; and 3) sustainability aspects.

42. ISWM examines both the physical components of waste management (collection, disposal, and recycling) – the 'hardware'; and the 'software' – i.e. the governance aspects (inclusivity of users and service providers; financial sustainability; coherent, sound institutions underpinned by proactive policies) (Wilson et al, 2012). Figure 3 represents these two separate but intersecting systems as two inverted triangles.

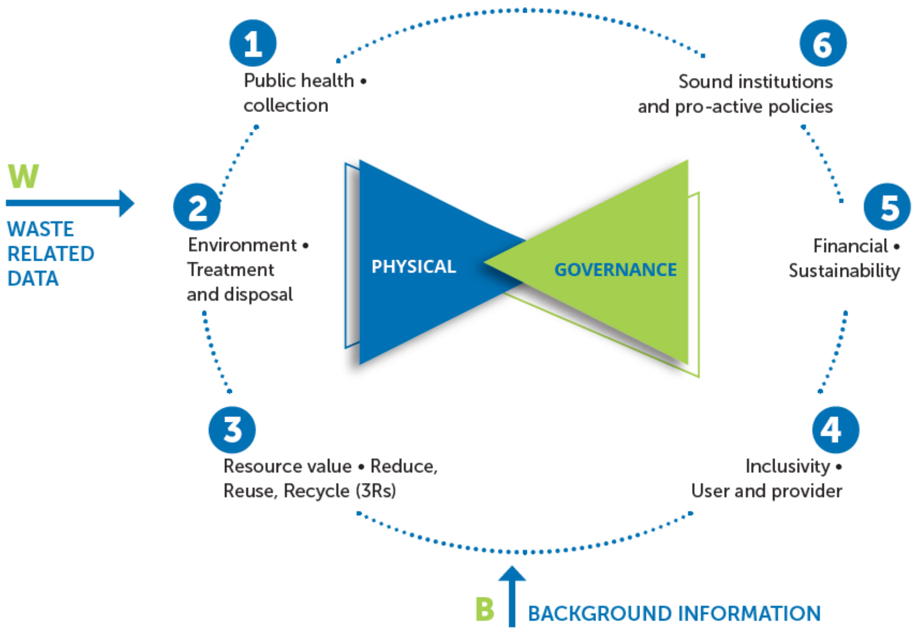

Figure 3: Schematic framework of Integrated Sustainable Waste Management (UNEP, 2019)

43. Depending on whether a WtE application treats or recycles/recovers wastes, the components numbered two and three in Figure 3 are relevant to WtE infrastructure, however all parts of the system need to be addressed to assess and deliver a well-functioning and sustainable system.

44. This includes the 'governance' side of the system, which according to Wilson et al (2012) needs to: be inclusive, allowing stakeholders to contribute as users, providers, and enablers;

[23] For example, refer to IJgosse, Anschütz and Scheinberg, 2004. Putting Integrated Sustainable Waste Management into Practice Using the ISWM Assessment Methodology.

be financially sustainable, that is cost-effective and affordable; and be resting on a base of sound institutions and proactive policies.

45. Solid waste production is intricately associated with air, soil, and water pollution (Brunner, 2013). As described by Seadon (2010), the catalyst to manage the waste problem eventuates when waste disposal affects people - via polluted air or water, or full landfills. The transfer of waste from one medium to another can be seen as a solution to a problem, or rather only shifting the problem to be out of sight-out of mind.

46. ISWM can be a useful framework to consider the interactions solid wastes have with these natural (and in te Ao Māori, spiritual) systems – air, land, water – as well as against physical urban systems, and the impacts waste discharges (in different states of atmospheric gas, aqueous liquids, or solids) – have on a system's overall sustainability.

47. Using the ISWM to consider a 'multi-media approach' – which considers waste energy also - enables a more holistic picture to become evident, although this comes with the disadvantage of adding further complexity. The implementation of a multi-media approach encourages reflection on upstream processes with a view to emissions reduction (Stiles, 1996), and life-cycle analysis tools can be used to assess these whole system impacts.

48. Regardless, as is the case with the waste hierarchy framework, the ISWM framework has limitations with directly challenging the wider economic systems that drive consumption and resource extraction, the connection with avoiding waste generation in the first place, as well as associated energy demands and emissions.

3.4 Zero Waste and the Circular Economy

49. Over the past two decades, a vision or aspirational goal of *zero waste* has featured in international and NZ government policy as well as in local government waste plans, including Auckland Council's WMMP[24]. More recently the concept of a *circular economy* has entered global discourse and national policy also[25].

50. In part drawing on the frameworks of the waste hierarchy and ISWM[26], the zero waste and circular economy approaches both aim to address the intractable challenges of curbing waste generation at source (and reducing resource consumption and regenerating natural systems), utilising waste as a resource, and creating circular and 'closed-loop systems'. The concepts aim to tackle these challenges by integrating the fields of sustainability, economics, governance and management.

51. The holistic picture of a circular economy is communicated in what is referred to as a butterfly diagram (Figure 4).

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[24] For example, C40 global cities zero waste declaration, https://www.c40.org/declarations/zero-waste/; in the first NZ Waste Strategy in 2002 which had the vision *'Towards zero waste and a sustainable New Zealand'* (MfE, 2002); and in numerous NZ council's adopted plans - including Auckland, Wellington, Taranaki, Opotiki, Timaru. https://www.wastenothing.co.nz/our-zero-waste-journey/; https://www.zerowastetaranaki.org.nz/; https://wellington.govt.nz/your-council/plans-policies-and-bylaws/policies/zero-waste-strategy; https://www.odc.govt.nz/our-services/rubbish-and-recycling/zero-waste.

[25] The circular economy was initially expressed by the Ellen MacArthur Foundation and is "*based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems*". https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview. Examples in international and national policy include: European Commission's A new Circular Economy Action Plan (European Commission, 2020), and the Circular Economy and Bioeconomy chapter in NZ's Emissions Reduction Plan (MBIE, 2022).

[26] As well as other concepts such as Industrial Ecology, Cleaner Production, Cradle to Cradle, and tools such as Triple Bottom Line and Life Cycle Analysis.

52. A circular economy challenges the conventional ‘linear’ way natural resources are taken, used, and disposed of. While contemporary within policy development, zero waste and circular economy concepts reflect certain traditional and indigenous beliefs and practices regarding resource management, including those that align within te ao Māori[27].

53. As highlighted by Simon et al, (2020) however, a circular economy requires a suite of accompanying legislation to make low waste and low carbon choices more viable, and other literature (Bianchi and Cordella, 2023; Henry et al., 2021) notes the scarcity of scientific work that addresses consumption in the context of a circular economy.

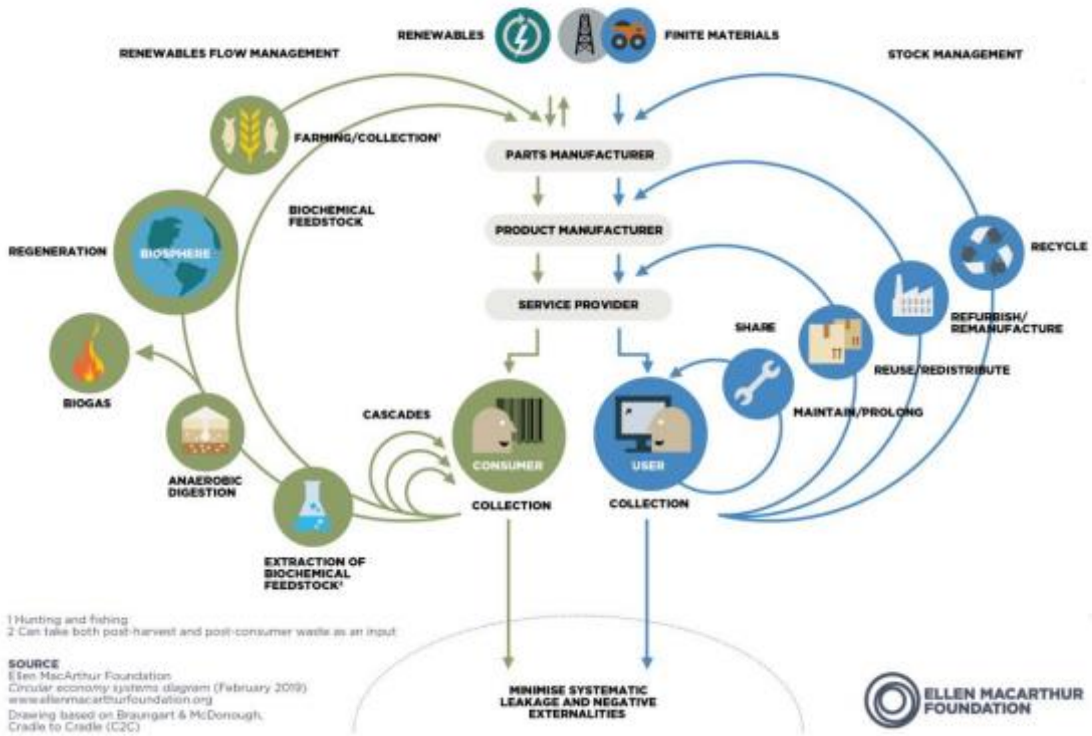

Figure 4: Circular economy – butterfly diagram (Ellen MacArthur Foundation)

54. Proponents of waste-to-energy facilities can propose the process contributes to circular economy and zero waste goals, by significantly reducing the quantity of waste requiring disposal (therefore claiming zero waste outcomes), while simultaneously creating an energy source to contribute to a community’s energy needs (‘circular’ use of waste materials).

55. Key opponents of WtE (large-scale MSW thermal processing in particular), however highlight the shortcomings with these two outcomes (waste reduction and energy generation), when considering other key principles of zero waste and the circular economy, relating to designing out waste, keeping materials in use, and regenerating natural systems.

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[27] For example https://doughnuteconomics.org/stories/24 outlines a model of a circular economy that draws on a Māori perspective; Para Kore expressed the following in WasteMINZ (2020) page 9 – *“Māori views on waste and recycling emphasise whakapapa (genealogical) connections between humans and the natural world. .. [and] precedes the concept of a circular economy (ōhanga āmiomio) but similarly acknowledges the mauri (life force) of natural resources”*.

4 Policy, legislation, and guidance relating to WtE

4.1 Government policy and guidance on WtE

56. In the absence of specific government policy relating to WtE, the Ministry for the Environment released a 13-page factsheet in 2020 entitled, *A waste to energy guide for New Zealand* (MfE, 2020).

57. The document sets out four principles the Ministry advise WtE proposals should be considered against (Figure 5), as well as posing a range of recommended questions for entities who may be assessing a WtE proposal (i.e. central or local governments, iwi/Māori, or commercial operators/investors).

Principle No	Definition
Principle 1	The proposal should support the goal of moving New Zealand steadily up the waste hierarchy towards a more circular economy approach to managing resources.
Principle 2	The environmental impacts must be well managed, especially the greenhouse gas emissions.
Principle 3	The proposal must be commercially viable over the long term.
Principle 4	There should be a strong level of support from the community and Treaty partners.

Figure 5: MfE guidance on WtE principles (MfE, 2020)

58. In late 2021 the Ministry for the Environment undertook public consultation to update the 2010 NZ Waste Strategy, as well as consulting on proposed changes to the Waste Minimisation Act 2008 and the Litter Act 1979. This led to the release of Te Rautaki Para - Aotearoa NZ Waste Strategy[28] in March 2023 which replaces the previous 2010 NZ Waste Strategy. The 2010 Waste Strategy or an early version from 2001 made no specific mention of WtE processes.

59. Te Rautaki Para is government's primary policy on waste minimisation and management. It sets out a high-level road map out to 2050 to transform how wastes are generated and managed in Aotearoa and offers the following vision:

By 2050, Aotearoa New Zealand is a low-emissions, low-waste society, built upon a circular economy.

We cherish our inseparable connection with the natural environment and look after the planet's finite resources with care and responsibility.

60. Building on the Ministry's guidance document on WtE from 2020, the strategy sets out the main considerations for WtE technologies, against five key aspects: purpose, feedstock, processing, and energy produced (Figure 6).

[28] https://environment.govt.nz/publications/te-rautaki-para-waste-strategy/

Aspects to consider	Questions to ask
Purpose	What is the primary aim: to dispose of a hazardous or problematic waste or to generate energy?
Feedstock	What waste material will be processed: is it biological, non-biological or mixed? Is the waste truly residual with no higher value? Is there a sustainable, long-term supply of the waste material, taking into account all our planned waste-reduction initiatives and commitment to reduce all waste (including residual waste)? How far will the waste material need to be transported?
Processing	What emissions will the processing plant produce? What other by-products will be created, and how harmful are they? How will by-products be disposed of?
Energy produced	Will the plant generate more energy than it uses, will there be a net gain? Can the additional energy produced be used? What type of energy will it displace: renewable or non-renewable?

Figure 6: NZ Waste Strategy - main considerations for WtE

61. The NZ Waste Strategy (page 46) states the following: "*waste to energy technology has the potential to displace fossil fuels in industrial applications like process heat and transport"*, and that "*proposals that use clean renewable biomass as a feedstock are most likely to align with our circular economy goals"*.

62. For proposals that use single waste streams (e.g. tyres, treated timber, waste engine oil and some plastics), advice from the strategy states these should be considered on a case-by-case basis, and "*that pyrolysis/gasification of municipal solid waste are unlikely to align with our circular economy goals".*

63. As stated in the Strategy, the next step is for government to work with local authorities, the waste management sector, and others to develop a first action and investment plan (AIP) – which would have a 5 year horizon. The AIP, alongside proposed new waste legislation[29], is to help govern planning and investment for central and local government, including waste infrastructure. At the time of writing, the first AIP was expected to be finalized in 2024.

4.2 Legislation relating to waste and emissions reduction

64. The Resource Management Act (RMA) 1991[30], Waste Minimisation Act 2008, and regulations under the Climate Change Response Act 2002 (relating to the NZ Emissions Trading Scheme) are Aotearoa New Zealand's main enabling and regulating laws with relevance to waste management, and waste to energy proposals and/or operations.

65. Other Acts of Parliament, with relevance to solid waste management include the Local Government Act 2002[31], Litter Act 1979, and the Health Act 1956. The Hazardous Substances and New Organisms Act (1996), Land Transport Act (1998), and the Health and Safety at Work Act (2015) also place controls on how waste is handled and transported to protect people and the environment.

[29] Refer to https://environment.govt.nz/what-government-is-doing/cabinet-papers-and-regulatory-impact-statements/cabinet-papers-seeking-policy-decisions-on-the-content-of-new-waste-legislation/ for Cabinet decisions on proposed content of new legislation to replace the Waste Minimsiation Act 2008 and Litter Act 1979. New legislation is expected to be enacted by 2025.
[30] Noting the recent reform of the RMA 1991. The Natural and Built Environment Act 2023 and the Spatial Planning Act 2023 replaces the RMA which will be phased in over the coming years.
[31] Under the Local Government Act 2002, solid waste collection and disposal is listed as a core service that a local authority must have *particular regard to* (Section 11A).

66. The Climate Change Response (Zero Carbon) Amendment Act 2019 requires government to have an Emissions Reduction Plan (ERP) which sets out policies and strategies to meet agreed emission budgets. Reducing emissions across a range of sectors is required, including the waste sector.

67. Most emissions from the waste sector in NZ (approximately 82 per cent) come from the disposal of organic waste to landfill (such as, food, garden, wood and paper waste) Emissions from wastewater treatment represents approximately 11 per cent of the waste sector's emissions, with incineration and open burning and biological treatment of solid waste (composting) making up the remaining 7 per cent[32]. The Emissions Reduction Plan aims to reduce these emissions by 40% by 2035, through various actions including diverting more organics waste from landfill and creating regulations to increase the capture of gas from municipal landfills.

68. Local authorities have obligations under the Waste Minimisation Act (2008) to *"encourage effective and efficient waste management and minimisation"* and have the responsibility to undertake regular waste assessments to provide a *"forecast of future demand for collection, recycling, recovery, treatment, and disposal services within the district…and how those demands will be met including proposals for new or replacement infrastructure*".

69. National Environment Standards (NES) for Air Quality Regulations, which came into force in 2004 under the RMA 1991, sets a guaranteed minimum level of health protection relating to air emissions from specific activities. The NES requires landfills with a capacity of more than one million tonnes of waste to collect landfill gases and to either flare or use the gas as fuel for generating heat/electricity. Further, under the Climate Change Response Act 2002, landfill owners are required to purchase emission trading units to cover methane emissions generated from the landfill. Regulations allow for a landfill operation to apply for a unique emissions factor (UEF), to make allowance for emission reduction methods such as gas extraction and utilisation.

70. The NES for Air Quality also prohibits, unless exemption criteria are met, the lighting of fires and burning of wastes at landfills, the burning of tyres, bitumen burning for road maintenance, burning coated wire or oil, and the operation of incinerators at schools or hospitals, and the operation of high-temperature *hazardous waste* incinerators. These prohibitions limit the range of incineration waste treatment/disposal options within New Zealand with the aim of protecting air quality.

71. Another NES regulation under the RMA 1991 of relevance to WtE, which recently came into effect in July 2023, is the Greenhouse Gas Emissions from Industrial Process Heat[33]. This sets the national direction for phasing out existing coal boilers by 2037 and stops the installation of new low-to-medium temperature industrial coal heating devices. The regulation will require councils, when making resource consent decisions, to consider climate change impacts caused by industrial process heat. WtE technologies and processes may have a role in this phase out – whether via landfill gas, co-processing, anaerobic digestion, or other thermal processing technologies.

4.3 Other relevant government policy

4.3.1 NZ Infrastructure Commission: 30-year Strategy

[32] https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/waste/

[33] https://environment.govt.nz/acts-and-regulations/regulations/national-environmental-standards-for-greenhouse-gases-from-industrial-process-heat/

72. A further indication of central government policy on WtE can be found in government's response to Te Waihanga – NZ Infrastructure Commission's 30-year Infrastructure Strategy published in 2021.

73. The Commission's 30-year strategy states, *"the use of waste-to-energy also needs to be considered carefully in the context of New Zealand's current renewable-energy goals"* and that *"waste-to-energy is only used to replace disposal to landfill, not replace recycling or disincentivise efforts to redesign and reduce waste*".

74. One of the Commission's 68 recommendations to government was "*Recommendation 35: Clarify the strategic role of waste-to-energy: [and] establish a position on waste-to-energy as part of the National Waste Strategy, noting its potential as an alternative to landfill.*"[34]. Treasury's response to the Commission's strategy and the recommendation 35 above was to give support in principle and noted the linkage with government's proposed Energy Strategy also.

4.3.2 Energy Strategy

75. The Government is currently developing a New Zealand Energy Strategy to be finalised by the end of 2024. The Energy Strategy will support the transition to a low emissions economy, address strategic challenges in the energy sector, and signal pathways away from fossil fuels[35].

76. Approximately 70% of NZ's total energy consumption is provided by fossil fuels (Figure 7) and this is predominately to meet the current demands of transportation and industrial processes. In 2020, greenhouse gas emissions from energy use in NZ made up 40% of the country's total gross emissions[36].

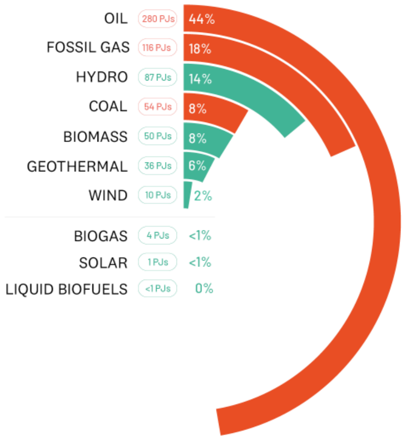

Figure 7: Primary Energy Consumption in NZ 2021[37]
(energy harvested directly from renewable/non-renewable resources)

77. The Government's 2050 vision for energy and industry is for Aotearoa New Zealand to have a highly renewable, sustainable, and efficient energy system that is accessible and affordable, secure, and reliable, and supports New Zealanders' wellbeing. It has committed

[34] https://media.umbraco.io/te-waihanga-30-year-strategy/mrtiklkv/rautaki-hanganga-o-aotearoa.pdf
[35] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand/new-zealand-energy-strategy/
[36] https://www.eeca.govt.nz/insights/energys-role-in-climate-change/new-zealands-energy-related-emissions/
[37] https://www.eeca.govt.nz/insights/energys-role-in-climate-change/the-future-of-energy-in-new-zealand/

to reaching net zero for long-lived gases by 2050, set a target that 50% of *total energy consumption* will come from renewable sources by 2035 (New Zealand's renewable share of energy consumption in 2021 was 28.4 per cent[38]), and has an aspirational target of 100% renewable *electricity* by 2030.

78. As set out in government's first Emissions Reduction Plan reducing GHG emissions generated by industrial process heat[39] is one specific area of interest to government, and biofuels and biomass materials are recognised as energy sources to help decarbonise NZ's total energy needs and support the government's vision. As indicated in Figure 7, biomass and biogas energy sources combined currently only make up approximately 8% of total energy sources.

79. Two of the specific actions in the ERP that relate to this bioenergy focus are: *"Commence a circular economy and bioeconomy strategy";* and "*Accelerate sustainable and secure supply and uptake of bioenergy in Aotearoa*". These actions include looking to increase woody biomass supply to replace coal and other carbon intensive fuels and materials and stimulate private sector investment[40].

80. Scion, a NZ Crown Research Institute, has been researching and promoting the bioenergy potential of forestry plantations and woody residuals for years[41]. Information presented in Eunomia (2023) indicates forestry residues offer the most promising source of biomass material for energy generation. It is noted that forestry wastes are not typically categorised as waste materials however, given they are rarely collected and/or disposed to landfill.

81. The NZ Bioenergy Association suggests there is significant potential for growth in the production of biogas – given a focus on processing residual organic wastes from food processing, at wastewater treatment facilities, and processing dairy effluent if supplemented with other organic material[42].

82. WtE processes that handle renewable feedstocks to produce biogas/biofuels all have the potential to contribute to this bioenergy generation – whether through utilising landfill gas, anaerobic digestion, or thermal processing of renewable wastes.

5 Waste minimisation and management in Tāmaki Makaurau

83. This section provides an overview of Auckland Council's waste management and minimisation plans, services, and infrastructure, and briefly explains the private-public waste systems that operate across the region. Consideration of the role of WtE within this context is provided throughout this section.

5.1 Waste Management and Minimisation Plan (WMMP) and Bylaw

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[38] https://www.mbie.govt.nz/dmsdocument/23550-energy-in-new-zealand-2022-pdf

[39] Process heat is heat energy (often in the form of steam or hot water or hot gas) used by the industrial, commercial and public sectors for industrial processes, manufacturing and space heating. For example, coal boilers for processing raw materials like dairy or paper, or boilers to heat hospitals/schools. Currently, more than half of the industrial process heat used comes from fossil fuels and process heat contributes about eight per cent of Aotearoa New Zealand's greenhouse gas emissions. https://environment.govt.nz/news/new-rules-for-industrial-heat-emissions/

[40] https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/circular-economy-and-bioeconomy/

[41] https://www.scionresearch.com/science/bioenergy/bioenergy-and-biofuels

[42] https://www.biogas.org.nz/documents/resource/Information-Sheets/IS47-Role-of-biogas-in-transition-to-low-carbon-economy.pdf

84. Under the Waste Minimisation Act 2008, council is required to produce a Waste Minimisation and Management Plan (WMMP) every six years. Auckland Council's first WMMP was adopted in 2012 and set a vision of "Zero Waste by 2040".

85. In 2018, Council approved Te Mahere Whakahaere me te Whakaiti Tukunga Para i Tāmaki Makaurau - Auckland's Waste Minimisation and Management Plan 2018, which maintains the same Zero Waste vision.

86. The 2018-2024 WMMP sets out targets for waste reduction, priority action areas, and 103 specific actions. A set of 'Māori priorities' are also represented in the WMMP which were developed through a draft mana whenua framework referred to as Te Kōhao o te Ngira.

87. None of the actions or priorities in the existing WMMP relate to specific WtE technologies or applications, although incineration is discussed in the plan. The WMMP will be reviewed through a public consultation process in 2024.

88. Using statutory powers of the WMA 2008 and Local Government Act 2002, council adopted its Waste Management and Minimisation Bylaw in 2019. This bylaw, among other things, enables Auckland Council to prohibit or regulate the deposit of waste, and to require operators of waste management and resource recovery facilities to obtain an approved licence from Auckland Council to operate.

89. Licences require operators to report to council on the types and quantities of materials deposited, collected, transported, received, stored, processed, or disposed of.

5.1.1 WtE considerations in Auckland's WMMP

90. As part of the preparation for council's first WMMP in 2012, council engaged Campbell MacPherson Consultants Ltd to prepare a discussion paper on the viability and suitability of applying WtE technology to process solid waste from within the Auckland region (Campbell MacPherson, 2011).

91. The discussion paper also provided recommendations regarding council's role with WtE, given the existing ownership structure of the Auckland solid waste market and council's strategic waste minimisation and management objectives. Key points from the 2011 discussion paper are summarised as follows:

- *The critical success factors for developing WtE in Auckland were analysed and a range of impediments and risks were identified relating to: knowledge gaps, available volumes of solid waste, council control of the waste stream and marginal economic viability.*
- *New Zealand has been slow to examine WtE due to the historical predominance of landfills as a waste management solution. However, diversion of waste to landfill is now both a central and local government priority and WtE deserves further consideration in the New Zealand context.*
- *WtE technologies are evolving rapidly with ongoing research and development and it is likely that thermal alternatives to combustion will become increasingly commercially proven over time.*
- *Council should have a minimal role in promoting WtE for Auckland at present and should focus its financial and operating resources on projects that maximise waste reduction, reuse and recycling ahead of lower waste hierarchy solutions such as WtE.*

- *Approaches to Council from WtE providers should be redirected to the key private sector waste companies (including landfill owners).*

- *Council should continue to monitor technological and operating performance of commercially operating WtE plants in other countries (and developments in New Zealand) to increase its knowledge of WtE options.*

92. Later, during the development of council's 2018 WMMP, SLR consultants were engaged to advise Auckland Council on future waste management strategies and service delivery options, which included consideration of best practice waste management/minimisation approaches adopted in comparable cities around the world.

93. Nine cities were studied[43], several of which use conventional WtE (incineration) waste treatment infrastructure, and/or AD plants. Recommended 'game changer' policies for Auckland Council recommended from this research were to: increase the waste levy, introducing bans of organic waste disposal, and introducing site waste management plans (SLR, 2017). Alongside these policy changes, SLR's work provided a high-level capacity assessment of future waste treatment infrastructure, of which WtE thermal processing of mixed waste and AD were considered[44].

94. Leading on from SLR (2017) research, one of three broad options presented in council's 2017 waste assessment to address how waste services could be delivered over the plan's six-year period, was for *'Investment in two to three residual waste treatment technologies with capacity of 300,000kTpa* (Auckland Council, 2017)'[45].

95. Council concluded that the WtE option would require significant investment from both the private and public sectors with capital beyond council budgets. Equally the option was not considered to support the WMMP's Zero Waste vision. Risks identified related to public acceptability, environmental performance (compared to landfill), the need for certainty of supply of residual waste, and developing markets for the resulting energy and materials.

96. Statements regarding WtE in the current WMMP 2018 are as follows (Auckland Council, 2018):

"A range of issues and risks mean that large scale facilities for energy from waste, relying on a mixed waste stream, are not appropriate at this time. Building a facility would be very expensive and, once built, would require a large, ongoing supply of waste to burn. This could undermine efforts to reduce, reuse and recycle waste at its highest and best value. It does not align with our Zero Waste vision."

"In Auckland, energy from waste may be appropriate for some hard-to-manage individual waste streams, such as timber, where there's no other viable use and the material will cause harm in landfills."

5.2 Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan 2020

97. Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan was adopted in 2020 and is council's long-term approach to climate action (Auckland Council, 2020). To guide Auckland's approach to climate action, mana whenua, through the Mana Whenua Kaitiaki Forum (now the Tāmaki

[43] Two cities in Europe, one in the UK, four in north America, and two in Australia.
[44] https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/docswastemanagementplan/waste-assessment-appendix-a.pdf
[45] Refer to page 147 of Auckland Council 2017 Waste Assessment.

Makaurau Mana Whenua Forum), partnered with council to provide a te ao Māori perspective throughout the development of the plan.

98. The plan sets out eight priority action areas to deliver the following two goals to reduce the region's emissions and adapt to the impacts of climate change:

- To reduce our greenhouse gas emissions by 50 per cent by 2030 and achieve net zero emissions by 2050.
- To adapt to the impacts of climate change by ensuring we plan for the changes we face under the current global emissions pathway.

99. Te Tāruke-ā-Tāwhiri outlines a decarbonisation pathway for Tāmaki Makaurau / Auckland that takes into consideration the nature and challenges of the region's greenhouse gas (GHG) emissions profile, which is predominantly comprised of transport emissions (43.4%), stationary energy (26.7%) and industrial processes and product use (21.3%).

100. Emissions from the 'waste' sector generates about 3.1 per cent of Auckland's total emissions as reported on page 42 of council's Te Tāruke-ā-Tāwhiri Climate Plan. These emissions are attributable to landfillled waste and wastewater treatment, with emissions from anaerobically decomposing waste in landfills responsible for the majority (97%) of the reported emissions.

101. Emissions associated with consumption of resources not utilised or wasted are not included as part of the 'waste' sector emissions. Likewise, emissions associated with the transportation of waste from source to landfill are not categorised under waste sector, rather captured as part of transport sector emissions.

102. The two specific action areas in the plan that relate to waste minimisation are:

- **Action area B7: Develop and support initiatives to minimise construction and demolition waste** *(for example, develop a deconstruction hub that provides infrastructure for industry to exchange key materials and share best practice expertise; continue research into the role of reused and recycled construction materials and ensure Auckland Council contracts are maximising opportunities to recover useful materials);* and
- **Action area E6: Manage our resources to deliver a zero waste, circular economy** *(for example, implement the Auckland Waste Management and Minimisation Plan; undertake research and feasibility studies to inform investigations into on onshore processing solutions).*

103. The plan also has the following action areas that relate to energy generation, including:

- **Action area EN1**: **Reduce process heat and industrial process emissions in the Auckland region** *(for example, collaborate and partner with central government and industry to decarbonise process heat; lead by example by decarbonising process heat on Auckland Council's and CCO's assets by phasing out natural gas boilers).*
- **Action area EN3: Reduce emissions from the electricity grid** *(for example, support the installation of renewable energy generation in the Auckland region)*

104. Specific organic wastes – food wastes, paper/cardboard wastes, plastic wastes and wood wastes – are targeted by the plan's decarbonisation model[46]. Anaerobic digestion of food wastes is recognised as a method to achieve emission reductions from food wastes, and the incineration of wood wastes is mentioned as a method to address GHG landfill emissions generated by disposing wood to landfill.

105. No mention of other specific waste to energy infrastructure or applications features in the Climate Plan.

5.3 Auckland Council's C40 commitment

106. Auckland Council became a signatory to the C40 Cities Climate Leadership Group in 2018 and has been a member since 2015.

107. C40 is a network of 97 global cities committed to fighting climate change and creating a healthier, more sustainable future. Auckland Council's membership includes a commitment to the C40 Zero Waste declaration and the following goals[47], which are reported on periodically:

- reducing the municipal solid waste generation per capita by at least 15% by 2030 compared to 2015;
- reducing the amount of municipal solid waste disposed to landfill and *incineration* by at least 50% by 2030 compared to 2015; and
- increasing the diversion rate away *from landfill and incineration* to at least 70% by 2030.

108. As noted by the italics above, reducing the quantity of waste disposed to landfill in C40 cities is targeted in the same way as any waste disposed of via incineration in these cities.

5.4 Auckland's waste management system

109. The management of wastes within Tāmaki Makaurau is highly complex, with large commercial enterprises, small-scale operators, and Auckland Council all contributing to waste management and minimisation services, infrastructure, and regional outcomes.

110. The establishment and operation of landfills and waste/resource recovery infrastructure in Auckland (and across the country) is not limited to local councils. Any entity can seek to establish a landfill, a WtE plant, or resource recovery facility, through a resource consent application under the RMA 1991 or a private plan change request.

111. Waste management legislation that sets out local authority's responsibilities, alongside private interests, and market-led solutions have all led to the existing public-private waste system within the region.

112. Despite having legislative responsibilities under the WMA 2008 to "encourage" waste minimisation, Auckland Council faces significant barriers to enable the reduction and diversion of wastes from landfill. Certain barriers, such as the low cost of landfilling compared to diversion have been shifting in recent years due in part to central government

[46] Auckland Council (2020), page 47 - Climate actions and targets.
[47] https://www.c40.org/declarations/zero-waste/

increasing (and expanding) the waste levy[48], however the reliance on further economic incentives/disincentives and regulatory tools remain.

113. As identified in council's 2011 waste assessment research on WtE by Campbell MacPherson (2011), and more recently in a report published by the NZ government by BERL (2019), the waste sector across the country and within the Auckland region is dominated by two large privately-owned companies, Waste Management NZ (WMNZ) Ltd and EnviroNZ Ltd, both of which provide collection services and own and operate landfills.

114. These two companies control the collection and disposal of the majority of New Zealand's waste either through direct collection contracts with private customers, through waste service contracts with local authorities, as well as via private (and joint-venture) landfill ownership arrangements.

115. The Auckland region relies on the following three main Class 1 landfills for waste disposal, two of which are within the Auckland region:

- Whitford Landfill in south-east Auckland owned by Waste Disposal Ltd (a joint venture between WMNZ and Auckland Council - operated by WMNZ)
- Redvale Landfill in Silverdale, north Auckland (owned/operated by WMNZ)
- Hampton Downs Landfill in the north Waikato area (owned/operated by EnviroNZ)

116. According to data presented in the 2018 WMMP (Auckland Council, 2018), around 40 per cent of Auckland's waste is currently transported and disposed of out of the region, and household waste represents approximately 20% of the total waste from the region disposed to landfill.

117. Numerous other operating landfills (e.g. managed fills, cleanfills and industrial landfills) exist within Tāmaki Makaurau also, these are referred to as Class 2 to 5 landfills[49]. The majority of these are privately owned and do not accept municipal waste materials.

118. The Class 1 Whitford Landfill has consents to enable it to operate until 2041. There are restrictions on vehicle movements to and from the landfill which limits the annual volume that can be received at the site. The Hampton Downs Landfill in Waikato has consents to accept waste until 2030.

119. In 2014 WMNZ sought a resource consent to extend the life of the Redvale landfill up until 2048. The application was granted but with a lesser extension until 2028. The inability to continue to use Redvale in the long-term future led to WMNZ's proposal to construct a new landfill in Wayby Valley, south of Wellsford within the Dome Valley.

120. The proposed new landfill is put forward on a commercial basis by WMNZ Ltd, with involvement from Auckland Council as a regulator. The decision to grant resource consent for the proposal was approved and supported by four of five independent commissioners at a hearing in 2020[50]. The decision has since been appealed and remains with the Environment Court.

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[48] The waste levy has increased from $10 per tonne to $30 in 2023 and increases to $60 by 2024. The waste levy has also been expanded to apply (at lower rates) to other classes of landfills (ie. cleanfills, managed fills). https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/waste-disposal-levy/expansion/

[49] https://environment.govt.nz/assets/publications/Waste/determining-your-disposal-facility-class-fact-sheet.pdf

[50] https://www.aucklandcouncil.govt.nz/ResourceConsentHearingDocuments/DomeValley-Dec-20201109.pdf

5.4.1 Council services for household wastes/materials

121. Council holds contractual relationships with numerous waste collection contractors who provide Auckland households with kerbside collection services – for refuse, recycling, and, currently in some areas, food scraps. In addition, council also provides a booking service for householders for the collection of inorganic items and owns/operates one resource recovery and waste transfer station in Waitākere.

122. Council's new 'three-bin' contracts were awarded in 2019 with the purpose of streamlining services across the region, and to incorporate mechanisms to incentivise waste reduction outcomes, in anticipation of rolling out the region's urban food scraps collections service.

123. Council controls the destinations for wastes/materials collected from these services through existing contracts. For example, refuse is disposed at landfills specified by council, and recyclables are taken to a Materials Recovery Facility in Onehunga for sorting and on-selling. A portion of inorganic materials collected from households is diverted from landfill through contract arrangements that enable the recovery of reusable/recyclable materials.

124. Further, in 2019 council awarded a 20-year supply agreement to EcoGas Ltd to receive and process food-scraps collected from Auckland households as part of council's new regional roll-out of a kerbside food-scraps collection service which began in 2023. The EcoGas plant owned and operated by Ecogas Ltd and is a purpose-built anaerobic digestion plant located in Reporoa, South Waikato.

125. In 2022 council approved the future funding provision for household refuse collection services across the region to be rates-funded. This was based on evidence that set out greater benefits would be achieved under a rates-based model compared with a Pay-As-You-Throw user-pays model – relating to carbon emission reductions, operational efficiencies, economic benefits, equitable access, and waste minimisation[51]. Shifting to a rates-based refuse service across the region, also results in council controlling the disposal destination for household refuse collected across a larger area of Auckland.

5.4.2 Resource Recovery Network across Auckland

126. Expanding Auckland's Resource Recovery Network (RRN) is a key action set out in the 2018 WMMP and is an essential tool to achieve the plan's waste diversion targets and Zero Waste vision.

127. The purpose of the network is to maximise the diversion of reusable and recyclable materials from landfill, and in the process generate multiple environmental, social, cultural, and economic benefits for Tāmaki Makaurau.

128. To date, council has led the establishment of thirteen Community Recycling Centres (CRCs) across the region forming the initial RRN. In 2021, council approved a revised strategy and associated budget to expand the network to a total of 21 Community Recycling Centres across the region, in addition to two commercial-waste focused resource recovery parks by 2031.

129. Many other facilities, resource recovery initiatives, and behaviour change programmes exist across the region that are not council-led and target household and commercial waste streams, including organic wastes, construction and demolition materials and packaging.

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[51] Agenda of Extraordinary Finance and Performance Committee - Tuesday, 7 June 2022 (aucklandcouncil.govt.nz) (see links at Item 11)

Refer to council's 2023 Waste Assessment for a stocktake of waste and resource recovery infrastructure, services, and initiatives that serve the Auckland region.

5.5 Waste to energy enquires received by Auckland Council

130. Council staff and elected members receive periodic enquiries from individuals and organisations with interests in waste to energy topics, proposals and/or specific technologies. Over the last three years, around 30 enquiries have been responded to by council's Waste Solutions team.

131. Some enquiries are to request information about council's existing waste minimisation policy/plans or to seek data on waste quantities/composition. Other enquiries involve requests to share information about conceptual or proposed waste to energy projects.

132. Proponents of specific technologies are typically seeking access to specific feedstocks for plant operation, either single-stream materials (such as plastics, tyres, sewage sludge) or mixed waste streams, such as municipal solid waste. All WtE proposals need a consistent supply of materials as a feedstock and secure markets or uses for end-products produced (including energy).

133. Since the last WMMP was adopted by council in 2018, the most significant support council has given to a waste to energy project relates to the establishment of New Zealand's first large-scale anaerobic digestion plant designed to process household food scraps. Council's support for the anaerobic digestion of food scraps came about through council's 2012 commitment to introduce a food scraps collection system across urban Auckland, alongside a formal procurement process to seek a supplier who could accept and process the estimated 75,000 tonnes of collected food scraps.

134. No enquiry relating to a large-scale waste to energy proposal has progressed beyond conceptual stage within the Auckland region in recent years.

135. In 2022, a private company Daroda Ltd applied to council for consents to establish a temporary thermal waste processing plant within an industrial site in Silverdale for a maximum 2-year duration. At the time of writing, Auckland Council is assessing the resource consent applications for air and stormwater discharges. The small-scale plant has a maximum capacity of processing 4 tonnes of material per day and the plant has been established to test and gather information on a range of feedstocks, air quality and environmental parameters and processing performance.

136. In mid 2023, the Mayor's office was invited by the Kaipara District Council to be part of an investigation to assess a proposal received from a company SIRRL for an incineration plant in the Kaipara district.

5.6 Auckland Council feedback on government policy development

137. In recent years, Auckland Council has submitted formal submissions and provided feedback to central government agencies, including the Ministry for the Environment on waste policy. Submissions have focused on strong advocacy for increases to the waste levy and introduction of mandatory product stewardship schemes (including a container return scheme for beverage containers), as well as support for legislative change and investment in resource recovery infrastructure.

138. As part of the Ministry for the Environment's public consultation on the NZ Waste Strategy and review of waste legislation, feedback was requested on whether the waste levy should

be extended to other final disposal activities such as WtE[52]. Auckland Council made the following statements in its submission:

"The waste levy needs to apply to the incineration of mixed waste, so as not to encourage waste producers to choose incineration over other diversion options further up the waste reduction hierarchy.

If a levy is not imposed on this type of activity, it would result in giving waste-to-energy incineration a financial advantage over landfill. It could also result in the loss of value in materials and the waste of embodied emissions, should waste generators choose an end-of-life waste-to-energy option, rather than resource recovery."

6 Discussion

139. This section provides an overview of considerations relating to waste to energy technologies, with regard to the context of Tāmaki Makaurau. Four key principles, as recommended by the Ministry for the Environment in its guidance document on WtE (MfE, 2020) are used to frame this discussion.

140. Although WtE technologies cover a broad range of processes, most published literature is focused on the thermal WtE process of incineration, and its comparison to landfill - given these are the two most common forms of municipal waste treatment/disposal. Where possible, published literature that discusses the environmental, economic, and social aspects associated with thermal WtE or non-thermal processes are referred to throughout this section also to highlight strengths and implications of key waste to energy technologies and applications.

6.1 Principle 1: Moving up the waste hierarchy and towards a circular economy

141. As expressed in a United Nations report on WtE (UNEP, 2019) the waste hierarchy is not a ladder whereby waste management efforts begin at the bottom with disposal and progress upwards. The report provides advice for countries considering waste to energy technologies and recommends that countries should be *"leapfrogging and adopting a top-down approach to introduce the 3Rs in their waste management systems before considering thermal WtE recovery options".* Similarly, Gertsakis and Lewis (2003) recommended that energy recovery from waste should only be used for materials that have no higher end use other than to be converted to energy.

142. Although utilising certain feedstocks and technologies to produce energy is acknowledged to play a role in decarbonising Aotearoa New Zealand and contributing to the circular economy as discussed earlier (such as the anaerobic digestion of food scraps, or the use of wood products as fuel to replace coal boilers), WtE remains a lower-level waste management tool that sits below the top tiers of the waste hierarchy ('avoid', 'reduce', and 'reuse'). No WtE facility will result in strong waste avoidance, reduction, or reuse outcomes, as the operation's own existence creates minimal incentives to avoid the generation of materials that the WtE process specifically requires for its throughput and operation.

143. Beneath the reduce/reuse tiers, the position of WtE on the waste hierarchy differs and is debated, depending on feedstocks processed and the outcomes a technology achieves. Further, the size, design, and application of certain WtE technologies/processes may offer more support to the circular economy than others.

[52] *Should the levy be able to be imposed on final disposal activities other than landfills (such as waste to energy)*? https://consult.environment.govt.nz/waste/taking-responsibility-for-our-waste/supporting_documents/wastestrategyandlegislationconsultationdocument.pdf

144. Anaerobic digestion, for example, is positioned within the 'recycling' tier of the hierarchy, according Te Rautaki Para NZ Waste Strategy (Figure 2), whereas thermal processing (incineration/pyrolysis of municipal waste, or co-processing tyres as a fuel) are positioned below in the 'recovery' tier. Those processes that do not capture heat or recover energy (and are therefore not considered WtE, such as combustion of waste or collection and flaring of landfill gas) are assigned to the lowest tier of the waste hierarchy, disposal.

145. Recent advice provided to NZ Cabinet in November 2022[53] on the use of WtE for processing waste plastics reflects the Minister's advice that WtE proposals should be assessed on a case-by-case basis, particularly where plastic wastes are involved.

146. The Cabinet paper notes that *"the most strategic consideration is whether deploying waste-to-energy technologies will support or undermine: (i) the principle to prioritise low carbon outcomes; (ii) the waste hierarchy; and (iii) a circular economy approach. … Stakeholders noted that failing to consider these aspects could lower incentives to reduce consumption and improve product design, further up the waste hierarchy".*

147. The Cabinet Paper described stakeholder preferences for plastic waste technologies that focus on creating new plastic materials (non-energy producing) rather generating a plastic-derived fuel. Therefore, a WtE technology such as pyrolysis or gasification that 'chemically recycles' plastic wastes into chemicals to reproduce plastic products would be positioned within the 'recycling' tier of the waste hierarchy above recovery (for fuel/energy).

148. Campbell MacPherson (2011) advised Auckland Council to *"utilise its internal resources to focus first and foremost on initiatives around the "top" of the waste hierarchy before considering applying resources to WTE"*.

149. The report noted that there had been little debate or analysis by Auckland Council (or other New Zealand territorial authorities or central government) on the merits of using WtE to process solid waste, largely due to the dominance that landfills have over waste management in this country. A similar sentiment was reported years later by BERL (2019) in research commissioned by the Ministry for the Environment.

150. Since council adopted its first WMMP in 2012, the NZ Waste Strategy policy direction and WMA 2008 have remained substantially unchanged with no specific mention or policy advice on WtE until this year. Debate and analysis of WtE has largely been constrained to specific WtE proposals in specific locations around the country, and the application of council planning rules under the Resource Management Act 1991.

151. Aside from the actual input and outputs of a WtE process, the waste management system context, alongside national waste minimisation and energy policy provisions influence the degree to WtE can enable higher waste hierarchy outcomes and/or supports a circular economy.

152. As an example, Figure 8 illustrates how in certain UK areas where incineration rates are high, corresponding recycling rates are typically lower[54], indicating incineration plants themselves do not necessarily enable or incentivise recycling collection and reprocessing systems - an outcome supported by UKWIN (2018)[55] which reports high levels of recyclable materials remain in feedstock burned by UK incineration plants.

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[53] https://environment.govt.nz/assets/publications/ENV-22-MIN-0038-Minute-and-cab-paper-10-Nov-22-v2.pdf
[54] https://www.newstatesman.com/spotlight/sustainability/energy/2023/01/waste-incineration-levels-green-defra-chief-scientist
[55] https://ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf

153. In comparison however, Germany reports the highest recycling rates in the world (>60%) despite relying primarily on incineration to manage its waste. A combination of stringent policy measures and targets helps to make this outcome possible in Germany, including the use of a deposit refund scheme for containers. In addition, from an energy context, the burning of waste can be considered beneficial (based on a carbon perspective), as it substitutes the use of fossil fuels in Germany's electricity grid.

154. For Tāmaki Makaurau, the introduction of a large-scale thermal waste to energy technology would require significant legislative and economic changes to ensure waste avoidance, reuse, and recycling initiatives can succeed alongside such a technology, or risk these higher waste hierarchy tier activities being displaced.

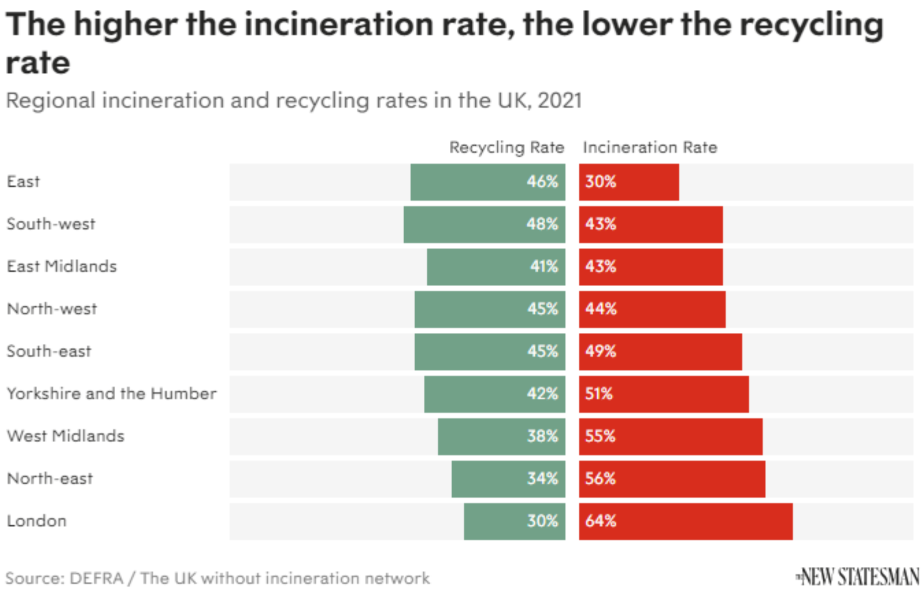

Figure 8: Comparison of incineration and recycling rates in UK

155. Since council's first WMMP in 2012, the establishment of EcoGas's AD plant is the most significant WtE development which has occurred to contribute to Auckland's waste and resource recovery system. While the plant is located outside the region, Auckland Council was instrumental in its establishment by committing to implementing a separate food scraps kerbside collection service and tendering for a dedicated processing solution.

156. In recent years, the collection and separation of specific wastes (including wood, used oil, and tyres) for use in co-processing WtE applications has continued and expanded through industry and commercial initiatives, alongside some government funding and policy provisions for product stewardship schemes. Further, landfill gas capture for energy utilisation continues to be a feature at all three of the main modern sanitary landfills that the Auckland region relies on.

157. Given national policy relating to waste minimisation and energy remains in development[56], and that Auckland Council has a Zero Waste vision, is committed to the expansion of a resource recovery network and continues to have limited influence over large quantities of

[56] As an example, the public consultation document on the review of the NZ Waste Strategy proposed the first phase of work require was to "Catch Up" and "Complete the foundations for transformational change" https://environment.govt.nz/assets/publications/waste-strategy-and-legislation-consultation-document-.pdf ; and the NZ Energy Strategy is in development and due by end of 2024.

waste generated across the region, the establishment of a large scale WtE plant that targets mixed wastes from the region presents a high risk of displacing waste minimisation initiatives that sit higher on the waste hierarchy.

6.2 Principle 2: Managing environmental impacts, especially greenhouse gas emissions

6.2.1 Greenhouse Gas Emissions

158. The impact on global warming potential from greenhouse house emissions (GHG) released by WtE processes depends largely on the **composition of the feedstock used**, the proportion of carbon-based materials, and the source of this carbon.

159. Most municipal solid waste contains biogenic (derived from plants) and non-biogenic (e.g. plastics, metals) components. Data from the US EPA (Environmental Protection Agency) shows the biogenic percentage of MSW continues to decrease as people use more (and discard more) non-biogenic materials. This is happening in parallel with increased recovery of biogenic materials (i.e. paper/cardboard, wood, food scraps, green waste) before these enter the waste stream.

160. Since non-biogenic material (i.e. plastics) typically contain higher heat potentials, the average heat content of MSW as a whole is increasing, making the feedstock a more efficient fuel for producing energy - however that comes with higher carbon emissions and climate change implications, as well as other environmental risks.

161. Most of the carbon content in waste feedstocks (both biogenic and fossil-fuel-based carbon) that gets processed by WtE technologies is emitted as carbon dioxide (CO_2) to the atmosphere. The main exceptions being carbon stored in by-products or chemicals produced through the processes or CO_2 captured by carbon capture and storage add-on technologies.

162. Life Cycle Assessment (LCA) models are often employed to evaluate the environmental impacts of waste disposal technologies in terms of greenhouse gas emissions. Accurate estimates of the Global Warming Potential (GWP) of different disposal methodologies depends on numerous factors that can differ substantially across locations of interest.

163. Some studies report that the GWP is lower for landfill than for waste incineration (e.g. Assamoi & Lawryshyn 2012), while the vast majority report the opposite as shown by Dastjerdi et al (2021) in a systematic review of GWP of landfill versus incineration research. Consideration of local context (i.e. waste composition, timescales, potential fossil fuel offset and carbon sequestration) is therefore imperative to identify the environmentally preferred option, from a GWP perspective (Istrate et al 2020).

164. The composition of waste is a key consideration for accurate emissions comparisons of the different disposal technologies (Dastjerdi et al 2021). Waste with higher concentrations of carbon from fossil sources (i.e plastics) will have greater emissions when incinerated than landfilled (Bishop et al. 2021). One Mt of plastic packaging will release, on average, about 2.9 Mt of CO_2 into the atmosphere (Hamilton et al 2019).

165. The incineration process volatizes and releases the fossil carbon in plastics almost instantaneously as CO_2, whereas plastics in landfill decompose so slowly that they are conventionally modelled as releasing zero GHG (e.g. Manfredi et al., 2011).

166. Incidentally however, a recent study demonstrated that plastic releases methane and ethylene – two powerful GHGs – when exposed to sunlight (Royer et al 2018)[57]. Crucially for considering emissions within landfill, once the release of emissions is initiated by sunlight, GHG emissions continue in the dark at a rate that depends on the amount of previous sunlight exposure.

167. Ultimately however, levels of GHG emissions from both biogenic and fossil sources of waste disposed to landfill will depend on the **efficiency of gas capture** utilised at the site. Significant uncertainty surrounds the topic of estimating landfill gas/methane emissions and gas capture rates however – both whole-landfill emissions each year and during the lifetime of a landfill.

168. The landfill gas capture rate is a percentage of the generation rate and is a function not only of the effectiveness of the gas capture system, but also of factors such as the original landfilling methods, depth of waste, leachate saturation levels, and cap permeability. The Climate Change Commission estimates the average gas capture for landfills in NZ to be 68%[58]. This is broadly in line with international estimates of lifetime landfill capture rates, although international studies and local reporting suggest rates can be significantly higher[59] or lower[60].

169. The timescale of focus is an important consideration regarding GHG emissions, as GHG emissions are released quickly from an incinerator/thermal processing plant, whereas landfills emit GHGs over decades. While methane is a potent GHG gas generated within landfills and released from decomposing biogenic (organic) waste in landfills, it remains in the atmosphere over a shorter timescale compared to CO_2 (Ballinger et al 2020).

170. While some biogenic waste decomposes to generate landfill gas, not all carbon is released as carbon dioxide and a portion of biogenic waste decomposition remains incomplete and is referred to as **carbon sequestration** (Anshassi et al 2021). Carbon storage (or carbon sequestration) is sometimes factored into landfill GHG emissions models by applying a carbon offset to the assumed portion of biogenic carbon that remains in landfill long-term, rather than being emitted to the atmosphere (Anshassi et al 2021).

171. A recent meta-analysis compiled information from numerous studies to identify which key assumptions resulted in the LCA reporting landfill or incineration to have a greater GWP (Anshassi et al 2021). A critical factor when determining that the GWP of incineration is more favourable than landfill is the inclusion of **energy recovery offsets** when energy produced by incineration displaces energy produced from fossil fuel sources.

172. For example, a review of 15 LCA studies found that all favoured incineration over landfilling because incineration does not produce methane, and the energy recovered from incineration offset energy produced from fossil fuel sources (Istrate et al 2020). However, in other studies, where the assumption that GHG emissions offset fossil fuel-derived energy

[57] The study examined the seven most common types of plastic, and while all release GHGs, due to its lower density LDPE breaks down more easily than other plastics and consequently emits GHGs at a much higher rate.
[58] https://www.climatecommission.govt.nz/public/Inaia-tonu-nei-a-low-emissions-future-for-Aotearoa/Inaia-tonu-nei-a-low-emissions-future-for-Aotearoa.pdf
[59] WMNZ Ltd's submission to The NZ Productivity Commission on Low-Emissions Economy states that *"Redvale, Whitford and Kate Valley landfills all recover greater than 90% of the methane gas that they produce. WM is of the view that less than 5% of the methane produced at a well operated Class 1 landfill is released to atmosphere as a GHG."* https://www.productivity.govt.nz/assets/Submission-Documents/633e4c513a/DR-332-Waste-Management-New-Zealand.pdf
[60] https://www.bioenergy.org.nz/resource/report-landfill-gas-capture-rates; https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_3_Ch03_SWDS.pdf

was not included in the LCA, this contributed greatly to the outcome of landfilling being more favourable (e.g. Assamoi & Lawryshyn, 2012).

173. This is a particularly crucial consideration for thermal WtE in New Zealand, as discussed earlier, the NZ electricity grid is currently based on 85% renewable energy with the goal of being 100% renewable by 2050, and our total energy sources (including transportation, industrial energy demands) sits around 30% renewables. The energy offset benefit from utilising WtE technologies in NZ therefore will be much higher if the existing energy sources are offsetting fossil-fuel energy sources, rather than displacing renewables. In the wider NZ electricity context, this would depend largely on what sources of energy are being displaced, and there is less chance of this for electricity grid compared to the use of fossil-fuel usage in other energy applications (e.g. natural gas or coal use for process heating, or transportation fuels).

174. The four factors discussed above that contribute most to the outcome of LCA models that favour either landfilling or incineration, from a GHG perspective are:

- The influence of varying **waste composition,** especially the percentage of mixed plastics. With a higher proportion of plastics in the feedstock, landfill is preferable to incineration.

- Accounting for **carbon sequestration** in the model had some influence towards favouring landfill.

- The biggest difference between the two waste disposal methods was the **gas collection efficiency**, where landfills with high gas collection efficiency are more favourable than incineration.

- **Energy offsetting** has a large impact on the outcome of models comparing the overall emissions from landfills and incineration plants. In a NZ scenario with 85% renewable energy, energy produced by incineration plants would not offset enough fossil fuels to favour this method over landfill.

175. A model prepared by Anshassi et al (2021) (which compared the four key assumptions of LCAs described above) agrees with the reported results in the literature: the more aggressive the landfill gas collection is and the less fossil-based the energy offset grid is, the more likely landfills will be more favourable in terms of GHG emissions.

176. Zero Waste Scotland's study reaches similar conclusions as presented in a report by Eunomia (2020) which investigated GHG impacts between landfills and incineration. The report stated that incinerators that produce only electricity are a more carbon-intensive form of electricity generation than the current marginal grid average, and thus *"EfW technologies can no longer be considered low carbon solutions"*[61]. The report concludes that the use of incineration is *"incompatible with the achievement of local net zero climate change targets in respect of emissions from energy generation, unless coupled with carbon capture and storage. This technology is not yet commercially viable and its use will considerably increase the cost of waste treatment".*

177. Most published studies on WtE compare waste incineration to landfill (with gas capture) because these technologies have been the predominant form of waste disposal globally. The performance of alternative thermal technologies, such as pyrolysis or gasification, have not been included in the LCA comparisons discussed above as empirical data on GHG emissions is lacking given there are few commercial facilities successfully operating at scale.

[61] https://www.clientearth.org/media/1h2nalrh/greenhouse-gas-and-air-quality-impacts-of-incineration-and-landfill.pdf

By extrapolation however, LCA comparisons of incineration versus landfill may apply more generally to the other thermal WtE processes vs landfill discussion. Recent modelling by Dong et al. (2019) found negligible difference in the GWP of three different WtE scenarios considered - Incineration, Pyrolysis, Gasification - although there were higher CO_2 emissions noted for the Gasification-melting technology scenario.

178. GHG emissions associated with anaerobic digestion relate primarily to fugitive emissions, and these are low especially when compared to the capture rate of landfill gas – which can be compromised by many influencing factors as discussed earlier. Comparatively the design and operation of an AD plant is about maximising bio-gas capture for combustion, and the efficiency of gas capture is a critical operational performance criterion. While fugitive emissions will result from leakages or inefficient operations, research by EU Biogas[62] indicate the levels of fugitive gases are low (ranging from 0.01 to 1.8%).

6.2.1 Other environmental impacts

179. In addition to the production of GHG emissions, all WtE plants create other environmental impacts during their lifetime – from construction through to operational and decommissioning phases. Potential harm to the natural environment (and human health and wellbeing) from WtE operations depends on numerous factors, including the waste feedstocks processed, plant location, technologies used, and operational performance.

180. The release of exhaust gases to the atmosphere and the discharge of residual wastes are key focal points for opponents of thermal WtE processing plants, as they are for plant operators as they represent critical performance measures too. Other key environmental, health and safety risks relate to operational failures (e.g uncontrolled discharges, fires, explosions), as well as general nuisances issues relating to odour, noise, dust etc.

Air quality - environmental and health impacts

181. In a report to ClientEarth, Eunomia Research and Consulting Ltd UK (2020) summarises research on air quality impacts from incineration in the UK. Outcomes from a recent systematic review of academic literature (Cole et al, 2019) was highlighted in Eunomia's report, in which it was reported that there is "*a dearth of health studies related to the impacts of exposure to WtE emissions*". The study by Cole et al (2020) found 19 academic articles which met inclusion criteria from 269 search results, and these included two epidemiological studies, five environmental monitoring studies, seven health impact or risk assessments, and five LCA assessments.

182. The limited evidence suggested that well-designed and operated WtE facilities using sorted feedstock are critical to reduce potential adverse health (cancer and non-cancer) impacts, due to lower hazardous combustion-related emissions. Poorly fed WtE facilities may emit concentrated toxins with serious potential health risks, such as dioxins, furans, polyaromatic hydrocarbons, and heavy metals; and these toxins may remain problematic in bottom ash also. Cole et al (2020) concludes that rigorous assessment of WtE facility/technological characteristics and refuse type used is necessary when planning/proposing facilities to protect human health.

183. Globally, the Stockholm Convention, which provides international guidance on the safe management of persistent organic pollutants (POPs), identifies waste incineration as a key

[62] https://www.europeanbiogas.eu/eba-report-sheds-light-on-the-efforts-of-the-european-biogas-industry-to-reduce-methane-emissions-with-sustainable-biogas-production/

source of dioxin and furans pollutants[63]. While significant improvements have been made to the design and operation of combustion, flue gas cleaning and emission controls systems in modern thermal WtE technologies (compared to incineration plants from the 1970s to the 1990s), the UNEP (2019) warns that mismanaged thermal WtE plants have been shown to produce unsafe emissions, despite these advanced emission control technologies.

184. Although technology improvements can result in WtE processes reliably achieving lower emission limit values than the European Union's Industrial Emissions Directive (2010/75/EU), cases of exceedances of dioxins have been reported in both developed and developing countries (UNEP, 2019; Gass et al, 2018; Wilken et al, 2018). According to Zero Waste Europe[64], even the most advanced thermal waste-to-energy technologies cannot avoid the release of pollutants into the air and surrounding environments.

185. Analysis of air quality emissions from incineration plants published on behalf of UK government bodies in 2010 provided the following statement – *"While it is not possible to rule out adverse health effects from modern, well regulated municipal waste incinerators with complete certainty, any potential damage to the health of those living close-by is likely to be very small, if detectable*"[65]. Eunomia (2020) acknowledges however that studies and data used for UK government analysis primarily focus on impacts from potential carcinogenic effects of pollution from incinerators (including emissions of dioxins), with some consideration of the impact of particulate pollution. No consideration has been made in the government analysis regarding the impact of nitrogen oxide (NOx) emissions on public health, or the emerging evidence regarding links between NOx and dementia and mental health[66].

186. A more recent UK study published in 2020 for the Greater London Authority by Air Quality Consultants Ltd, as reported by Eunomia (2020), provided one of the first attempts to quantify the impact on health from both particulates and NOx pollution from incineration. The report's analysis concluded that 15 deaths of London residents per year are calculated to be attributable to emissions of nitrogen oxides and particulate matter from the city's five EfW facilities[67].

187. The report also highlights that during plant shut down and start up stages, emissions, and therefore health impacts, can be much higher, and may also rise where operational stoppages occur. The UNEP (2019) cites studies that have similarly concluded that dioxin and furan emissions are substantially higher in transient stages after a cold start-up than in stable combustion conditions.

188. A systematic review of health impacts of incineration was published by Australian medical and public health researchers in 2020 (Tait et al, 2020), which reviewed outcomes from 93 manuscripts. The paper concluded that significant health risks are associated with waste incineration, including many older incinerators being linked with neoplasia (abnormal and excessive growth of tissue), reproductive issues and other diseases, and while the results were not consistent across the literature, *"based on a precautionary principle there is insufficient evidence to conclude that any incinerator is safe".* The report notes there is

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[63] https://www.pops.int/Implementation/BATandBEP/BATBEPGuidelinesArticle5/tabid/187/Default.aspx

[64] https://zerowasteeurope.eu/2018/02/9-reasons-why-we-better-move-away-from-waste-to-energy-and-embrace-zero-waste-instead/

[65] Health Protection Agency (2010). The Impact on Health from Municipal Waste Incinerators. https://www.gov.uk/government/publications/municipal-waste-incinerators-emissions-impact-on-health/phe-statement-on-modern-municipal-waste-incinerators-mwi-study - cited in Eunomia (2020).

[66] See reference list: Cerza., et al., 2019; King, 2019.

[67] Air Quality Consultants. (2020). Health Effects due to Emissions from Energy from Waste Plant in London, Report for the Greater London Authority. https://www.london.gov.uk/sites/default/files/gla_efw_study_final_may2020.pdf

some suggestion that newer incinerator technologies with robust maintenance schedules may be less harmful, but diseases from exposures tend to manifest only after many years of cumulative exposure, so it is premature to conclude that these newer technologies improve safety (Tait et al, 2020). The study also offers several policy recommendations, including proposed plants requiring independent third-party studies, ensuring health and safety standards for workers, plant operational requirements, and ensuring plants are located away from areas of food production.

189. Such studies raise the importance of independent long-term monitoring for plant emissions, in addition to the inclusion of pollutant (including dioxins) monitoring during transient operating stages. Unlike pollutants such as NOx and particulates, which are subject to continuous monitoring at UK facilities, dioxin levels are typically only assessed at specific points in the year. Without certainty of on-going emission levels there is therefore higher risks of emissions and thus associated health and environmental risks.

Residual waste and other technological considerations

190. While incineration plants can reduce waste quantities by between 75-90 per cent, there remains residual quantities of ash (approximately 20%) that requires final disposal. Disposal of the residues is one of the most environmental impactful phases of thermal WtE technologies, according to life cycle analysis research by Zamon (2010).

191. Incineration WtE produces three main types of residues: bottom ash (BA), fly ash, and air pollution control residues. A greater quantity of bottom ash is produced than the other two residues, and it is comparatively less hazardous. Fly ash and air pollution residues are characterised by having high content of chlorides, heavy metals and organic compounds, including dioxins and furans.

192. To avoid disposal of bottom ash, alternative uses are often sought. The most common application for utilizing bottom ash is as aggregate for the construction of roads and embankments. Where alternative uses for WtE bottom ash are proposed, whole of life impacts and costs are important considerations, as research indicates there are concerns with this utilization due to elevated metal concentrations and leaching potential[68].

193. Pyrolysis and gasification processes are often portrayed as ‘alternative’ technologies capable of solving two key environmental challenges associated with thermal incineration (e.g. air emissions and disposal of ash). There remain few examples however of alternative thermal WtE plants of commercial scale which process mixed wastes streams, and limited associated published evidence to support claimed benefits and impacts.

194. Perrot and Subiantoro (2018) compared gasification and pyrolysis technology options with anaerobic digestion and incineration processes, and states that while gasification technology can emit less carbon dioxide than incineration plants, the technology is more expensive due to emissions treatment, and both pyrolysis and gasification technologies are not yet mature.

195. In a comparative life-cycle-analysis studies of incineration and pyrolysis-gasification processes, Zaman et al (2013) reported incineration has higher environmental impacts than pyrolysis-gasification for the following categories: acidification, eutrophication, global warming, human toxicity, and aquatic toxicity; however, pyrolysis-gasification had the higher potential environmental impact for terrestrial ecotoxicity and photochemical oxidation

[68] Refer to reference list: Margallo, M. et al. (2015); Xiaomin Dou., et al. (2017); Boyu et al (2023).

categories. The environmental burdens for both technologies are mainly caused by the volume of the thermal gas (emissions) produced and the final residue to disposal.

196. Of note, both pyrolysis and gasification processes are defined as incineration by the U.S. Environmental Protection Agency and the European Union – as the gas products or liquid fuels produced are combusted. Should the technology be applied to 'chemical recycling' processes (i.e. plastic feedstock being converted into chemicals for use into new plastic products[69]) this type of definition may be less applicable.

197. A critique of the use of pyrolysis and gasification processes for 'chemical recycling' of plastics is provided in a technical report by Rollison and Oladejo (2020). They describe the process as being akin to chemical processing plants rather than conventional incineration and highlight a gross lack of independent evidence on the technologies promoted.

198. Rollison and Oladejo (2020) states that inadequate reporting on the status of chemical recycling has led to it being portrayed well above and beyond its capabilities. Recommendations are for greater transparency on operational performance, energy balances, and environmental impact assessment – especially as "*multiple pathways to adverse environmental impact exist and these are grossly under-assessed. Managing these impacts will impose high costs and operational constraints on technology operators. For this reason, chemical recycling should be treated with extreme caution by investors, decision makers, and regulators*".

199. Levidow and Upham (2017) discuss how, for the past decade in the UK and EU, there have existed technological expectations with respect to anticipated improvements to alternative thermal treatment options, as expressed in this statement by UK government authority DECC in 2012…. "*advanced technologies **have the potential** to deliver more efficient generation in the long term and **have the potential** to deliver further benefits beyond renewable electricity generation', e.g. through a clean syngas that can substitute for fossil fuel*."

200. Advice to Auckland Council on WtE by Campbell MacPherson (2011) indicated a similar expectation of future technology advancement: *"We anticipate that the continued improvements in WTE technology, particularly in the areas of gasification and pyrolysis, will lead to a renewed examination of WTE in New Zealand over the next decade as increasing landfill levies and other measures focus attention on minimising waste to landfill".*

201. Further, Levidow and Upham (2017) report that UK government emphasised expectations for energy benefits from *future* gasifiers as a rationale for subsidising current two-stage combustion gasifiers (to the same subsidy level as other AD plants)[70] – despite the fact that anaerobic digestion was in existence already generating clean bio-gas.

202. A report from 2017 by a US-based WtE opposition group, No Burn (2017), highlighted examples of pyrolysis and gasification proposals that were unable to progress due to community opposition, government scrutiny or lack of investment, and plants that have been forced to shut down due to technical or financial failures. A more recent report (No Burn, 2021) further warns of numerous risks associated with investing in unproven alternative technologies that use mixed wastes to produce jet fuel.

[69] For example, investigations by NZ Packaging Forum into options for soft plastics includes the consideration of pyrolysis/gasification to convert plastics to chemicals for repolymerisation – which it states as being "*still a relatively novel commercial process with nascent but significant markets*". Nextek (2023).

[70] Refer Levidow and Upham (2017), page 7 - "*In the longer term, as the technology becomes more advanced, the use of syngas **may** make a significant contribution to our renewable energy and low-carbon ambitions and it has therefore been afforded the same financial support as biogas produced from anaerobic digestion" (UK Renewable Energy Strategy)*.

6.3 Principle 3: Commercial viability over the long term

203. In 2011, advice to Auckland Council concluded *"the current economics around a WtE plant for Auckland look marginal*", and the actual viability of a WtE project would depend on a range of factors specific to a proposal (Campbell MacPherson, 2011).

204. As part of council's last waste assessment in 2017, the cost and benefits of a large-scale incineration plant were analysed with the conclusion being that thermal incineration of municipal wastes would require capital beyond council budgets and would not support council's Zero Waste vision.

205. From a general perspective, the financial performance and commercial viability of any WtE facility will vary given the wide range of dependent factors, including the following:

- Type of WtE technology
- Composition of the waste
- Long term supply and access to feedstock/waste materials
- Scale and throughput of the facility
- Capital expenditure cost (including feasibility studies and consenting)
- Operating costs (including disposal costs for residual wastes)
- Operational performance (downtime, thermal and electricity efficiency)
- Environmental performance
- GHG emissions and carbon tax/credits costs
- Regulatory and legislative environment
- Competition for source waste material and local market conditions (e.g. comparative cost of landfilling)
- Potential revenue for WtE outputs (e.g. electricity, heat, recycled products, other by-products)
- Decommissioning costs

206. WtE guidance from MfE (2020) highlights the following considerations as key to the commercial viability of WtE proposals in NZ:

- ongoing supply of enough feedstock and whether the feedstock is mixed or requires pre-sorting;
- transportation requirements;
- health and safety costs;
- demand/competition for products, including from other forms of renewable energy; and
- whether a proposed technology is well tested.

207. Beyond these considerations, capital investment and operating costs are the two major economic components which determine the development of any WtE facility. While significant capital investment is required for thermal processing plants, operating costs represent a significant proportion of total plant cost also, as illustrated in Figure 9 (Estimated total cost of a thermal WtE plant in Europe (cited in UNEP, 2019)), which represents costs for a large scale thermal WtE plant with an estimated lifespan of 40 years.

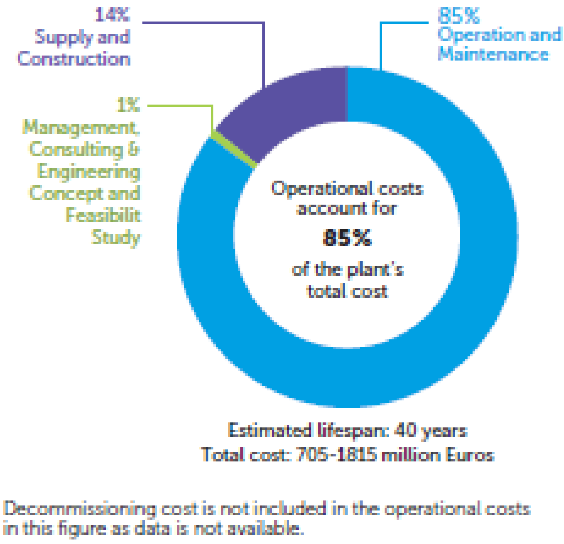

Figure 9: Estimated total cost of a thermal WtE plant in Europe (cited in UNEP, 2019)

208. Research by Campbell McPherson (2011) for Auckland Council presented a range of capital costs for different sized WtE plants, as well as presenting a graph from a UK report by SLR Consulting Limited (Figure 10) showing the relative costs of thermal WtE compared with less capital-intensive AD plants.

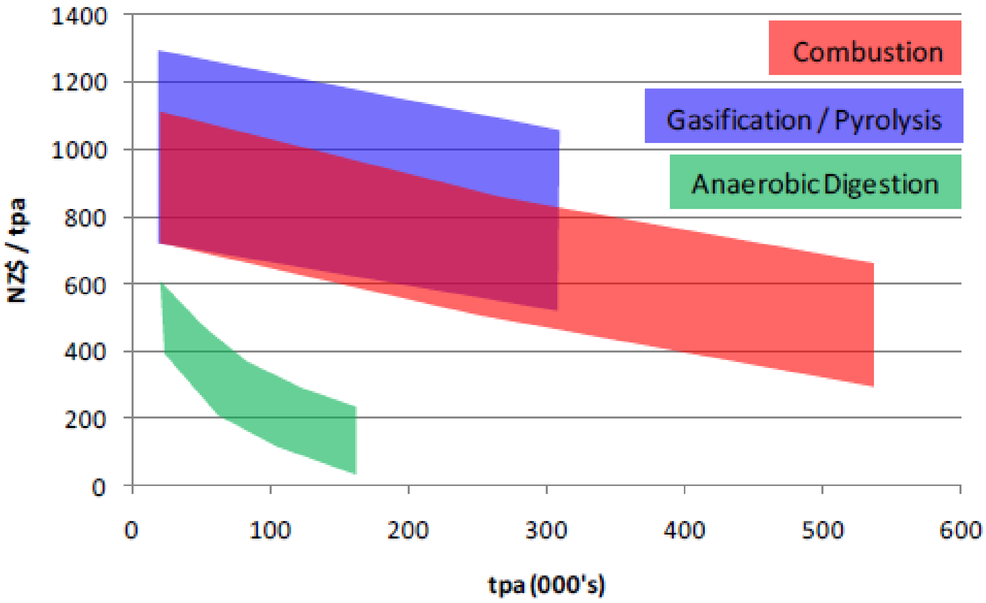

Figure 10: Comparison of Relative Capital Costs of WTE Technologies (cited in Campbell MacPherson, 2011)

209. For an incineration plant, a range of between NZ$666 and NZ$2,223 per annual design tonne was reported, which in today's dollar terms[71], for a 300,000 tpa plant, equates to between $275 million and $917 million. The costs for pyrolysis or gasification plants were reported to be higher.

[71] https://www.rbnz.govt.nz/monetary-policy/about-monetary-policy/inflation-calculator

210. By comparison, a proposed 365,000 tpa incineration plant in Waimate by company SIRRL is reported to require an investment of $350 million[72].

211. Recent evidence presented by a consultant for Waste Management Ltd as part of Environment Court proceedings for the proposed landfill in Wayby Valley[73], reported the estimated capital cost to establish a 600,000 tpa WtE plant would be between $560 million and $1,100 million NZD. This was a direct currency translation from UK estimates, and it was noted NZ local market conditions could increase this price significantly.

212. Regarding operating costs, UNEP (2019) report for a moderately large scale thermal WtE plant these can range between USD $95 to $200 per tonne, which are typically higher than operating costs for a non-thermal anaerobic digestion plant ($USD 65-150). Factoring in costs for thermal WtE to ensure the safe treatment and disposal of residual wastes (or the costs required to enable the safe utilization of bottom ash products) is an important economic consideration also, as ash generated from incineration may not meet landfill waste acceptance criteria as Waste Management NZ has highlighted[74].

213. Evidence presented by Grant (2022) indicate gate fees in NZ for a WtE plant (excluding any waste levy) would be in the order of $155 to $238 NZD (conversion from UK pounds). BERL (2019) reported one large waste company in NZ had determined a gate fee for a WtE plant would need to be around $400 per tonne to be profitable.

214. In a recent report by the US Department of Energy (2019), a key recommendation was to seek methods to reduce operating costs and increasing revenues of existing incineration plants. Opportunities were stated as being "*advanced emissions control strategies to lower costs associated with environmental compliance, development of novel corrosion-resistant materials to reduce maintenance costs, and advanced separations to recover valuable materials from ash*". Further, the report recommended "*Develop waste preprocessing and handling strategies to reduce feedstock variability of MSW streams".*

215. Regarding anaerobic digestion, the report also recommended enhancing the economic viability of existing anaerobic digestion facilities. Opportunities identified were to research of co-digestion strategies to enhance methane production and extend steady-state operation, low cost strategies for biogas cleanup to result in pipeline quality natural gas, novel thermocatalytic processes for the conversion of biogas and landfill gas to fuels and high-value co-products, and advanced reactor design and optimization of organisms to enhance biological conversion of gases to fuels and coproducts (US Department of Energy, 2019).

216. Detailed analysis of a WtE plant's business case would be required to assess a project's commercial and financial viability (including return on investment and payback period), as well as identifying the potential risks associated with applying the technology[75]. A key operational risk, particularly for newer technologies, relates to a potential gap between actual and design performance outcomes – as this would have potentially severe impacts on a project's cost, as well as environmental, and social outcomes.

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[72] https://www.projectkea.co.nz/about

[73] Statement of Evidence of Eleanor Grant on behalf of Waste Management NZ Ltd. Waste to Energy Technologies. 11 February 2022.

[74] https://www.wastemanagement.co.nz/news-and-media/waste-to-energy-in-new-zealand/

[75] For example, the Ministry for Business, Innovation and Employment and Air New Zealand have recently announced they are co-funding a feasibility study into the production of 'Sustainable Aviation Fuel' using forestry residues and mixed municipal wastes. The technologies proposed are offered by two separate companies - Fulcrum BioEnergy and LanzaTech. The first uses a proprietary, patented process to process mixed wastes using a gasification process, and Lanzatech propose to convert forestry residues into ethanol using its newly commercialised gas fermentation technology. https://www.mbie.govt.nz/about/news/studies-fuel-investigation-into-sustainable-air-travel/

217. There are no large-scale mixed waste WtE operation operating in New Zealand, and the reasons for this are varied and go beyond economic viability, although according to Eunomia (2023), one of the principal reasons is the relatively high cost of a thermal WtE plant compared to existing large-scale landfill. Further, internationally WtE facilities are typically associated with both heat and electricity generation which is not a straightforward economic proposition in New Zealand as heat users need to be found and co-established, and electricity can be produced from other lower cost renewable resources.

218. Levidow and Upham (2017) note that regardless of the type of thermal WtE technology, the energy conversion and capture efficiencies are poor if there is no economic use for the heat produced, such as via a nearby district heating system. Interestingly however, waste heat has only been used in 2% of the UK's WtE schemes according to DEFRA (2014), and this is reported to be partly due to state subsidy, market incentives and distribution infrastructure are weaker for heat use than for electricity. In the UK, incinerators have been the recipient of large implicit subsidies, following the introduction of the EU Landfill Directive.

219. Given Auckland's moderate climate, the need and ability to utilize heat generation locally is expected to be limited without a dedicated industrial co-partner. Further, district heating systems are not a common feature of NZ urban infrastructure, and as demonstrated by a recent failure in post-earthquakes Christchurch to establish such a scheme, the benefits versus costs are not obvious or compelling[76].

220. A study by Auckland Council and Waikato University in 2018 investigated process heat demand in Auckland, alongside potential focus areas to reduce emissions[77]. One of the key outcomes from this research was that users of process heat in the low to medium temperature range (20 to 200°C) – which accounts for approximately 70 per cent of Auckland's process heat applications – are expected to be able to transition away from coal/natural gas to instead use the electricity grid by adopting high temperature heat pumps and process optimisation. This would suggest the remaining 30% of process heat applications in the region would be seeking alternative decarbonisation solutions (e.g. bio-mass/bio-energy applications).

221. The potential to convert existing coal/natural gas plants to instead use Auckland's mixed solid waste was assessed by Campbell Macpherson (2011) as part of Auckland Council's waste assessment research, over 10 years ago. The lower calorific value of solid waste compared to coal/natural gas was identified as a key limiting factor, along with a range of other potential economic, operational, and social risks and impediments. By comparison, Genesis Energy recently successfully trialed the use of (imported) torrefied wood as a coal substitute at the Huntly power station[78] - which demonstrated that specific biomass feedstocks can offer equivalent calorific value to coal, and more appropriate and effective than seeking energy from heterogenous municipal waste.

222. Securing funding for WtE operations (either via private operators/investors, banks or government) is likely to be predicated on securing both long-term supply agreements for both waste/feedstocks, as well as off-take agreements for outputs (e.g. heat, electricity, syngas, bio-char etc). Obtaining long-term supply agreements for feedstocks suitable for the type of WtE is therefore a critical factor influencing the financial viability of a proposal.

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76 https://www.researchgate.net/profile/Steve-Matthewman-2/publication/342902944_From_perfect_green_dream_to_total_failure_The_rise_and_fall_of_Christchurch%27s_District_Energy_Scheme/links/5f0ccf72299bf1074456d02d/From-perfect-green-dream-to-total-failure-
77 https://www.mbie.govt.nz/dmsdocument/5348-auckland-council-process-heat-technical-paper-submission
78 https://www.genesisenergy.co.nz/about/news/genesis-biomass-trial-successful

223. To obtain feedstock, any proposed large scale thermal WtE facility in Auckland would need to compete for and get access to wastes from the same companies that own and operate incumbent landfills, and/or other resource recovery infrastructure (including AD, and co-processing of tyres, wood).

224. Reports by BERL (2019) and Eunomia (2023) both suggest that landfill owners and/or resource recovery companies are unlikely to support a move to large-scale WtE, given their sunk investments in existing or new/expanded landfills and/or other resource recovery infrastructure. It is also noted that while the parent companies who own EnviroNZ and WMNZ (the two largest waste operators in NZ) operate WtE facilities in other countries, they have not publicly expressed interest to date in establishing a large scale WtE plant in Aotearoa, rather in the case of WMNZ, rejected the option[79].

225. UNEP (2019) suggests a minimum processing capacity for incineration plants of 100,000 tpa, with facilities commonly sized between 200,000 and 600,000 tpa. Smaller operations for AD and pyrolysis/gasification are more common – for example from 10,000 to 100,000 tpa. The quantity of household refuse controlled by council is in the order of 200,000tpa, although this tonnage is expected to reduce following the implementation of council's food scraps collection service, alongside increased diversion via other measures.

226. The total waste disposed to landfills from Auckland includes significant quantities of materials that do not possess high calorific value, and would add little value and more cost to a WtE process – for example, soils, rubble, large metal components, plasterboard, as well as sludges with high moisture content or other hazardous materials such as asbestos. As explained in evidence presented by Grant (2022) on behalf of Waste Management NZ Ltd as part of court proceedings for WMNZ's new landfill proposal, depending on the feedstock supplied there may need to be significant segregation or pre-treatment required, and the quantity of residual ash increases when non-combustible materials are processed, adding to disposal costs also. The composition of waste received by a WtE plant is therefore a significant factor influencing an incineration plant's commercial viability.

227. Further, despite waste levy fees increasing in recent years and indications the levy could be applied to differing forms of WtE, this pricing signal remains uncertain.

6.4 Principle 4: Strong support from both Treaty partners and community

228. As reported in council's waste assessment in 2011, *"New Zealand has no established record of utilising WtE technologies as a solution to process unsorted municipal or commercial solid waste…[and] in terms of culture, capital costs and population density, etc both New Zealand and Australia have historically favoured landfill as the final waste solution rather than considering WtE technologies".*

229. The proposal for a new privately-owned and operated landfill in Auckland in the Wayby Valley – currently with the Environmental Court of Appeal - has garnered community opposition to the proposed landfill and, for some, created renewed interest in landfill alternatives, including WtE technologies[80]. A quote from Te Rūnanga o Ngāti Whātua Chief

[79] In a position statement by WasteMINZ Behaviour Change Sector Group in 2022, WMNZ states "*Waste Management has done years of research (including visiting countries where it is in use) into the potential role of WtE in New Zealand and has concluded that they are uneconomic, requiring at least four times the capital and operational cost of modern landfills for the equivalent waste volume*". https://www.wasteminz.org.nz/files/Behaviour%20Change/Behaviour%20Change%20WtE%20position%20paper.pdf

[80] For example, 393 submissions opposed a Private Plan Change to allow a landfill operation at a proposed site by WMNZ Ltd and some of these submissions promoted alternative Waste-to-Energy technologies – refer section 14.1.4 (p 159). https://www.aucklandcouncil.govt.nz/HearingDocuments/waybyvalley-pcagd-2020-11-09.pdf

Executive[81], reflects this position: *"the Iwi oppose this application as we wish to focus on applying our responsibilities as Kaitiaki. We will continue to work in partnership with our local community and research waste solutions that will have less impact on our environment. We have initiated discussions with providers who provide alternative options such as marae based waste and education services (Para Kore Trust) and waste to energy technologies*".

230. Further, in recent years there appears growing interest in technologies such as pyrolysis or gasification that target plastic wastes to produce fuels, energy, or chemicals[82]. This interest has likely been influenced by the global impacts China's 'National Sword' policy has had on recycling markets in recent years[83], the impacts of the COVID-19 pandemic on plastic usage and waste generation, and the growing public/industry awareness of and investment in efforts to address impacts of plastic pollution (including the development of a Global Plastics Treaty[84]).

231. Despite this interest in WtE technologies, three large-scale WtE proposals in other parts of the country have been receiving strong opposition from their local communities, mana whenua/iwi representatives, and the coordinating efforts of the Zero Waste Network and Para Kore organisation[85].

232. In Manawatu, a proposal for a pyrolysis plant by a company called BioPlant Ltd has recently been abandoned following vocal community opposition and technical critique[86]. In the Waipā District (Te Awamutu)[87] and in Waimate in the South Island[88], there exists community opposition to current incineration proposals. The proposal by company SIRRL for an incineration plant in Waimate has recently been 'called-in' to the Minister for the Environment on the grounds that the resource consent application is of national significance[89].

233. Involvement of mana whenua/iwi in decision-making processes, and seeking public acceptance, or "social license" as described in He et al (2023), is essential to progress any WtE proposal of scale. Experience has shown however, both globally and locally, that proposals for new large-scale incineration plants attracts widespread controversy particularly regarding potential health hazards, cultural/social injustices, and environmental sustainability concerns.

234. As expressed by mana whenua interests in relation to the proposed pyrolysis plant in the Manawatu rohe – *"As Mana Whenua, our kaupapa, our purpose, is to protect the Aorangi, or skies above us, and the Hautapu, or sacred winds and airways, around us. The prospect of pyrolisis is a frightening one for our people, it threatens to destabilise our commitment to*

[81] https://www.scoop.co.nz/stories/AK2005/S00530/auckland-council-ignores-obligations-to-mana-whenua.htm
[82] https://www.gminsights.com/industry-analysis/plastic-waste-pyrolysis-oil-market; Nextek (2023).
[83] China introduced a 'National Sword' policy in 2018 which restricted and stopped in most cases the import of other countries' plastics and mixed recyclables.
[84] https://environment.govt.nz/what-government-is-doing/international-action/towards-a-global-treaty-to-combat-plastic-pollution/
[85] https://zerowaste.co.nz/waste-to-energy-incineration/; The Zero Waste Network is comprised of various groups around the country all working with their local community towards Zero Waste; Para Kore as mentioned earlier in this report is NZ's largest kaupapa-Māori zero waste organisation and offers this statement on WtE - https://www.parakore.maori.nz/waste-to-energy/
[86] https://www.stuff.co.nz/environment/300524420/petition-launched-to-fight-proposed-feilding-pyrolysis-plant
[87] https://www.scoop.co.nz/stories/PO2306/S00016/south-auckland-fire-shows-risk-of-flock-in-incinerator-proposal.htm
[88] https://frankfilm.co.nz/frank-changing-south/stories-from-the-south-season-5-2023/does-new-zealand-need-a-waste-to-energy-plant/.
[89] https://www.stuff.co.nz/timaru-herald/132309497/council-staff-ask-elected-officials-to-call-in-government-over-wastetoenergy-plant-proposal

the kaupapa of our ancestral home Aorangi, and threatens to diminish our collective capacity to practice Kaitiakitanga, or environmental stewardship" (WasteMINZ, 2022)[90]

235. The main causes for public opposition to WtE plants typically relate to the connections communities have with the location of a plant, the 'lock-in' effect, trade-offs relating to waste avoidance/minimisation outcomes, and depending on the technology and proposed activity a host of public concerns relating to health, safety and the environment. In the recent case in Manawatu, community representatives also cited concerns with the lack of transparency with council decision-making process and community consultation.

236. Similar concerns about council decision-making and transparency were expressed in relation to a since abandoned proposal for an incineration plant on the West Coast of the South Island in Hokitika[91] - by a company with connections to SIRRL.

237. As highlighted by Auckland Council's experience with the establishment of NZ's first AD plant processing food scraps, a new waste to energy technology needs to not only meet resource management planning requirements but seeks to gain support from those communities that enable the supply of wastes, as well as the communities who are connected to the plant's location.

238. While WtE proposals can highlight that local job creation is a key community benefit for the establishment of a plant – these social benefits need to be considered against the types of jobs and enterprise that may be generated through resource recovery initiatives which utilize the same products and wastes that the proposed facility targets. Analysis by Eunomia (2014) and Ribeiro-Broomhead and Tangri (2021) show that the higher up the waste hierarchy the economy progresses, the more jobs are generated.

239. For example, typical WtE infrastructure (landfills and incinerators) generate roughly 1 full time employee (FTE) per 10,000 tonnes of waste treated. This rises for organic waste treatments, with 2 FTEs being forecasted for AD and in vessel composting, and 4 FTEs for windrow composting. The studies from the analysis showed that the number of jobs increased by an order of magnitude for employment in the recycling sector, between 60 and 100 FTEs per 10,000 tonnes. Employment opportunities in re-use and repair rose again by another order of magnitude, with over 500 FTEs per 10,000 tonnes.

240. Of interest also, is consideration of the quality of the work environment across these different activities, given the health and safety risks that workers at a thermal WtE plant are exposed to are considerably higher than jobs that involve reuse and repair functions. Further, as mentioned by WasteMINZ (2022) repair jobs are more beneficial for small communities as they develop skills, build social capital, while also aligning with a circular economy.

241. Given this analysis and considering Auckland is not currently in a WtE 'lock-in' mode, there are likely abundant employment opportunities for the transition to a circular economy by shifting to activities that address the topic tiers of the waste hierarchy. These opportunities are already being demonstrated by Auckland Council's commitment to and expansion of Auckland's Resource Recovery Network, which is resulting in numerous community engagement, innovation, and enterprise benefits realized through the avoidance and separation of wastes and resource recovery efforts.

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[90] https://www.wasteminz.org.nz/files/Behaviour%20Change/Behaviour%20Change%20WtE%20position%20paper.pdf
[91] https://www.stuff.co.nz/national/111782266/why-did-west-coast-plans-for-a-wastetoenergy-plant-fail?rm=a

6.5 Assessment of WtE processes against key principles

242. Table 2 presents a broad assessment of WtE process-feedstock combinations, based on the research discussed in Section 6 in relation to the MfE's four key principles and with consideration of the local Auckland context.

243. A strong preference is shown for AD and co-processing processes, whereas no alignment is given for thermal WtE processing of mixed wastes. For the other options, there remain uncertainties and therefore consideration on a case-by-case basis is recommended.

244. The outcomes presented in Table 2 generally support the asssesment of WtE technologies as presented on page 46 of the NZ Waste Strategy.

Table 2: Broad assessment of WtE against four principles

Process and feedstock	Principle 1 – Waste Hierarchy	Principle 2 – Environmental Impacts	Principle 3 – Commercial viability	Principle 4 – Iwi and Community Support
Co-processing – specific wastes	×	✓	✓	✓
Incineration – mixed wastes	×	×	×	×
Pyrolysis/Gasification – mixed waste	×	×	×	?
Pyrolysis/Gasification – targeted wastes/feedstocks	×	?	?	?
Anaerobic digestion – organic wastes	✓	✓	✓	✓
Landfill Gas	×	✓	✓	✓

7 Summary and recommendations

245. The purpose of this report is to help guide Auckland Council and its communities in decision-making processes regarding the role that WtE technologies have in the development of the region's Waste Minimisation and Management Plan.

246. The key findings presented in the report reinforce outcomes from council's previous waste assessment research, while offering an updated review of recent literature with consideration of national waste and energy policy context and the existing, complex waste system in Tāmaki Makaurau.

247. Key research findings and recommendations are summarised as follows:

- Considering the local context in Auckland as described in this report, large scale incineration of mixed wastes is not a recommended approach for waste minimisation and management for Tāmaki Makaurau. Any proposal in this regard would need to undergo a thorough feasibility study to determine the level of community support and overall viability. Despite improvements in air quality emissions controls over the years, the establishment of a conventional incineration plant in Tāmaki Makaurau is not expected to receive strong political or community support.

- Alternative thermal technologies, such as pyrolysis or gasification, may be favoured over combustion, however the level of support is dependent on the types of feedstocks processed and key outputs, and a thorough evaluation against the MfE's four key principles on a case-by-case basis.

- The capture of landfill gas is deemed a necessary requirement and should receive ongoing support from the council, as it provides an important contribution to reducing landfill greenhouse gas emissions when flared or utilised. Energy generated from captured gas serves as a secondary priority, given stronger emphasis can be directed towards methods to reduce and divert organics materials from landfills to avoid/reduce the generation of bio-genic landfill gas. Notably, there are numerous initiatives in Auckland focused on reclaiming nutritional value and benefits from specific organic wastes to return to people, animals, and/or soils – some with the recovery energy and others not.

- The use of anaerobic digestion (AD) as a WtE technology to recover energy from specific organic wastes aligns well with national and regional policy direction and local context. Compared to thermal processing of wastes or landfill gas capture, AD provides a cost-effective WtE option with fewer environmental/social risks. It is also typically positioned higher up the waste hierarchy than thermal WtE processing according to the NZ Waste Strategy.

- The degree to which a WtE process/application gains implementation success depends on the local context – in particular, the presence of supportive partners, stakeholders, and enabling infrastructure/services, institutions, and policies. The Ministry for the Environment's 2020 WtE guide, and associated four key principles, provide a useful framework to evaluate waste-to-energy proposals.

References

Anshassi, M., Sackles, H., Townsend, T.G., 2021. A review of LCA assumptions impacting whether landfilling or incineration results in less greenhouse gas emissions. Resources, Conservation and Recycling 174, 105810. https://doi.org/10.1016/j.resconrec.2021.105810

Assamoi, B., Lawryshyn, Y., 2012. The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. Waste Management 32, 1019–1030. https://doi.org/10.1016/j.wasman.2011.10.023

Auckland Council., 2017. Auckland's Waste Assessment 2017. https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/docswastemanagementplan/waste-assessment-2017.pdf

Auckland Council., 2018. Te Mahere Whakahaere me te Whakaiti Tukunga Para i Tāmaki Makaurau - Auckland's Waste Minimisation and Management Plan 2018. https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/docswastemanagementplan/auckland-waste-management-minimisation-plan.pdf

Auckland Council., 2020. Te Tāruke-a-Tawhiri. Auckland's Climate Plan. https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/aucklands-climate-plan/Documents/auckland-climate-plan.pdf

Ballinger, A., Shanks, W., Hogg, D.D., Sherrington, D.C., Duffield, L., 2020. Greenhouse Gas and Air Quality Impacts of Incineration and Landfill. Eunomia Research & Consulting report for ClientEarth.

Beca., 2021. Biogas and Biomethane in NZ - Unlocking New Zealand's Renewable Natural Gas Potential. Report prepared by Beca Consultants, Firstgas Group, Fonterra and EECA. https://www.beca.com/getmedia/4294a6b9-3ed3-48ce-8997-a16729aff608/Biogas-and-Biomethane-in-NZ-Unlocking-New-Zealand-s-Renewable-Natural-Gas-Potential.pdf

Bianchi, M., and Cordella, M., 2023. Does circular economy mitigate the extraction of natural resources? Empirical evidence based on analysis of 28 European economies over the past decade. Ecological Economics, Volume 203. https://doi.org/10.1016/j.ecolecon.2022.107607.

Bishop, G., Styles, D., Lens, P.N.L., 2021. Environmental performance comparison of bioplastics and petrochemical plastics: A review of life cycle assessment (LCA) methodological decisions. Resources, Conservation and Recycling 168, 105451. https://doi.org/10.1016/j.resconrec.2021.105451

Boyle, C.A. 2000. "Solid Waste Management in New Zealand". School of Engineering, University of Auckland.

Campbell MacPherson Ltd., 2011. Discussion Paper: Waste to Energy for Auckland. Report prepared for Auckland Council, May 2011. Included in Auckland Council's Waste Assessment 2021, Appendix F (Supporting Reports and Data Update).

Cerza, F., Renzi M., Gariazzo C., Davioli M., Michelozzi P., Forastiere F., and Cesaroni G., 2019. Long-term exposure to air pollution and hospitalization for dementia in the Rome longitudinal study, Environmental Health, 18, pp72.

Chen, B., Perumal, P., Illikainen, M., Ye, G., 2023. A review on the utilization of municipal solid waste incineration (MSWI) bottom ash as a mineral resource for construction materials. *Journal of Building Engineering*, Volume 71. https://doi.org/10.1016/j.jobe.2023.106386

Cole-Hunter T et al., 2020. The health impacts of Waste-to-Energy emissions: A systematic review of the literature, Environ. Res. Lett, https://iopscience.iop.org/article/10.1088/1748-9326/abae9f

Dastjerdi, B., Strezov, V., Rajaeifar, M.A., Kumar, R., Behnia, M., 2021. A systematic review on life cycle assessment of different waste to energy valorization technologies. Journal of Cleaner Production 290, 125747. https://doi.org/10.1016/j.jclepro.2020.125747

Diprose, G., Lee, L., Blumhardt, H., Walton, S., and Greenaway, A., 2022. Reducing single use packaging and moving up the waste hierarchy, Kōtuitui: New Zealand Journal of Social Sciences Online, 18:3, 268-289, DOI: 10.1080/1177083X.2022.2154230

Dong, J., Tang, Y., Nzihou, A., Chi, Y., 2019. Key factors influencing the environmental performance of pyrolysis, gasification and incineration Waste-to-Energy technologies. Energy Conversion and Management 196, 497–512. https://doi.org/10.1016/j.enconman.2019.06.016

Environment Assessment Institute., 2005. Rethinking the Waste Hierarchy. Clemen Rasmussen and Dorte Vigs. March 2005, Copenhagan. ISBN.: 87-7992-032-2. https://www.osti.gov/etdeweb/servlets/purl/20623175

Eunomia., 2014. Development of a Modelling Tool on Waste Generation and Management, Appendix 9: Employment in Municipal Waste Operations.

Eunomia., 2020. Greenhouse Gas and Air Quality Impacts of Incineration and Landfill. Report to ClientEarth. https://www.clientearth.org/media/1h2nalrh/greenhouse-gas-and-air-quality-impacts-of-incineration-and-landfill.pdf

Eunomia., 2023. Waste and Resource Recovery Infrastructure and Services Stocktake and Gap Analysis. Full Project Summary Report. Prepared for the Ministry for the Environment, Wellington NZ.

European Commission., 2020. Circular economy action plan. For a clearer and more competitive Europe. https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1/language-en/format-PDF/source-170854112

Gass, H. C., Luder, K., & Wilken, M., 2002. PCDD/F emissions during cold start-up and shut-down of a municipal waste incinerator. Organohalogen compounds, 56, 193-196.

Gertsakis and Lewis, H., 2003. Sustainability and the Waste Management Hierarchy   A discussion paper on the waste management hierarchy and its relationship to sustainability. EcoRecycle, Victoria, Australia.

Gharfalkar, M et al., 2015. Analysis of waste hierarchy in the European waste directive 2008/98/EC, Waste Management, Volume 39, Pages 305-313. https://doi.org/10.1016/j.wasman.2015.02.007

Hamilton, L.A., Feit, S., Kelso, M., 2019. Plastics and Climate: the Hidden Costs of a Plastic Planet. Center for International Environmental Law (CIEL).

Harmsworth GR, Awatere S., 2013. Indigenous māori knowledge and perspectives of ecosystems. In Dymond JR ed. *Ecosystem services in New Zealand – conditions and trends*. Manaaki Whenua Press, Lincoln, New Zealand.

He, X., Xu, M., Cui, C., Xia, B., Ke, Y., Skitmore, M., & Liu, Y., 2023. Evaluating the social license to operate of waste-to-energy incineration projects: A case study from the Yangtze River Delta of China. Journal of Cleaner Production, 388. https://doi.org/10.1016/j.jclepro.2023.135966

Henry, M., Schraven, D., Bocken, N., Frenken, K., Hekkert, M., Kirchherr, J., 2021. The battle of the buzzwords: A comparative review of the circular economy and the sharing economy concepts, Environmental Innovation and Societal Transitions, Volume 38 https://doi.org/10.1016/j.eist.2020.10.008

IJgosse, J., Anschütz J., and Scheinberg, A., 2004. Putting Integrated Sustainable Waste Management into Practice Using the ISWM Assessment Methodology. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/sesp/CLUES/Toolbox/t12/D12_1_Anschuetz_et_al_2004.pdf

Istrate, I.-R., Iribarren, D., Gálvez-Martos, J.-L., Dufour, J., 2020. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. Resources, Conservation and Recycling 157, 104778. https://doi.org/10.1016/j.resconrec.2020.104778

Karaitiana and Maya., 2022. The Role and Influence of Te Ao Māori and mātauranga Māori in Waste Management Practice in Aotearoa New Zealand. Final Report. CHEMMAT 763 Research Project. University of Auckland.

King J., 2019. Air pollution, mental health, and implications for urban design: a review, Journal of Urban Design and Mental Health, 4, pp6.

Levaggi, L, Levaggi, R., Marchiori, C., Trecroci., C., 2022. Waste-to-Energy and recycling: The role of plant ownership and waste mobility, Waste Management, Volume 141, Pages 35-51. https://doi.org/10.1016/j.wasman.2022.01.020

Levidow, L and Upham, P., 2017. Innovating thermal treatment of municipal solid Waste (MSW): Socio-technical change linking expectations and representations. Science and Public Policy, 44(2) pp.211–224.

Manfredi, S., Tonini, D., Christensen, T.H., 2011. Environmental assessment of different management options for individual waste fractions by means of life-cycle assessment modelling. Resources, Conservation and Recycling 55, 995–1004. https://doi.org/10.1016/j.resconrec.2011.05.009

Margallo, M. et al. 2015. Environmental sustainability assessment of the management of municipal solid waste incineration residues: a review of the current situation. Clean Techn Environ Policy 17, 1333–1353. https://doi.org/10.1007/s10098-015-0961-6

Ministry for the Environment., 2020. A waste to energy guide for New Zealand - Factsheet. Published by the Ministry for the Environment, August 2020. INFO 964. https://environment.govt.nz/assets/Publications/Files/waste-to-energy-guide-for-new-zealand.pdf

Ministry for the Environment., 2023. Te Rautaki Para – Aotearoa NZ Waste Strategy. Published by the Ministry for the Environment, March 2023. ME 1742. https://environment.govt.nz/publications/te-rautaki-para-waste-strategy/

Ministry for the Environment., 2002. The New Zealand Waste Strategy: Towards zero waste and a sustainable New Zealand. Published by the Ministry for the Environment, 2002.

Morgan, K., 2004. A Tangata Whenua Perspective on Sustainability using the Mauri Model: Towards decision making balance with regard to our social, economic, environmental and cultural well-being. In International Conference on Sustainability Engineering and Science, Auckland, New Zealand.

Negi, H., Agrawal, R., Verma, A., Goel, R., 2019. Chapter 14 - Municipal Solid Waste to Bioenergy: Current Status, Opportunities, and Challenges in Indian Context. Editor(s): Jay Shankar Singh, D.P. Singh, New and Future Developments in Microbial Biotechnology and Bioengineering, Elsevier, Pages 191-203. https://doi.org/10.1016/B978-0-444-64191-5.00014-6

Nextek. 2023. Circular Economy Solutions for Aotearoa New Zealand's Soft Plastic Packaging. Report prepared for The Packaging Forum, Soft Plastics Scheme.

Nilsen, H., 2017. The Hierarchy of Resource Use in a Sustainable Circular Economy. University of Oslo Faculty of Law Research Paper No. 2017-22. http://dx.doi.org/10.2139/ssrn.2981673

No Burn., 2017. Waste Gasification & Pyrolysis: High Risk, Low Yield Processes for Waste Management. A Technology Risk Analysis. Report prepared by Global Alliance for Incinerator Alternatives (GAIA). no-burn.org/gasification-pyrolysis-risk-analysis.

No Burn., 2021. The reality of waste-derived fuels: up in the air. Report prepared by Rollinson, A. https://www.no-burn.org/wp-content/uploads/2021/11/Jet-fuel_technical-briefing_September-8-2021.pdf

OECD., 2023. "Municipal waste" (indicator). https://doi.org/10.1787/89d5679a-en (accessed on 7 April 2023).

Perrot, J-F., and Subiantoro, A., 2018. Municipal Waste Management Strategy Review and Waste-to-Energy Potentials in New Zealand. *Sustainability* 10, no. 9: 3114. https://doi.org/10.3390/su10093114

Price, J.L, and Joseph, J.B., 2000. Demand Management - A Basis for Waste Policy: A Critical Review of the Applicability of the Waste Hierarchy in Terms of Achieving Sustainable Waste Management. Sustainable Development, 8, 96–105.

Rollinson, A. and Oladejo, J., 2020. Chemical Recycling: Status, Sustainability, and Environmental Impacts. Global Alliance for Incinerator Alternatives (GAIA). doi:10.46556/ONLS4535; https://www.no-burn.org/wp-content/uploads/CR-Technical-Assessment_June-2020.pdf

Royer, S.-J., Ferrón, S., Wilson, S.T., Karl, D.M., 2018. Production of methane and ethylene from plastic in the environment. PLOS ONE 13, e0200574. https://doi.org/10.1371/journal.pone.0200574

Ribeiro-Broomhead, J. & Tangri, N. (2021). Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions. Global Alliance for Incinerator Alternatives. www.doi.org/10.46556/GFWE6885

Seadon, J.K., 2006. Integrated waste management – Looking beyond the solid waste horizon, Waste Management, Volume 26, Issue 12, 2006, Pages 1327-1336 https://doi.org/10.1016/j.wasman.2006.04.009

Seadon, J.K. 2010. Sustainable waste management systems, Journal of Cleaner Production, Volume 18, Issues 16–17, 2010, Pages 1639-1651, ISSN 0959-6526 https://doi.org/10.1016/j.jclepro.2010.07.009.

Schall, J., 1992. Does the solid waste management hierarchy make sense?: A technical, economic and environmental justification for the priority of source reduction and recycling. School of Forestry and Environmental Studies, Yale University.

Simon, et al., 2020. The zero waste masterplan: turning the vision of circular economy into a reality for Europe. Brussels, Zero Waste Europe. https://zerowastecities.eu/wp-content/uploads/2020/07/2020_07_07_zwe_zero_waste_cities_masterplan.pdf

SLR., 2017. Waste Management Options Review and Modelling – Executive Summary. Report prepared for Auckland Council. May 2017. Forms Appendix A of Auckland Council's Waste Assessment Report (2017).

Stockholm Convention., 2008. Guidelines on best available techniques and provisional guidance on best environmental practices relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants. Published by the Secretariat of the Stockholm Convention on Persistent Organic Pollutants. https://www.pops.int/Implementation/BATandBEP/BATBEPGuidelinesArticle5/tabid/187/Default.aspx

Stiles, S.C., 1996. A multi-media, integrated approach to environmental compliance and enforcement. UNEP Industry and Environment 19 (1), 12–14.

Taelman, S Tonini, D., Wandl, A., and Dewulf, J., 2018. A Holistic Sustainability Framework for Waste Management in European Cities: Concept Development. Sustainability 10, no. 7: 2184. https://doi.org/10.3390/su10072184

Tait, P., Brew, J., Che, A., Costanzo, A., Danyluk, A., and Davis, M., Khalaf, A., McMahon, K., Watson, A., Rowcliff, K., Bowles, K., 2020. The health impacts of waste incineration: a systematic review, Australian and New Zealand Journal of Public Health, Volume 44, Issue 1, 2020, Pages 40-48, ISSN 1326-0200, https://doi.org/10.1111/1753-6405.12939.

UKWIN., 2018. Evaluation of the climate change impacts of waste incineration in the United Kingdom October 2018 (Rev 1.01: April 2019). https://ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf

US Department of Energy (2019). Waste-to-Energy from Municipal Solid Wastes. Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/bioenergy/articles/waste-energy-municipal-solid-wastes-report

Van Ewijk and Stegemann., 2016. Limitations of the waste hierarchy for achieving absolute reductions in material throughput. Journal of Cleaner Production, Volume 132, 2016, Pages 122-128 https://doi.org/10.1016/j.jclepro.2014.11.051

WasteMINZ., 2022. Behaviour Change Sector Group Position Paper on large scale Waste-to Energy proposed to take municipal waste.

https://www.wasteminz.org.nz/files/Behaviour%20Change/Behaviour%20Change%20WtE%20position%20paper.pdf

Wilken, M., Dehoust, G., Marsch, F., 2003. Start-up of Hazardous Waste Incinerator-impact on the PCDD/FEmission. Organohalogen compounds, 63, 29-32.

Wilson, D., Velis, C., and Rodic. L., 2012. Integrated sustainable waste management in developing countries. Waste and Resource Management. Volume 166. Issue WR. https://www.icevirtuallibrary.com/doi/epdf/10.1680/warm.12.00005

Xiaomin Dou., et al., 2017. Review of MSWI bottom ash utilization from perspectives of collective characterization, treatment and existing application, *Renewable and Sustainable Energy Reviews*, Volume 79, Pages 24-38, ISSN 1364-0321. https://doi.org/10.1016/j.rser.2017.05.044

Zaman. A.U, 2010. Comparative Study of Municipal Solid Waste Treatment Technologies Using Life Cycle Assessment Method. International Journal of Environmental Science and Technology. 7. 10.1007/BF03326132

Zaman, A.U., 2013. Life cycle assessment of pyrolysis–gasification as an emerging municipal solid waste treatment technology. Int. J. Environ. Sci. Technol. 10, 1029–1038. https://doi.org/10.1007/s13762-013-0230-3