Waikato Regional Council Technical Report 2023/TR23-27

Waste to energy technology implications in the Aotearoa New Zealand context

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

Prepared by:
Research Team
Will Wilson, Sam Hirons, Lisa Eve and Mark Hilton, (Eunomia Research & Consulting Ltd)
Amy Whetu (Whetu Consulting)
Technical Leads
Adrian Gibbs, Ann Ballinger and Lisa Eve (Eunomia Research & Consulting Ltd)
Quality Review
Adrian Gibbs, Duncan Wilson and Mark Hilton (Eunomia Research & Consulting Ltd)
Approved by
Mark Hilton

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

and

Tauranga City Council
Private Bag 12022
TAURANGA 3143

August 2023

Peer reviewed by:

Soph Brockbank and Chris Purchas
(Tonkin & Taylor Ltd)

Date August 2023

Approved for release by:

Brent Sinclair

Date September 2023

Disclaimer

This technical report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.

Waste to Energy Technology Implications in the Aotearoa New Zealand Context

A Report for Waikato Regional Council and Tauranga City Council

October 2023

eunomia

Report For

Waikato Regional Council

Tauranga City Council

Research Team

Will Wilson, Sam Hirons, Lisa Eve, Mark Hilton, Amy Whetu

Technical Leads

Adrian Gibbs, Ann Ballinger, Lisa Eve

Quality Review

Adrian Gibbs, Duncan Wilson, and Mark Hilton

Approved By

Mark Hilton

Project Director

Acknowledgements

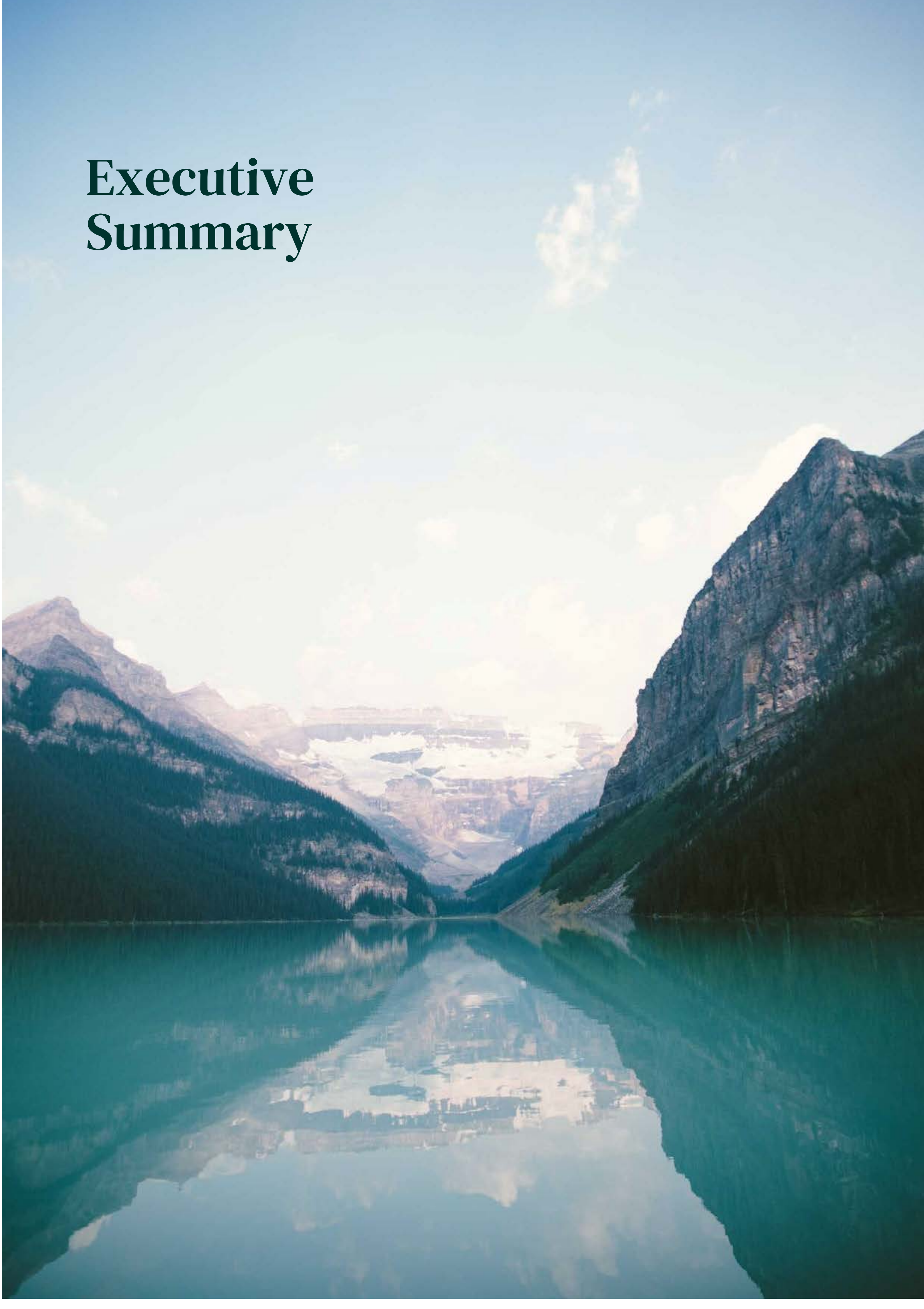
Eunomia Research & Consulting Ltd
37 Queen Square
Bristol
BS1 4QS
United Kingdom

Tel +44 (0)117 9172250
Fax +44 (0)8717 142942
Web www.eunomia.co.uk

Version Control Table

Version	Date	Author	Description
V0.1	14/02/23	Adrian Gibbs	First draft (internal)
V0.2	17/03/23	Adrian Gibbs/Will Wilson/Mark Hilton/Lisa Eve	Second draft (sent to client)
V0.3	04/05/23	Adrian Gibbs/Will Wilson/Mark Hilton/Lisa Eve	Draft Final (sent to client)
V0.4	16/06/2023	Adrian Gibbs/Will Wilson/Mark Hilton/Duncan Wilson/Lisa Eve	Revised draft final
V0.5	19/06/2023	Adrian Gibbs/Will Wilson/Mark Hilton/Duncan Wilson/Lisa Eve	Revised draft final (sent to client)
V0.6	28/06/2023	Adrian Gibbs/Will Wilson/Mark Hilton/Duncan Wilson/Lisa Eve	Final (sent to client)
V0.7	20/07/2023	Duncan Wilson/Lisa Eve/Katy Chamley	Final (minor updates)
V0.8	10/10/2023	Duncan Wilson/Lisa Eve/Katy Chamley	Final (updated to reflect input of peer review)
V0.9	11/10/2023	Duncan Wilson/Lisa Eve/Katy Chamley	Final (updated to reflect input of peer review)
V1.0	25/10/2023	Duncan Wilson Katy Chamley	Final for release

Executive Summary



Introduction

This report presents the outcomes from a study undertaken by Eunomia Research & Consulting on key Waste to Energy (WtE) technologies and their potential application in the Aotearoa New Zealand context generally, and in Waikato and Tauranga specifically.

WtE is a term that covers a range of different technologies that have in common the generation of energy from waste. WtE is often viewed as an alternative to landfill disposal. The most common WtE technologies include those shown in the following table:

Technology	Characteristics
Incineration	The controlled burning of (usually mixed) waste in oxygen. The heat is typically used to produce steam to drive turbines and generate electricity. Relatively simple technology that is well proven as technically viable for the treatment of mixed wastes.
Gasification and pyrolysis	Gasification is controlled oxidation at high temperatures to produce a gas that can then be used for energy generation (or other purposes). Pyrolysis involves heating in the absence of oxygen. This tends to be used more for synthesis of chemicals than generation of energy. These technologies require a homogenous fuel. This means pre-treatment of mixed feedstock is necessary. They have a long history with high carbon single feedstocks such as wood, plastics, and tyres but, poor track record with mixed wastes.
Anaerobic digestion (AD)	Decomposition of organic matter in anaerobic conditions (without oxygen) to produce a biogas, and a solid and/or liquid digestate (that can be applied to land). AD is a proven and effective treatment for putrescible organic waste. There are some concerns over application of digestate, although these can be managed through tight controls.
Production of refuse derived fuel (RDF)	This involves the pre-treatment of mixed wastes to remove contaminants and create a more homogenous fuel in terms of size and calorific value (energy). Plants that produce RDF are well established in Europe with some examples also in Australia.
Cement kilns/co-processing	Cement kilns can substitute some of their standard fossil fuels for wood, tyres, or RDF. High substitution rates of 80%-100% have been achieved internationally. The Golden Bay Cement plant in Whangārei has achieved coal substitution above 30% by using waste tyres and wood and is targeting 80%.

The study considered WtE technologies primarily in terms of their potential climate change impacts. It also considered the historical use of WtE globally, but with a particular focus on Europe (which has similar circular economy ambitions to New Zealand), employment impacts, and how WtE may align with a Te Ao Māori perspective. The key findings from each of these aspects are outlined below:

Climate Change Impacts

The study modelled carbon emissions in four scenarios, three for WtE, and one for the current practice of landfill, in the New Zealand context. These scenarios were as follows:

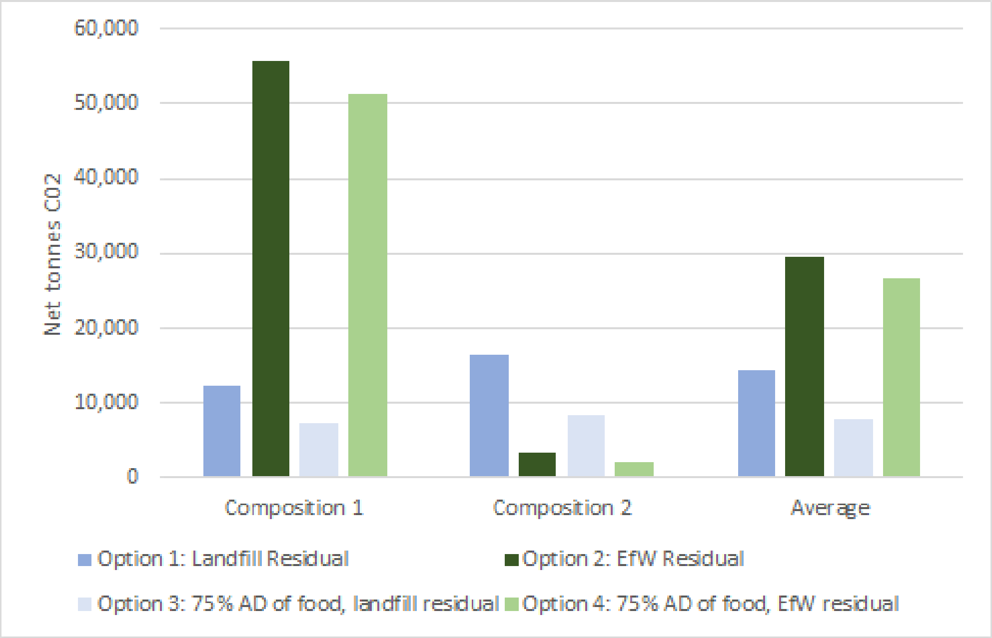
- **Option 1:** Landfill 100% residual waste (as current practice);
- **Option 2:** Send 100% residual waste to incineration with energy recovery[1];
- **Option 3:** Assuming 75% of the food waste generated is captured and sent to anaerobic digestion (AD), with the remainder of the residual waste being landfilled; and
- **Option 4:** Assuming 75% of the food waste generated is captured and sent to AD, with the remainder of the residual waste being incinerated with energy recovery.

Each of these scenarios waste modelled using two different assumed compositions for the waste:

- Composition 1 assumes, in line with the intent of the Te Rautaki Para / New Zealand Waste Strategy2 and the Emissions Reduction Plan, that a large proportion of organic waste is separated for beneficial use, and so the feedstock for Composition 1 is high in fossil carbon content.
- Composition 2 assumes that the waste sent to WtE facilities still has a lot of organic material in it, so it is high in biogenic carbon.

The results of the modelling are shown in the chart below:

Overall Waste System Carbon Emissions (per 100kt of Residual Waste)



---

[1] The performance of 3 configurations of EfW were modelled: Incineration with energy recovery, incineration with energy and heat recovery (combined heat and power or CHP), and gasification/pyrolysis (collectively known as 'thermal' EfW). The best performing from a carbon perspective was incineration with CHP. However, because of the need to co-locate a facility with a user of the heat, this was considered less likely to be implemented, and so the scenario modelling used incineration with energy recovery as the default form of EfW.

[2] Te rautaki para | Waste strategy | Ministry for the Environment

The key takeaway from the modelling is that if the waste that is treated has a high fossil carbon content (for example plastics or rubber), then WtE technologies will have higher carbon emissions than landfill. It should be noted that this situation aligns most closely with New Zealand's current policy and strategy settings. However, if there is a high biogenic carbon content (for example food waste or garden waste) then WtE can create lower carbon emissions. The modelling indicates that, with a typical composition, WtE technologies can be expected to perform worse than landfill.

The other key takeaway was that in every scenario, whether waste went to WtE or to landfill, the modelling showed it is always more beneficial to separate out organic waste for treatment in AD.

Employment

Analysis of the literature showed that more jobs are generated by recovery activities than by disposal activities[3]. Typical disposal 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 (IVC), and 4 FTEs for windrow composting. The studies from the analysis showed that the number of jobs increases by an order of magnitude for employment in the recycling sector.

This means that focusing on recovery activities that are high in the waste hierarchy (reuse, recycling, composting), consistent with a transition to a circular economy, is likely to deliver higher levels of employment in the sector.

Māori views on WtE

There are competing interests, varying levels of understanding, and complexities in navigating Te Ao Māori and iwi considerations in the WtE space.

Iwi have the mandate for speaking on WtE issues within their rohe, but there is currently no dedicated collective iwi body specifically focused on waste management, such as there are with freshwater and climate. This is compounded by a lack of clarity and understanding generally of WtE in its various forms and little guidance for territorial authorities in how to appropriately engage with iwi on WtE projects.[4] There is opportunity to develop a more cohesive approach to engaging with Māori views on waste issues.

International Experience of WtE

Today, there are an estimated 2,600 WtE incineration plants active worldwide processing estimated 460 million tonnes annually.[5] Most of the plants are concentrated in a few countries, with Japan alone accounting

---

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

[4] The issues surrounding Māori views on WtE are discussed further in Appendix A 1.0 which presents a peer review paper from Whetū Consultancy Group.

[5] https://www.ecoprog.com/publications/energy-management/waste-to-energy.htm#:~:text=Today%2C%20more%20than%202%2C600%20WtE,capacity%20of%2044.4%20million%20tpy.

for approximately 45% of the plants, while Europe is also prominent with total number of incineration plants in Europe estimated to be over 500.

The European context is particularly instructive as European policy and practice is most closely aligned with the New Zealand Waste Strategy's stated ambition to move towards a low emissions circular economy.

While still widespread, Europe is, in general, moving away from WtE. This is because as rates of organic waste diversion increase, feedstocks are becoming more carbon intensive. At the same time electricity generation has steadily been decarbonising, with greater use of hydro, wind and solar power, complemented by nuclear power in some countries, with coal, oil and gas use reducing. Alongside this, circular economy policies focused at the top end of the waste hierarchy now drive the waste management strategies in Europe.

Recommendations

The residual waste treatment and disposal technologies that are chosen should be those that best align with strategic aims to create a circular economy and reduce climate change impacts. Based on these considerations, the report recommends, for the Waikato region and Tauranga city and indeed Aotearoa New Zealand more generally, that:

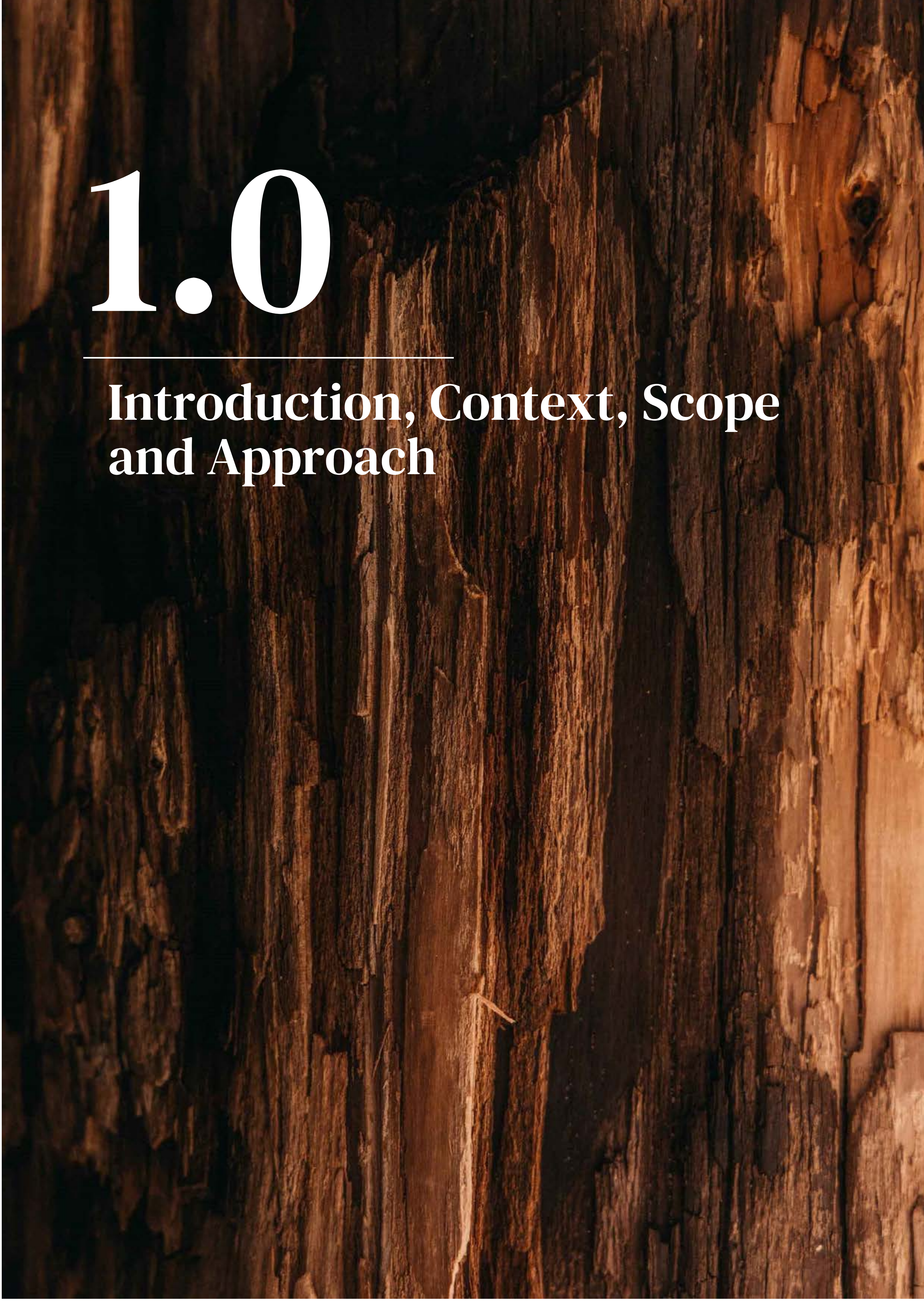
- Food waste should be separated for anaerobic digestion (AD), and/or composting with other organics, and this should be mandated nationwide,
- WtE 'incineration' for mixed waste and fossil-based materials should be avoided unless there is strong evidence that:
    - fossil fuel use will be directly offset, with a clear carbon benefit; and
    - drives to increase circularity (as part of a circular economy) will not be impeded by the technology, in the short to medium term,
- In our view, if WtE for uses other than the above is to be effectively avoided, this will potentially require a strong level of sanction, and legislative and/or regulatory instruments should be considered,
- Advanced thermal treatments, such as pyrolysis and gasification, should be avoided for treatment of mixed solid waste as these technologies are unlikely to be viable in practice due to high technical and commercial risks,
- Burning mixed waste as refuse-derived fuel only be allowed in co-processing, e.g. in a cement kiln or a thermal power station, as a transitional solution where offsetting the burning of coal or oil,[6]
- Landfill (with optimised gas capture and energy generation, to limit methane emission impacts) be used as the only waste management approach for genuinely residual mixed waste (i.e. that cannot be reused, recycled, anaerobically digested or composted) in the transition to a circular economy. It is important to note that waste to landfill can be gradually reduced in that transition, whereas waste to incineration can only realistically be reduced by closing whole facilities, and,
- Māori are proactively engaged in WtE matters. Options for this include establishing a representative iwi body for waste issues, providing iwi with the resources for well-informed decision making, engaging through genuine relationships and partnerships, and empowering councils to provide resources to support iwi and Māori to engage.

---

[6] Specific use of RDF in the Huntly or Golden Cement facilities was outside the scope of this report and these options were not investigated.

Finally, while wider issues around circular economy have not specifically been covered by this report, or the impacts modelled, we would also recommend that Aotearoa New Zealand should prioritise options that are higher in the waste hierarchy, and which yield the most positive carbon benefits and work to ‘close the circle’ on material use.

Table of Contents



1.0

Introduction, Context, Scope and Approach

1.1 Introduction

This report, commissioned by Waikato Regional Council (WRC) and Tauranga City Council (TCC), aims to synthesise the latest research and evidence regarding the principal waste to energy (WtE, sometimes referred to as energy from waste or EfW) technologies. It is intended to provide an evidence-based assessment of the relative merits and implications of these different technologies in the Aotearoa New Zealand context.

The vision of the recently released New Zealand Te rautaki para - Waste Strategy[7] is that "By 2050, Aotearoa New Zealand is a low-emissions, low-waste society, built upon a circular economy" In this context how residual waste is managed throughout this transition to a circular economy will be critical. Alternatives to landfill disposal are being promoted and considered by communities in the Waikato and Bay of Plenty regions, and indeed throughout Aotearoa New Zealand. There is a need for considered, unbiased, evidence and analysis to enable communities and local and regional authorities to be able to make sound decisions that take into account the wider strategic context for Aotearoa New Zealand.

The Ministry for the Environment's (MfE) "waste to energy guide for New Zealand"[8] provides a high-level introduction to EfW/WtE technologies, noting that they refer to a family of technologies that process some kind of waste material to generate energy. Different technologies use a range of waste materials as 'feedstock' for the processing plant, and each plant might produce energy in the form of heat, electricity, or a fuel. The WtE technologies considered within this current report are defined in Table 1-1.[9]

Table 1-1: MfE Waste to Energy Technology Guide (adapted)

Types of waste to energy technology		Definition	Typical feedstocks
Thermal	Incineration	Burns the combustible materials within waste by heating to the necessary ignition temperature with oxygen. The heat generated is captured in a boiler to raise steam for a steam turbine. These plants typically produce exhaust gases (including greenhouse gases) and fly ash, which must be removed in flue gas treatment, as well as bottom ash.	Mixed residual waste. RDF [see penultimate row of table below].

---

[7] Ministry for the Environment. 2023. Te rautaki para | Waste strategy. Wellington: Ministry for the Environment.

[8] Ministry for the Environment (August 2020) *A waste to energy guide for New Zealand*, https://environment.govt.nz/assets/Publications/Files/waste-to-energy-guide-for-new-zealand.pdf

[9] It is acknowledged that there are other technologies that will not fit into these classifications, such as plasma arc, torrefaction, hydrolysis, and hybrid processes. These were considered beyond the scope of the current study.

Types of waste to energy technology		Definition	Typical feedstocks
	Advanced thermal treatment – pyrolysis and gasification	Gasification heats waste at high temperature, in a limited amount of oxygen, to produce combustible gas and an ash residue known as char waste. Pyrolysis 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.	Pulverised coal. biomass feedstocks. RDF (but with poor track record). SRF (but lacking commercial track record).
	Co-processing (cement kilns / process co-incineration)	Uses feedstock derived from waste 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 and in thermal power plants.	RDF. Waste wood. Shredded tyres. Other waste streams.
Non-thermal	Anaerobic digestion	A controlled decomposition process where organic matter decomposes under the influence of microorganisms, in the absence of oxygen. The products are biogas (mainly methane), and a digestate, which may be solid and/or liquid.	Food waste. Crop wastes. Manures. Slurries.
	Landfill gas capture	Gas is collected through vertical and horizontal piping buried in a landfill and then processed and treated for use (typically combusted for electricity or flared).	All non-hazardous wastes.
Auxiliary technologies	Refuse derived fuel (RDF) and solid recovered fuel (SRF) production	Preparation of waste within material recovery facilities (MRFs) or mechanical biological treatment facilities (MBTs), to produce a combustible fuel which is somewhat more consistent than mixed residual waste. Waste is typically shredded and sorted for recovery of some recyclables. More rudimentary treatment produces RDF, while SRF can be produced to particular fuel specifications.	Mixed residual waste.
	Carbon capture, utilisation, and storage (CCUS)	A series of technologies aimed at capturing, transporting and either permanently storing or using CO_2 that would otherwise be released into the atmosphere. Has potential application for all thermal and non-thermal technologies listed above, but situational feasibility is a limiting factor, and economies of scale are currently limiting its application solely to very large and logistically well-located incineration facilities.	

This study examines those technologies that divert waste from landfill whilst generating energy, and hence does not discuss landfill gas capture, other than in the context of carbon calculations. Furthermore, while hydrolysis can be a supporting front-end stage (increasing the digestibility of biological wastes) prior to anaerobic digestion, it is a less commonly used process and is rarely used in isolation. The focus on non-thermal treatments in this study is limited to standalone anaerobic digestion (without a hydrolysis stage).

The MfE guide discusses how a transition to more WtE may conflict with the current waste system (with reference to the waste hierarchy) and broader policy settings. The guide acknowledges that reaching national and global net zero targets, and a societal shift to a circular economy (CE), are fundamental guiding principles that will shape future thinking on the implementation of WtE technologies in Aotearoa New Zealand. Whilst it poses questions and presents a set of principles that WtE proposals should be considered against, it stops short of providing clear guidance that councils and businesses can follow. Other papers and position statements on WtE have also recently been produced in Aotearoa New Zealand, offering different perspectives[10].

WRC and TCC, however, felt that a more detailed, fully independent and science-based assessment of these technologies was needed, in the Aotearoa New Zealand context, drawing from the latest literature and international experience, and clarifying some of the confusion surrounding some of the technologies, hence this report. Whilst primarily written for WRC/TCC, it is hoped that the report will be of wider benefit to other decision-makers in Aotearoa New Zealand, given that its scope is of relevance Aotearoa New Zealand-wide rather than Waikato and Bay of Plenty-specific.

1.2 Scope

1.2.1 (refer to Appendix A 5.1 for a list of landfill classifictions)Technologies

The following technologies have been considered:

Table 1-2: Scope of WtE Technologies Assessed

Technology	Used for treatment of residual waste	Used for treatment of source segregated wastes
Incineration with energy recovery	Yes	No
Pyrolysis/gasification (where gases are burnt)	Yes (prepared fuels only)	See discussions in Section 3.3
Cement kilns / process co-incineration	Yes (prepared fuels only)	No

---

[10] The Zero Waste Network: https://zerowaste.co.nz/waste-to-energy-incineration/; also the Behaviour Change Sector Group coordinated by the Waste Management Institute of New Zealand https://www.wasteminz.org.nz/files/Behaviour%20Change/Behaviour%20Change%20WtE%20position%20paper.pdf

Creation of refuse derived fuels (RDF) / solid recovered fuels (SRF) out of mixed waste (e.g. via mechanical and biological treatment [MBT]) for burning in WtE / cement kilns / power plants	Yes	No
Anaerobic digestion (AD)	Potentially yes as one part of wider mechanical biological treatment (MBT) systems	Yes (food waste)

It is worth noting that in some ways, developed nations are having to relearn the more sustainable ways that were quite natural to earlier generations that lived more in harmony with the land, something that resonates strongly here in Aotearoa New Zealand, most notably in Te Ao Māori.

While this current study takes a global view of WtE technologies, we recognise that Europe is (in terms of recent developments in industrialised nations) leading the way on issues of waste, resources, the circular economy, and net zero carbon emissions, as well as having significant experience with WtE. The literature review, therefore, takes a strong focus on evidence from Europe, so as to provide the most insightful technical and policy direction insight on energy from waste technologies for Aotearoa New Zealand. The Aotearoa New Zealand context, however, is fully recognised; for example, in terms of the energy mix used for electricity generation, treatment alternatives, geographical and economic considerations, Te Ao Māori, community considerations, and the existing waste policy and regulatory context.

An introduction to carbon emissions from waste treatment

With the exception of pure prevention and direct reuse (e.g. person to person), all forms of waste treatment, including recycling, involve the use of some energy through collection, sorting and treatment. If this energy is from non-renewable 'fossil' sources, this leads to carbon emissions (it should be noted that emissions associated with recycling are nearly always smaller than the avoided emissions from extracting and making new materials, i.e. there is a net carbon benefit).

In a landfill, the organic waste breaks down gradually through anaerobic biodegradation. Contrary to popular belief, this is a bad thing since it results in methane (CH_4) emissions, which are 84 times more potent than CO_2 in global warming terms over a 20-year timespan[11]. Although these gases can also be burnt to turn the methane into CO_2 through 'flaring', or combustion in an engine to generate energy, they are very difficult to capture completely. This leads to significant 'fugitive' emissions over the lifetime of the landfill. So, while gas capture will reduce the problem, it will not solve it. Non-biodegradable 'inert' waste is therefore best suited to landfill – materials including rubble, glass, metals and (in effect) conventional plastic.

Incineration of plastic, in the form of packaging and textiles for example, will release carbon (as CO_2) that may have previously been locked up for millions of years as oil in the ground. This happens immediately. Burning waste from biogenic sources[12], like food and paper, is less harmful since it is released as CO_2 not methane, and

---

[11] Intergovernmental Panel on Climate Change. The assumed potency of methane is related to the timescale it is viewed over. It has very high impacts relative to CO^2 in the short term but degrades over time in the atmosphere and so declines in impact. The Intergovernmental Panel on Climate Change (IPCC) has indicated a Global warming potential (GWP) for methane between 84-87 when considering its impact over a 20-year timeframe (GWP20) and between 28-36 when considering its impact over a 100-year timeframe (GWP100). https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change

[12] A biogenic substance is a product made by or of life forms

some of the carbon that is released to atmosphere has recently been captured from the atmosphere in growing organic matter such as food crops and wood for paper (although some energy will still have been used, and emissions created, in making that natural material into a product). As a rule, if organic matter is burnt it will have lower net carbon emissions than energy from burning fossil-based materials.

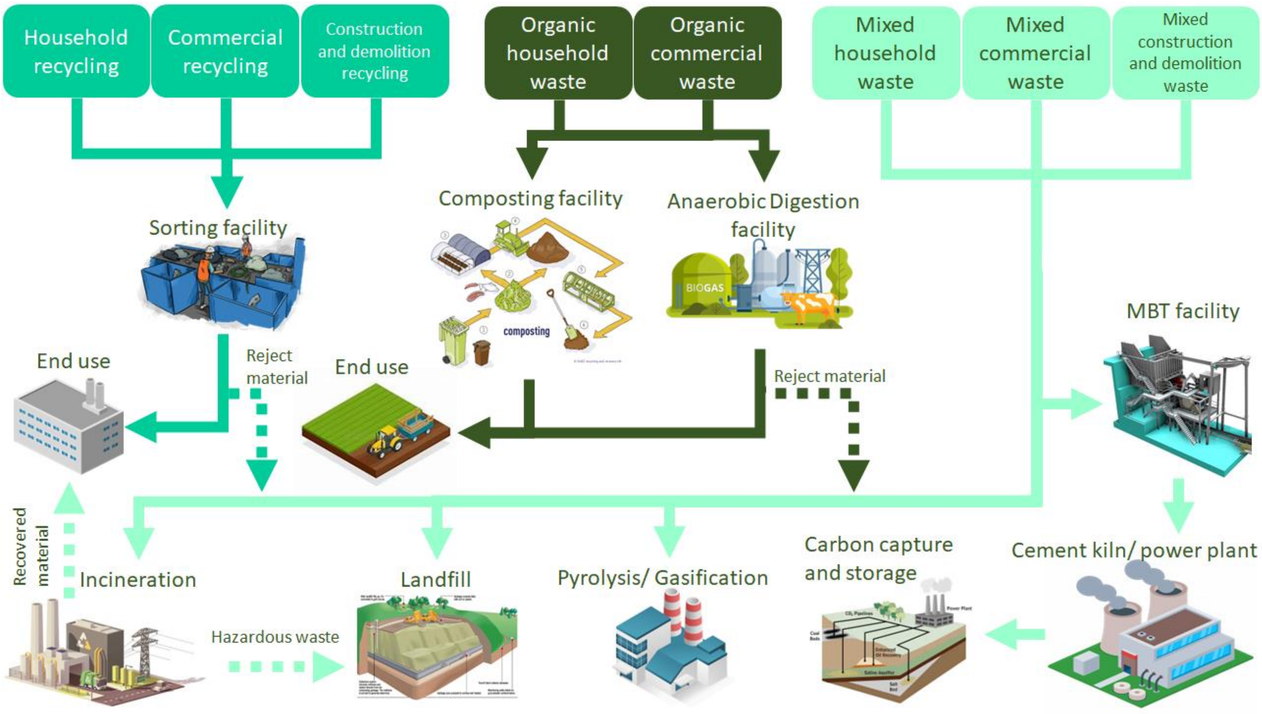
Composting (aerobic treatment) of organic waste also releases biogenic CO_2, which is relatively low impact, while anaerobic (without oxygen) digestion produces methane, but in a way that can be fully captured in an enclosed vessel and utilised for various purposes. These and other related issues are described more fully in the rest of the report.

1.2.2 Waste Streams

The review focuses on mixed 'municipal' wastes that are currently disposed of to Class 1 and Class 2 landfills (as defined in regulation[13]). The term municipal is used throughout the report to mean waste that, in current general practice, is sent to Class 1 and/or Class 2 disposal facilities. For further information on landfill classifications in New Zealand, refer to Appendix A 5.1.

The diagram below illustrates, in a simplified manner, different sources of waste materials and how these may flow to one or more of the types of facilities considered here:

Figure 1: Illustration of Waste Flows



Please note that the above illustration is a significant simplification, and actual flows are more complex and nuanced (for example, some organics could go straight to pyrolysis/gasification, or MBT facilities may include composting or anaerobic digestion as part of their processes).

---

[13] Waste Minimisation (Calculation and Payment of Waste Disposal Levy) Regulations 2009, available at www.legislation.govt.nz

In the above hypothetical waste flow diagram, the main sources of material that go to WtE facilities, apart from anaerobic digestion, are from mixed municipal waste sources, that currently go to landfill. Some reject material from resource recovery processes (such as contaminated plastics, paper, timber, or organics) could also constitute feedstocks.

1.2.3 Location Considerations

While this report is commissioned by and written for the Waikato Regional Council and Tauranga City Council the findings are likely to be applicable to a wider audience. The project team reviewed the New Zealand context as well as the Waikato and Bay of Plenty context. From a WtE perspective there are likely to be a number of factors related to location that could impact consideration of WtE outcomes. These include (but are not limited to):

- Proximity to/competition with other disposal facilities that could compete for feedstock;
- the quantity of feedstock available – in particular mixed wastes which are likely to be the primary type of feedstock that would be utilised in a WtE facility;
- transport connections, and;
- availability of suitable sites.

In the project team's view, there are no unique features in the Waikato and Bay of Plenty regions that are likely to make WtE significantly more or less viable than other parts of New Zealand. The feedstock compositions and scenarios that were modelled were designed to cover the likely operating boundaries for WtE plants, and the Waikato and Bay of Plenty situation falls within these boundaries.

1.3 Method Overview

In order to develop an appropriate evidence base and detailed understanding of the context, Eunomia undertook a literature review, building on previous Eunomia studies in Europe and elsewhere. This information was combined with Aotearoa New Zealand context information provided by the local Eunomia team (which is expert in waste management matters here, including both operational and regulatory aspects), and information provided by the client team within Waikato Regional Council and Tauranga City Council.

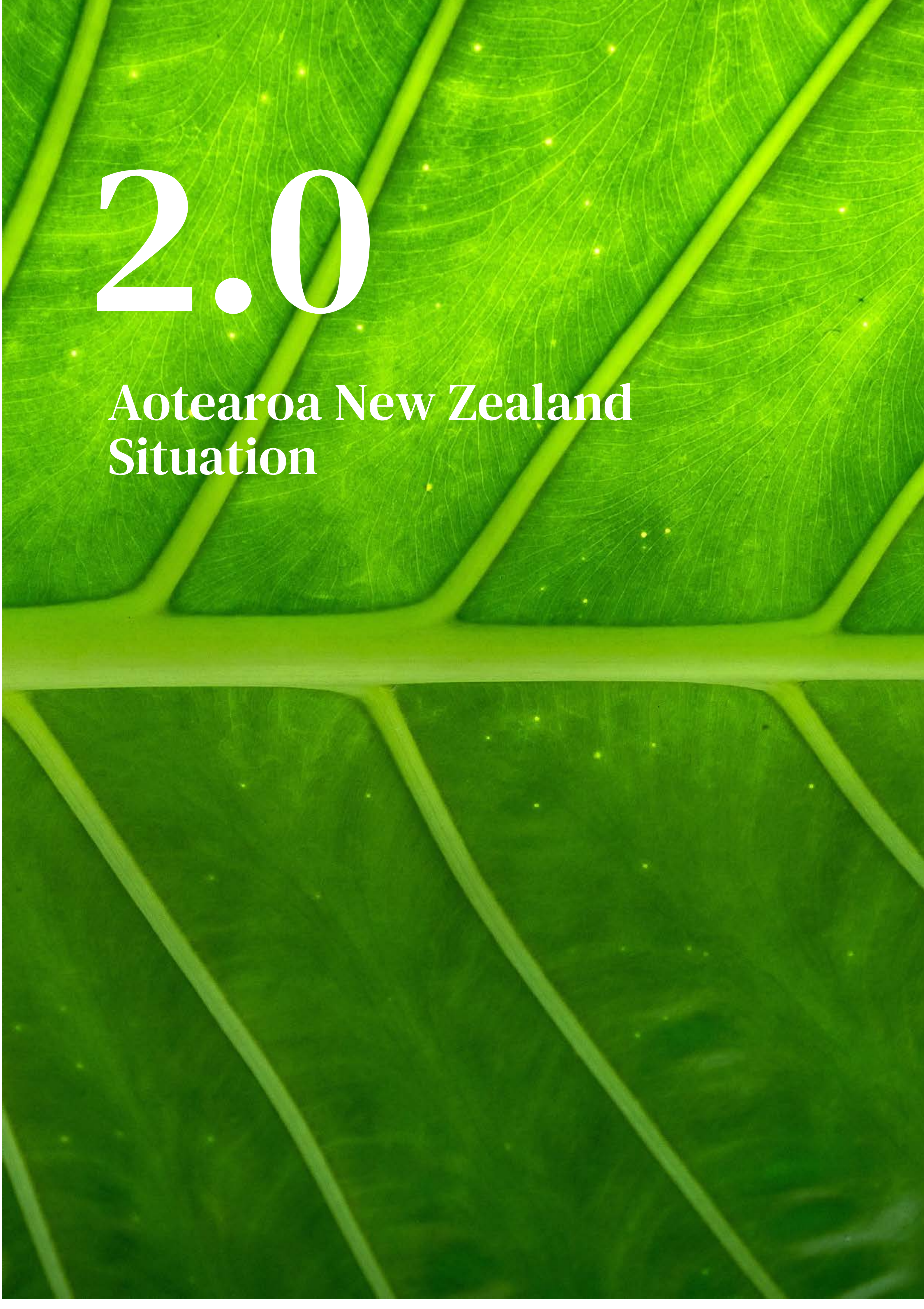
This information set the parameters and assumptions for subsequent quantitative modelling of carbon impacts (within the specialist UK team), and wider analysis of the practical and economic feasibility of WtE solutions in the Aotearoa New Zealand context. In addition, some consultation work was also undertaken with Waikato Regional Council expert staff (e.g., in environmental science roles). Transpower in relation to the way electricity generation works; and waste industry specialists, for example at the Ecogas plant in Reporoa, to help ensure that the modelling was representative of likely scenarios in Aotearoa New Zealand.

This analysis allowed us to draw conclusions and make recommendations around the suitability of each WtE technology in the Aotearoa New Zealand context.

1.4 Structure of this Report

The remainder of the report is structured as follows:

- **Section 2** provides essential background information pertinent to the Aotearoa New Zealand situation, as it impacts on the types of WtE technologies and how they may be deployed within the country.
- **Section 3** provides high-level technical descriptions of the WtE technologies, and related waste treatment methods in the context of landfill, recycling and composting, as alternatives.
- **Section 4** outlines the historical and international context for WtE.
- **Section 5** presents a critical analysis of the technologies, and an overview of the economic/employment impacts, which should be considered regarding their deployment in Waikato/Tauranga and Aotearoa New Zealand more generally.
- Conclusions and recommendations are given in **Section 6**, for Waikato/Tauranga, and more generally for Aotearoa New Zealand (noting how specific circumstances can change outcomes).
- The appendices contain a range of material that supports the information presented in the body of the report:
    - Appendix A 1.0 provides a Te Ao Māori view of the information presented about WtE in this report
    - Appendix A 2.0 contains context around the historical use of WtE internationally, and how thinking and views of WtE have evolved
    - Appendix A 3.0 outlines key carbon accounting principles and how the carbon calculations have been presented in the report
    - Appendix A 4.0 sets out the assumptions used in the carbon modelling
    - Appendix 0 provides a glossary of key terms used in the report.



2.0

Aotearoa New Zealand Situation

2.1 Aotearoa New Zealand Context

2.1.1 Overview

As noted in Te rautaki para | Waste strategy[14]: "In 2021, each New Zealander is estimated to have sent nearly 700 kilograms of waste to Class 1 landfills. That makes us one of the highest generators of waste per person in the Organisation for Economic Co-operation and Development. We have inconsistent systems and services, and markets that have at times been fragile, for many recycled materials. This is, in part, because of the challenges posed by our geography and small population."

Aotearoa New Zealand is unusual, compared to most other developed nations, in that it has a low population density overall and only a few large urban areas, notably the Auckland, Wellington and Christchurch regions. The remainder of the population lives in a number of smaller cities and towns and in rural areas. This, together with the nature of the geography and road network, and the country being long and narrow, can make waste collection and transportation more difficult and investment in waste infrastructure more costly. There are however, abundant renewable energy resources, most notably hydro and geothermal; and this is reflected in the relatively high proportion of electricity (approximately 87%[15] on average) that is generated through renewable methods.

Aotearoa New Zealand has Te Tiriti o Waitangi as its founding document. All legislation and policy is influenced by the Treaty and reflects the relationship between tau iwi (non-Māori New Zealanders) and Māori. Increasingly, agencies seek to embed and reflect Te Ao Māori (the Māori worldview) in policy and strategy documents. Para Kore, a prominent Māori waste-focused organisation, describe Te Ao Māori in relation to waste:

> *"Within Te Ao Māori, the relationships between land and humans are intimate. The Earth is our mother and the sky is our father. We are related to mountains, to rocks, to insects, to birds, to the rivers and bush, to all parts of the natural world. They are our ancestors, our relations. We are the teina, the youngest sibling, and part of the family of nature. We identify with the landforms and the place."*[16]

This inherent and deep-rooted connection translates to a desire for a waste management system that protects the land, and values resources. Waste principles such as 'zero waste' and the more recently emerging CE are naturally more closely aligned with the Te Ao Māori worldview of waste management, including the drive to manage waste as close to the source as possible.

Fully respecting the role of Māori as kaitiakitanga, or guardians of the land, would require that iwi, hapu, and mana whenua are involved in waste management decisions. This can be both a strength, in terms of providing a strong drive towards environmental improvement, but also a potential challenge where there is a need for regional or national solutions from an economies of scale perspective.

---

[14] Ministry for the Environment. 2023. *Te rautaki para* | *Waste strategy* | *Waste strategy*. Wellington: Ministry for the Environment.
[15] Energy in New Zealand 2023 shows renewable electricity generation increased to 87% | Ministry of Business, Innovation & Employment (mbie.govt.nz)
[16] www.parakore.maori.nz

A Te Ao Māori perspective in relation to WtE is provided in Appendix A 1.0. This takes the form of a peer review of the information presented in this report, through a Te Ao Māori lens.

2.1.2 Electricity generation

The way electricity is generated has implications for any benefits associated with electricity generation via EfW/WtE.

Aotearoa New Zealand has long benefited from a high percentage of renewable electricity generated from hydropower, geothermal and, increasingly, from wind and solar photovolatics. As a result, electricity generation is responsible for only 5% of Aotearoa New Zealand's greenhouse gas emissions, whereas fossil fuels used in transport and process heat account for over 30%[17].

Despite recent increases in coal use for electricity generation, due to droughts in the South Island, the renewable share for electricity generation increased to 82.1% for 2021; up from 81.1% in 2020.[18] Top-up 'peak demand' generation (e.g. early evenings), and support for seasonal variations in supply and demand (the main issue being occasional dry winters, where demand is high but supply from hydro diminished for two or three months), is currently provided as required by what might be termed 'slow peakers', i.e. supply that takes a while to come on stream. This is a combination of gas-fired open cycle gas turbines, coal-fired Huntly Rankine units, and currently also by one of the two remaining combined-cycle gas turbines (CCGT).

According to Transpower, generation of around 95% renewable electricity by 2035, moving to 100% by 2050, is achievable[19]. In part, this will be delivered through new solar farms and battery energy storage systems (BESS), biomass burning, and most importantly through a major water pump storage system (the planned Lake Onslow hydro 'battery'), which will provide far more flexibility in managing peak demand[20], potentially eliminating the need for any further coal or gas use. The pumped storage scheme, if approved, could commence construction as early as 2028.

It is worth noting that municipal waste incinerators generally have to operate most of the time to be efficient and constantly deal with the volumes of waste that they are planned for. Hence, they are considered baseload power and cannot be easily turned on and off to meet peak demand requirements or be left idle for most of the year when renewables alone are adequate to meet demand.

2.1.3 Gas use

Natural gas is only piped on the North Island and provides only 272,000 Aotearoa New Zealand homes (out of approximately 2 million in total) and around 18,000 businesses and industrial users[21]. Only around 10% of gas is used for homes and small/medium businesses, and around 30% of natural gas produced in Aotearoa New Zealand is used to make electricity (as noted above). The rest is used primarily by large industrial and commercial gas customers around the North Island, e.g., for process heat such as steam raising.

---

[17] Interim Climate Change Commission, Accelerated Electrification, April 2019

[18] https://www.mbie.govt.nz/about/news/energy-in-new-zealand-2022-shows-a-strong-share-of-renewable-energy/

[19] https://www.transpower.co.nz/about-us/our-strategy/whakamana-i-te-mauri-hiko-empowering-our-energy-future

[20] https://www.beehive.govt.nz/release/100-renewable-electricity-grid-explored-pumped-storage-%E2%80%98battery%E2%80%99

[21] https://gasnz.org.nz/what-we-do

Bottled LPG (liquified petroleum gas, which is far higher in carbon terms due to liquification by compression) is also widely used in homes with gas appliances, and entirely on the South Island. Bottled LPG meets the energy needs of nearly 300,000 homes and business; it is available in both the North and South Island and New Zealanders use around 190,000 tonnes of it each year - primarily for heating, water heating and cooking. LPG is also used as a process fuel in industrial applications where it displaces less environmentally friendly fuels like coal and fuel oil, and as a cleaner-burning vehicle fuel.

Key initiatives to phase out fossil gas include the development of a gas transition plan by the end of 2023. This will set out a transition pathway for the fossil gas industry, explore opportunities for renewable gases (e.g., biogas from AD), and ensure an equitable transition. The gas transition plan will be an input to the energy strategy[22]. It is notable that the new Ecogas AD plant at Reporoa will be connected to the North Island gas grid, to help (in a small way) to replace fossil gas used for heating and energy generation.

2.1.4 Waste management policy considerations

Waste management practices in Aotearoa New Zealand are governed by the New Zealand Waste Strategy (2023)[23] and the Waste Minimisation Act (2008). The latter is due to be replaced with revised legislation understood to be being drafted by the MfE.

2.1.4.1 Aotearoa New Zealand Waste Strategy

Te rautaki para | Waste strategy (March 2023) is subtitled “Getting rid of waste for a circular Aotearoa New Zealand” and has a focus on achieving a ‘more circular’ economy for materials and waste. The timelines for implementation are extended; (in the context of climate change impacts and remaining carbon emission budgets), with a multi-decade pathway towards this. More specifically the strategy lays out:

- the vision for 2050 and guiding principles, which set the direction and tone for the changes ahead;
- the broad pace and phasing for the changes;
- goals for the strategy’s three phases between now and 2050;
- targets for the first phase, to achieve by 2030
- the work priorities to focus on to achieve the 2030 goals and targets, and;
- the approach to measuring and assessing progress.

The strategy sets three national targets for Aotearoa to achieve by 2030:

1. Waste generation: reduce the amount of material entering the waste management system, by 10 per cent per person.
2. Waste disposal: reduce the amount of material that needs final disposal, by 30 per cent per person.
3. Waste emissions: reduce the biogenic methane emissions from waste, by at least 30 per cent.

The signals will allow the waste management industry, local authorities, community organisations, businesses, and individuals to start to plan their own changes, although the only mandatory requirements set out thus far relate to the standardisation of household kerbside collections.

The strategy will be directly relevant for local government:

- When a territorial authority is preparing, amending or revoking a waste management and minimisation plan, it must “have regard to the New Zealand Waste Strategy” or any equivalent government policy (Section 44 of the Waste Minimisation Act 2008).

---

[22] https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/energy-and-industry/
[23] Ministry for the Environment. 2023. *Te rautaki para | Waste strategy | Waste strategy*. Wellington: Ministry for the Environment.

- The government may direct a territorial authority to change its waste management and minimisation plan if that will help achieve the waste strategy (Section 48 of the Waste Minimisation Act 2008).
- Under section 49 of the Waste Minimisation Act 2008, the government may set performance standards for a territorial authority, and under section 37 can retain payments of the Waste Levy if they fail to meet those standards. This means that the government may set performance standards relevant to the achievement of targets within the strategy or supporting documents and plans.

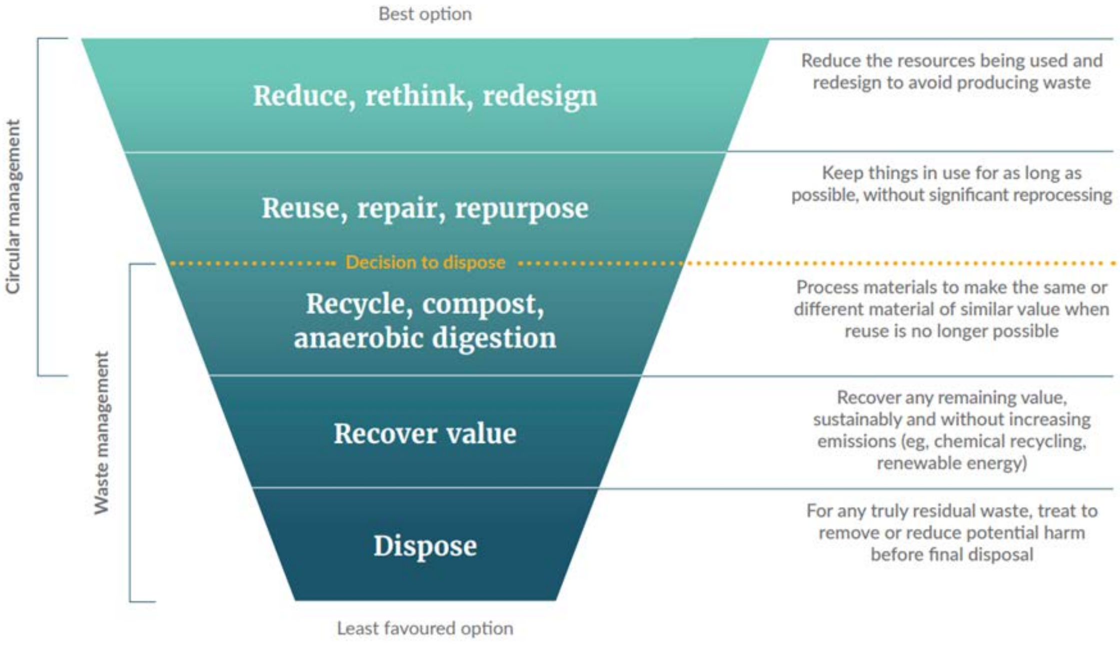
Further to this last bullet point, government has indicated that they will be enforcing performance standards for councils relating to kerbside collections; 30% diversion by 1 July 2026, 40% by 1 July 2028, and 50% by 1 July 2030. Private kerbside collectors will be required to report data to MfE to enable the performance for each city and district to be calculated.

The strategy provides high-level direction only. The next step is for government to work with local authorities, the waste management sector and others to develop the first Action and Investment Plan (AIP). The AIP is a supporting plan that will flesh out what's needed to deliver on the waste strategy. It will spell out:

- the immediate priorities for the next five years in different geographical areas, communities, material streams and risk areas;
- the mix of regulatory, investment, behaviour change, infrastructure, system change and other actions planned to address the immediate priorities;
- the sequence of the actions and how they fit together, and;
- who needs to do what.

Waste to energy is recognised as a key strategic issue in the strategy, with various key references. The new waste hierarchy in the strategy specifically categorises anaerobic digestion at the same level as recycling and composting, with 'recover value' (energy recovery, such as WtE incineration) the next level down, above 'dispose'.

Figure 2-1: The Waste Hierarchy According to the Aotearoa New Zealand Waste Strategy[24]



---

[24] Ministry for the Environment. 2023. Te rautaki para | Waste strategy | Waste strategy. Wellington: Ministry for the Environment.

On page 16 of the strategy, it is noted that "anaerobic digestion of organic material produces biogas, as well as solid and liquid material, to return to the soil" and hence it is not simply regarded as a 'recovery' process, but on a par with recycling and composting.

Goal 6 'Recovering value' is all about energy from waste and notes that "if we can use truly residual waste without harming the environment we should do so", which reinforces the preference for energy from waste, over landfill and incineration without energy recovery. The strategy notes, however, that any technology needs to consider four key aspects - purpose, feedstock, processing, and the type of energy produced, and implies that there is a preference for WtE that uses biological material as a feedstock, over waste streams like plastics or tyres which are likely to be better handled at higher levels of the hierarchy, e.g., through recycling. The strategy also makes a distinction between single, clean streams of material relative to mixed wastes and indicates that, while there may be a valid role for processes that use clean single stream feedstocks to generate energy, using mixed streams is not aligned with the circular economy:

> *Pyrolysis and gasification of municipal solid waste are unlikely to align with our circular economy goals, due to their negative effects on the climate, dependency on continued linear waste generation, and likelihood of causing hazardous discharge. (p46)*

The document also references the MfE's guidance on WtE, mentioned earlier in this report.

2.1.4.2 Waste Minimisation Act

The Waste Minimisation Act (2008)[25] (WMA) includes a number of relevant provisions:

1. The meaning of 'disposal' and 'disposal facility'
2. Enables a levy to be imposed on disposal facilities.

The definition of disposal is crucial as, although 'incineration of waste' is specifically included, 'incineration' is described as "the deliberate burning of waste to destroy it, but **not to recover energy from it**" (our emphasis). This excludes WtE technologies from being liable for the landfill levy under the current WMA. [26]

At the introduction of the WMA, a waste disposal levy was introduced for landfills that fit the definition of a disposal facility, i.e., that accepted household waste; known as 'Class 1 landfills'[27]. These facilities are also required to report on waste quantities (and so there has been good data available on quantities of waste disposed of to Class 1 landfills since this time). At the time the levy was introduced, it only applied to Class 1 landfills; with no levy on the almost 90% remaining landfills throughout the country.

In 2021, the NZ government passed a number of regulations that further control the landfill disposal sector. This formalised four additional types of fills – Class 2 landfills for construction and demolition waste, Class 3 as managed landfills, Class 4 as controlled landfills and Class 5 as 'cleanfill'.[28] These classes are now, or soon will

---

[25] https://www.legislation.govt.nz/act/public/2008/0089/latest/DLM1166800.html
[26] It is interesting to note that in Te-rautaki-para-Waste-strategy.pdf (environment.govt.nz) (page32) states that "Disposal infrastructure includes waste to energy plants, incineration facilities and landfills." However, this is not a legal definition.
[27] According to both guidelines produced by the Waste Management Institute of New Zealand, and through government regulation.
[28] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://environment.govt.nz/assets/Publications/regulatory-impact-statement-waste-disposal-levy.pdf p23

be, required to either report quantities and pay a reduced landfill levy (Class 2-4) or just report quantities (Class 5). This data is not yet publicly available.

Recent regulation has expanded and increased the landfill levy, and at the time of writing the levy is:

- $50 per tonne for Class 1 landfills (but is set to increase to $60 per tonne as of July 2024).
- $20 per tonne for Class 2 landfills (also known as construction and demolition waste landfills, and set to increase $30 per tonne as of July 2024),.
- From 1 July 2024; $10 per tonne Class 3 and 4 managed/controlled fills.

It should be noted that even the increased levy will be low compared to many other countries. For example, in Australia, ACT has a rate for municipal solid waste of NZ$97, NSW has a rate of NZ$148.50 (in metropolitan areas), and South Australia $93.50 (in metropolitan areas).[29] In Europe, the UK Landfill Tax is now at a rate of ~NZ$200/t and Wallonia in Belgium has the highest EU rate at ~NZ$208/t for general waste. Some countries, like Germany, have no landfill tax but have high gate fees for landfill due to other reasons.

There is no current indication that WtE facilities in Aotearoa New Zealand would be required to pay any sort of levy. This would require an amendment of the WMA. A review of WtE (focusing on 'the incineration option') carried out in 2019[30] suggested that WtE facilities should pay a levy, and potentially at the same level as Class 1 landfills, where the facility displaced a renewable energy source. If this or a similar approach was not taken; current WtE pathways which are relatively low net carbon-impact, such as the tyres and wood waste used by Golden Bay Cement (offsetting coal use) and wood waste used in pellet and chip boilers around the country (using a biogenic material), would perhaps become less attractive since WtE incineration could become a lower-cost option.

2.1.5 Emissions Reduction

2.1.5.1 Emissions Trading Scheme

Emissions from waste make up 4% of Aotearoa New Zealand's greenhouse gas emissions, and 9% of methane emissions. Around 80% of the emissions from the waste sector come from landfills, mainly in the form of methane fugitive emissions[31]. In June 2021, the Climate Change Commission released a report[32] outlining how Aotearoa New Zealand could meet its international emissions reduction commitments and its obligations under the Climate Change Response Act 2002. The report's advice was clear that our current policy settings will not achieve the targets set out in the Act. The report advised that achieving even the lower end of the 2050 biogenic methane target would require comprehensive action to:

- Reduce waste;
- divert organic waste from landfill to recycling and composting, and;
- improve and extend landfill gas capture systems.

---

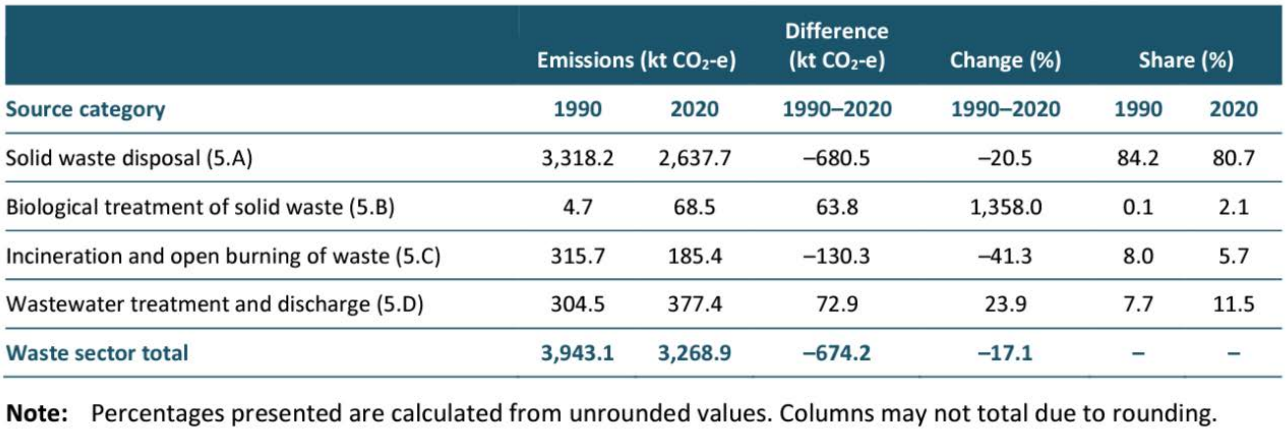
[29] https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/WasteandRecycling/Report/c04

[30] Nick Robertson and Merewyn Groom (for Business and Economic Research Ltd) (2019), "Waste to energy: the incineration option", available at www.berl.co.nz

[31] https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020/

[32] Ināia tonu nei: a low emissions future for Aotearoa, Climate Change Commission, June 2021

Table 2-1: Aotearoa New Zealand Greenhouse Gas Inventory 1990 and 2020



	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)	Share (%)	
Source category	**1990**	**2020**	**1990–2020**	**1990–2020**	**1990**	**2020**
Solid waste disposal (5.A)	3,318.2	2,637.7	–680.5	–20.5	84.2	80.7
Biological treatment of solid waste (5.B)	4.7	68.5	63.8	1,358.0	0.1	2.1
Incineration and open burning of waste (5.C)	315.7	185.4	–130.3	–41.3	8.0	5.7
Wastewater treatment and discharge (5.D)	304.5	377.4	72.9	23.9	7.7	11.5
Waste sector total	**3,943.1**	**3,268.9**	**–674.2**	**–17.1**	**–**	**–**

Note: Percentages presented are calculated from unrounded values. Columns may not total due to rounding.

The decline in emissions from solid waste disposal noted in the above table is due mainly to the installation of landfill gas capture and methane destruction systems at Class 1 landfills. This is a combination of existing landfills installing gas capture systems, and older landfills without gas capture systems closing with the material that would have gone to those landfills now going to large regional facilities with modern gas capture systems.

Since 2013, operators of waste disposal sites have been required by the Climate Change (Emissions Trading) Amendment Act 2008 to monitor their greenhouse gas emissions and to surrender carbon emission offsets (in the form of New Zealand Units [NZUs)[33] to cover methane emissions. There is, therefore, a financial cost for landfills to emit methane. As described above, waste disposal sites include Class 1 landfills and incinerators that **do not recover energy.**

The number of emissions units that needs to be surrendered is based on a calculation of how much methane is generated from a tonne of waste. As a starting point, landfills use a default emissions factor for waste (DEF). This is the methane assumed to be generated by each tonne of waste and is currently set at 1.023 tonnes of CO_2e (CO_2 equivalent) per tonne of waste.[34] However, landfill operators can reduce their liabilities under the ETS through use of a unique emissions factor (UEF). The UEF is a calculation of methane released by the specific landfill. There are two different types of UEF – a gas capture UEF and a gas generation UEF. A gas capture UEF is calculated by measuring the proportion of generated methane that is captured; while a gas generation UEF is calculated by measuring the composition of material entering the landfill and showing that this is different to the default assumptions and that therefore the quantity of methane generated would be different.

It makes sense for a landfill to apply for a gas capture UEF where the landfill has any level of gas capture and destruction in place (with or without generation of energy).

A landfill can apply for a composition UEF where the composition of the waste going into the landfill (calculated by a number of detailed waste composition audits) is significantly different to the default national composition. In reality, this will only make commercial sense where the UEF shows a lower level of methane generated than the DEF. Where the opposite is true, it makes sense for the operator to just use the DEF, whilst

---

[33] NZUs are carbon credits that are officially accepted to offset liabilities under the NZETS

[34] https://www.legislation.govt.nz/regulation/public/2010/0338/latest/whole.html

actually allowing a higher proportion of biogenic waste to be disposed of, which doesn't need to be declared and hence won't be penalised under the ETS.

Whether a landfill operator has a composition based UEF or not, there is a perverse incentive for the landfill operator to maximise the intake of quickly degrading biological material, e.g. food waste, as this increases the quantity of gas generated (and hence captured) which makes the gas capture rate appear higher (and hence the liability under the ETS to be lower). If the proportion of food waste accepted drops below the assumed composition, then it will cause difficulties for the landfill operator in capturing the desired amount of greenhouse gas, and the operator would also have to carry out further composition audits to confirm the lower proportion of biogenic waste to obtain the ETS discount. An additional factor is that food waste and similar materials, which break down quickly, don't take up much space in a landfill in the longer term. When landfill gate charges are based on weight, but resource consent limits are generally based on volume, this provides an additional incentive to take food and other biogenic waste.

The other component of the calculation of a landfill's liability under the ETS is the price of carbon. NZU currently change hands for between NZ$50 and NZ$85, with prices at NZ$52.50 at the time of writing[35]. Although prices have recently declined, the cost of NZUs had been increasing steadily for the last couple of years, due largely to changes made to the types of offsets that are eligible under the ETS.

Class 2 to 5 fills, closed landfills, and WtE facilities (along with certain other excluded landfills) are not currently covered by the ETS given, as mentioned above, they are not considered to be disposal facilities. Some of these facilities could still, however, be taking biogenic material, such as construction and demolition wood waste, and hence generating methane.

2.1.5.2 National Environmental Standards for Air Quality

The Resource Management (National Environmental Standards for Air Quality) Regulations 2004 S 25 require all landfills over 1 million tonnes total capacity and that contain at least 200,000 tonnes of waste with over 5% organic waste content to have a landfill gas capture and destruction system. S26 also requires a minimum level of efficiency for the landfill gas capture.[36]

2.1.5.3 Emissions Reduction Plan

The Emissions Reduction Plan (ERP), released in May 2022, sets out actions the Government is taking to put Aotearoa New Zealand on a path to achieve our long-term climate targets and contribute to global efforts to limit temperature rise to 1.5˚C above pre-industrial levels.

Currently Aotearoa New Zealand's economic activity exceeds environmental limits on several measures, of which high emissions (in absolute terms and per capita) is one. As a signatory to the Paris Agreement, Aotearoa New Zealand's 'nationally determined contributions' (NDC) target is to reduce Aotearoa New Zealand's net emissions by 50 per cent below gross 2005 levels by 2030. This equates to a 41 per cent reduction on 2005 levels using what is known as an 'emissions budget' approach.

---

[35] Accessed from https://www.carbonnews.co.nz/tag.asp?tag=Carbon+prices 14/05/23

[36] https://www.legislation.govt.nz/regulation/public/2004/0309/latest/DLM287035.html?search=ta_regulation_R_rc%40rinf%40rnif_an%40bn%40rn_25_a&p=3

Commencing work on a Circular Economy and Bioeconomy (CEBE) strategy is an action in the ERP. MBIE is leading this work on a CEBE strategy. The Circular Economy and Bioeconomy chapter in the ERP signals that: 'Moving to a circular economy with a thriving bioeconomy is essential to meeting our emissions budgets and our 2050 targets. In addition to helping us reduce emissions, it will create new opportunities (including new jobs such as in resource recovery, bioproducts and design), drive innovation, reduce the amount of waste we produce, and can result in cost savings for households and businesses. This transition will require us to change the way that we think about, and use, resources.'

Approximately 45 per cent of global emissions come from making products. Of these emissions, up to 80 per cent are created in the design stage. Moving to a more circular economy is an opportunity to rethink how we design and use our resources to meet our material needs, such as shelter, mobility, and nutrition. The ERP sets out the following vision for a CEBE strategy:

The ERP proposes that by 2050, Aotearoa New Zealand will have a circular economy with a thriving bioeconomy that seizes the opportunities from global trends and shifting consumer preferences. Key outcomes signalled in the ERP include:

- more sustainable resource and energy use;
- protecting and restoring ecosystems and ecosystem services, with particular attention to indigenous biodiversity;
- more prosperous and climate-resilient people, businesses, and communities;
- maximising the value of our renewable bioresources for our national wellbeing, and;
- contributing more broadly to prosperity and wellbeing, consistent with government's economic plan for a 'high wage, low emissions economy that provides economic security in good times and bad'.

It is worth noting that the Resource Management Act (RMA) now states that local government must have regard to the National Adaptation Plan (NAP) and ERP when making and amending regional policy statements and regional plans (Section 66 of the RMA). This means that regional/local councils can take carbon implications into consideration when assessing a consent application.

2.1.5.4 Climate Change Commission Draft Advice to the Second ERP

It is worth noting that the Climate Change Commission Draft Advice to the Second ERP specifically addresses thermal waste to energy. It notes that there are 'tensions' over the use of WtE in Aotearoa New Zealand, and states the following:

> *Thermal waste-to-energy premised on non-renewable feedstock is less favourable within the waste hierarchy. Such facilities have the potential to undermine future national waste reduction and recycling goals and displace the use and advancement of alternative renewable electricity generation options within Aotearoa New Zealand.*
>
> *For the reasons identified above, a precautionary approach could beneficially inform waste-to-energy policy and investment considerations in Aotearoa New Zealand.*[37]

---

[37] 2023 Draft advice to inform the strategic direction of the Government's second emissions reduction plan. April 2023. Page 154

2.1.6 Aotearoa New Zealand Waste Management

The Aotearoa New Zealand waste management sector has historically relied heavily on landfill disposal. A small and decreasing proportion is disposed of through burning in some form; however, this is generally because of the type of waste involved (such as medical waste and biohazardous material) rather than seeking to produce energy. There is also a significant, but unquantified, amount of farm waste material disposed of through informal, on-property, burning.

The Aotearoa New Zealand waste management system has also historically had limited regulation and monitoring. The introduction of the Resource Management Act in 1991 significantly increased the environmental compliance requirements for landfill disposal and was key in driving a transition from a large number of small disposal sites (often operated by local authorities) or informal sites to a smaller number of large, highly engineered, general waste disposal sites owned and operated by private businesses.

The role of private businesses has been significant in the recovery sector also, with the major material recovery facilities and material reprocessing facilities in Aotearoa New Zealand in private sector ownership. This has resulted in a waste infrastructure network that has been driven to a large extent by commercial imperatives. It is useful to note that to date, this has not included a significant role for WtE facilities. The recent exception to this is the establishment of a large AD plant in the central North Island.

2.1.6.1 WtE in Aotearoa New Zealand

There have been several attempts to establish large WtE facilities in Aotearoa New Zealand. The first major effort was in the late 1990s when Olivine NZ bought the mothballed Meremere coal fired power station with plans to convert it to an incinerator with capacity to handle one million tonnes per annum.[38] In 2015, Renew energy floated a proposal to establish an incinerator on the site of a former cement works near Westport on the West Coast. Backing of a Chinese operator China Tianying Inc (CNTY) was obtained for $300 million for a waste-to-energy plant.[39]

Current proposals to establish large WtE facilities include:

South Island Resource Recovery (SIRRL), Waimate, South Canterbury (Project Kea) A 350,000 tonnes per annum (tpa) plant is planned for Waimate, South Canterbury, at an estimated cost of $350M. The company has applied for consents for the facility, which would produce steam and electricity from municipal waste and construction and demolition waste. The consent application has been returned to the applicant several times by Environment Canterbury (the regional authority) due to the lack of information, such as the failure to carry out a site-specific cultural impact assessment. The Overseas Investment Office (OIO) is currently considering the application by SIRRL to purchase 15 hectares of land at Glenavy for this project; and the Zero Waste Network filed a submission to the OIO against this sale on the basis that the proposal does not provide ‘benefit to New Zealand’. The councils involved applied to the Minister for the Environment to review the application as a project of national importance. This was supported by SIRRL, and the Minister has (at the time of writing

---

[38] https://www.nzherald.co.nz/nz/plan-junked-for-power-plant-fired-by-rubbish/6JJFFIZ36CACCLOVSIXYUI5FCM/
[39] https://www.stuff.co.nz/national/111782266/why-did-west-coast-plans-for-a-wastetoenergy-plant-fail

called in the project.[40] A number of individuals behind this proposal were also behind the WtE plant proposed for the West Coast.[41]

'Paewira Recycle Plant' in Te Awamutu, Waikato. Global Contracting Solutions (GCS), a subsidiary of Global Metal Solutions (GMS), is proposing to build and operate a WtE plant near Te Awamutu, Waikato that will generate power from thermal processing of refuse-derived fuel (RDF). The approximately 175,000 tonnes per annum (tpa) plant will accept a range of feedstocks including municipal solid waste, waste from remediation of old landfills, end-of-life tyres, plastic, and shredder flock from metal recycling. The company applied for resource consent in late 2021, and at the time of writing the application was still under consideration.

BioPlant Pyrolysis Plant, Feilding, Manawatu. BioPlant applied for resource consent for a 30,000 tpa capacity pyrolysis plant. The proposed plant would be using mainly sorted municipal solid waste (MSW) as its feedstock and it would be supplemented by diverted non-recyclable plastics and end-of-life tyres. At the time of writing the company announced it had withdrawn its application but may apply for consent again in the future.[42]

In addition, Golden Bay Cement in Northland have used wood waste and fuel for its cement kilns for many years and since 2021 have the technology to accept shredded waste tyres, with capacity to process approximately 3 million tyres annually.[43] There have also been numerous attempts to develop other WtE projects in NZ,[44] however there are none currently operational, with the exception of the Reporoa AD plant.

The two key barriers to establishing large WtE facilities in Aotearoa New Zealand have been obtaining resource consent, and proving economic viability. In general, WtE facilities taking mixed waste streams are competing with landfill, which have historically been relatively low cost (although with significant regional variation)[45]. One of the large private waste operators, Waste Management NZ Ltd, has publicly stated that "in [our] experience, the costs associated with WtE are significantly higher than current methods of waste disposed to landfill… it would need government intervention… to make it a viable proposition for commercial investment."[46]

2.1.6.2 Māori views on WtE

There are a number of complexities when engaging with Māori on WtE. There are competing interests, varying levels of understanding, and complexities in navigating Te Ao Māori and iwi considerations in the WtE space.

Iwi have the mandate for speaking on WtE issues within their rohe, but there is currently no dedicated collective iwi body specifically focused on waste management, such as there are with freshwater and climate. This is compounded by a lack of clarity and understanding generally of WtE in its various forms and little guidance for territorial authorities in how to appropriately engage with iwi on WtE projects.

---

[40] Project Kea

[41] https://www.projectkea.co.nz/

[42] https://www.stuff.co.nz/manawatu-standard/300901213/contentious-feilding-wastetofuel-plant-proposal-withdrawn-due-to-technicalities

[43] https://fletcherbuilding.com/news/golden-bay-cement-sustainable-disposal-solution-for-waste-tyres-a-new-zealand-first/

[44] A brief but incomplete list includes, Hokitika BioPlant Pyrolysis Plant, Hokitika, West Coast, Tairawhiti BioPlant Pyrolysis Plant, Gisborne, Olivine in Gisborne, Materials Processing Limited Torrefaction Plant in Tokaroa, Sierra Energy Gasification South Island, Waste Transformation Limited pyrolysis Timaru (small scale pilot plant operating using wood waste), Hydrogen Solutions (Pyrolysis),

[45] However where disposal costs are higher is generally in more remote parts of the country where there is less waste which could justify an large EfW facility

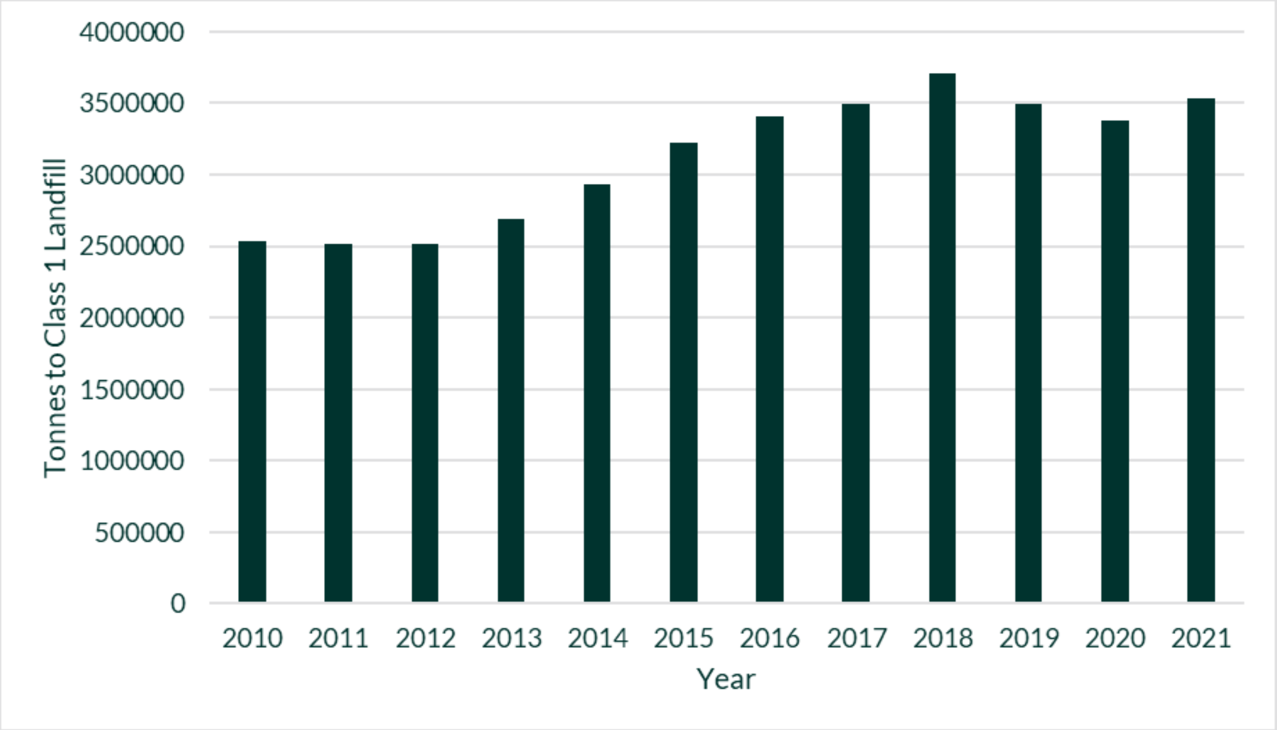
[46] 2019 statement; can be found here https://www.wastemanagement.co.nz/news-and-media/waste-to-energy-in-new-zealand/

The issues surrounding Māori views on WtE are discussed further in Appendix A 1.0 which presents a peer review paper from Whetū Consultancy Group.

2.1.7 Aotearoa New Zealand Waste Data

Given the limited regulation and monitoring of the sector, until recently, historical data on quantities and composition of waste in Aotearoa New Zealand is not available. However, as mentioned above, since the introduction of the landfill levy to Class 1 landfills in 2010, the quantity of waste disposed of to these facilities has been reported as part of levy payments. This data is shown in the chart below.

Figure 2-2: Waste Disposal to Class 1 Landfills



The 2022 figure is now available, with a rise to 3,601,273 tonnes, showing that the COVID-19 pandemic management period created only a temporary dip in waste arisings.

Class 2 – 5 facilities are now, or soon will be, required to either report quantities and pay a reduced landfill levy (Class 2-4) or just report quantities (Class 5). This data is not yet publicly available. There is also no consistent data collected on ‘diverted’ waste (material that has been recycled, composted, or otherwise diverted from disposal). All these factors mean it is very difficult to estimate total national waste generation.

Composition data for waste streams in Aotearoa New Zealand varies, ranging from very good information relating to waste disposed to Class 1 landfills to only high-level estimates based on small local studies. The current situation is summarised in the table below.

Table 2-2: Current Situation of Data Available on Waste Disposal in Aotearoa New Zealand

Waste stream	Quality of Data	Sources of Data
Waste disposed of to Class 1 landfills	High	Calculated by collating the results of multiple detailed waste audits carried out at most of the large Class 1 landfills in the country
Diverted materials	Moderate	Can be estimated by combining a number of data sources, including data from councils, waste operators, processors, and export figures.
Waste disposed of to Class 2 – 4 landfills	Low	Estimates are currently based on very few informal composition surveys and estimates from operators.
Waste disposed of to Class 5 fills	Low	Estimates are currently based on information provided by operators and as defined by facility acceptance criteria
Waste disposed of on-property through burning or burial	Very low	Based on two small studies that have a number of data collection and analysis issues

The estimated composition of waste to Class 1 landfills is shown below:

Table 2-3: Estimated Composition of Waste to Class 1 Landfills in Aotearoa New Zealand

Material category	Percentage of total (%)
Paper	5.9
Plastic	8.3
Food scraps	9.0
Garden waste	5.7
Ferrous metal	2.7
Non-ferrous metal	0.8
Glass	1.8
Textiles	5.0
Sanitary paper	2.5
Rubble & concrete	20.1
Timber	12.6
Rubber	2.1
Sewage sludge	1.9
Other potentially hazardous	21.5

Source: Waste Not Consulting (2020) Update of National Average Waste Composition for Class 1 Landfills Prepared for the Ministry for the Environment

We have previously highlighted, in our work on marginal abatement cost curves to reduce carbon emissions[47] , that very large levels of abatement can come from biostabilisation of waste to landfill. This has implications for

---

[47] MfE. (2020). Marginal abatement cost curve analysis for New Zealand.

landfill business models which currently rely on energy exports and for existing GHG capture targets applied to managed landfill sites. However, such GHG targets may be driving perverse outcomes anyway (e.g. landfill operators lobbying against separate food waste collections). So, it may be that widespread policy reform – including exploration of alternative landfill business models – would need to be considered alongside adoption of this measure to ensure a just transition.

2.2 Local Government Consenting

The planning and consenting approach in Aotearoa New Zealand works at a local and regional level. While local and regional councils work under the same regulatory environment, there can be variation in how a specific consent application would be handled due to variations in local and regional plans.

At the local level, waste infrastructure (including WtE) is required to comply with consenting requirements under District Plans. However, the more stringent and costly consenting and regulatory impacts are likely to come at the regional consenting level, with facilities required to apply for a consent under the Resource Management Act (1991) which aims to protect environmental quality – particularly air, land and water. An application is accompanied with an environmental and cultural impact assessment, which should identify potential negative environmental or cultural impacts and show how these will be mitigated or managed. The consent, if awarded, will contain conditions around monitoring and operation to ensure that unwanted impacts do not occur.

The effects of GHG emissions, as per the Emissions Reduction Plan and national adaptation plans, are required to be considered as part of any WtE proposal; although prior to November 2022 regional councils were explicitly prohibited from considering the climate change effects on such emissions. The prohibition has now been removed such that climate change effects are now on the table to be considered along with all other adverse effects on GHG emissions.[48] Central government is (as of early 2023) preparing national direction for regional consent authorities to ensure that there is national consistency in the way climate change effects from GHG emissions are regulated, but based on the content of draft guidance, it may not have direct applicability to WtE schemes because their focus, at least at this stage, appears to be on emissions resulting from the burning of fossil fuels. Despite this, under the RMA, WtE proposals will still need to assess their GHG impacts on climate change (as well as other matters) and demonstrate how they will appropriately avoid, remedy, or mitigate their effects. Section 104 (1) © also enables consideration of 'any other matter', which would reasonably now include any Action and Investment Plans (AIPs) developed by MfE.

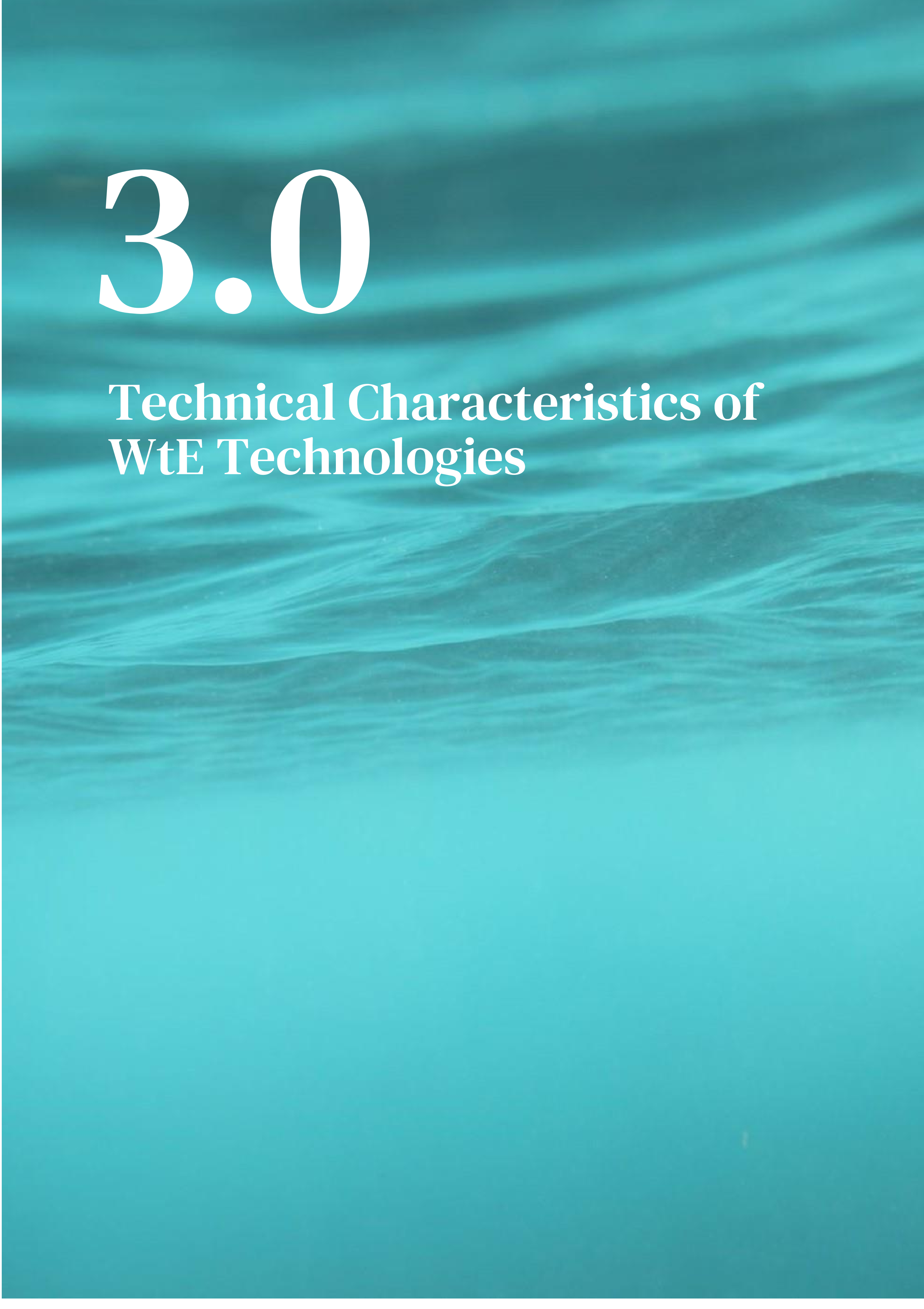
Central government is currently in the process of replacing the RMA with three new Acts (currently going through the processes as proposed Bills); the Natural and Built Environment Bill Spatial Planning Bill; and the Climate Adaptation Act. It is not yet known how these changes will impact on the consenting process for WtE facilities. However, it is hoped that an Act focused on spatial planning at a regional or multi-regional level would include provision for waste facilities, and this may extend to commentary about what types and sizes of various waste facilities are desirable.

---

[48] From 30 November 2022 provisions in the RMA have been repealed which previously: Precluded regional councils from having regard to the effects of discharges of GHG on climate change when making discharge rules in plans; and Precluded consent authorities from having regard to the effect of GHG discharges on climate change when considering discharge and coastal permits.

Both the current, and future, planning environments place an emphasis on considering Te Ao Māori. As more becomes known about the future planning authorities, it may become apparent that there will be an even stronger emphasis on cultural impact assessments and incorporation of Te Ao Māori in future. Given the variation in the interpretation and views of specific waste management practices between various iwi/ hapū, each planning authority will need to establish the local viewpoint on various WtE technologies.

There are currently three major WtE projects in the resource consenting process, as described in section 2.1.6.1.



3.0

Technical Characteristics of WtE Technologies

3.1 Introduction

The following sections address six WtE/WtE technologies:

- Mass burn incineration.
- Advanced thermal treatment (ATT) - pyrolysis and gasification.
- Anaerobic digestion (AD).
- Facilities producing refuse-derived fuels (RDF).
- Cement kilns / process co-incineration.
- Carbon capture, utilisation, and storage (CCUS).

For each of the six technologies covered, the following sections include a technology overview/definition, and summaries of technical viability, key characteristics, and economics.

3.2 Mass Burn Incineration

3.2.1 Technology Overview

Incineration is the controlled burning of waste in oxygen, usually involving some form of energy recovery. In practice, various names are applied to the technology, including *“mass burn incineration”* (to reflect the burning of solid waste), *“municipal solid waste (MSW) incineration”* (to reflect the source of waste most commonly burned, in the UK analogous to council-collected waste), and very often *“waste-to-energy (WtE)”* or *“energy-from-waste (EfW)”* (in disregard of other energy-generating waste treatment technologies).

When burnt in the presence of oxygen, the chemical energy in the waste is released as heat, while breaking down into gaseous carbon dioxide, water vapour, various further gases, and solid ash. The standard approach for the recovery of energy from MSW is to utilise the combustion heat through a boiler to generate steam, drives a turbine to generate electricity. Alternatively, a combined heat and power (CHP) approach can be adopted, which generates electricity in the same way, but then subsequently uses the waste steam in a heat network to provide heat for local homes or industry. Of the total available energy in the waste, up to 80% can be retrieved in the boiler to produce steam, which is typically converted into electricity using steam turbines – where the most efficient net overall plant efficiencies achieved peak at around 30% (as discussed below). Electricity is generated at lower efficiencies in CHP plants than electricity-only plants because steam leaving the electricity turbine needs to be at a higher temperature to be able to provide useful heat. However, because the heat in this steam can then be used (at a high efficiency), the overall thermal efficiency can be higher.

Because of the inconsistent nature of solid waste, most mass-burn facilities burn MSW on a sloping, moving grate that vibrates or otherwise moves to agitate the waste and mix it with air. Moving grate (MG) incineration technology doesn’t technically require prior MSW sorting or shredding, and can accommodate large sized ‘bits’ of waste and variations of MSW composition and calorific value (CV, i.e. how much energy is released per kg of waste). Despite this, some of the more advanced municipalities/operators separate the waste on the front end to save recyclable products.

Another technique used in WtE incineration is combustion of MSW using a fluidised bed (FB). This always involves the pre-treatment of MSW material to reduce particle sizes and remove heavy and inert objects prior to processing in the furnace. Overall, the waste requires more preparation than if a moving grate was used. The combustion is normally a single stage process and consists of a lined chamber with a granular bubbling bed of an inert material such as coarse sand/silica or similar bed medium. The bed is 'fluidised' by air being blown vertically through the material at a high flow rate. This technology is more thermally efficient than a MG-type incinerator but of course is more expensive to build and more complex to operate. The process remains the same as mass burn incineration in other respects.

3.2.2 Technical Viability

As MSW incineration is a relatively simple technology which has been applied at scale around the world for many years, there is significant international experience and track record, and it is well proven as a technically viable technology in many settings (refer to AppendixA 2.0.

Several studies have compared energy efficiency, economic viability, and environmental performance of MG and FB technologies, with both technologies having positive and negative aspects.[49] MG technology is considered the more proven method of MSW combustion, having a relatively simple and reliable structure that is easy to operate. In contrast, FB has been introduced in this field more recently and its properties are less known and less developed for WtE incineration. Some benefits concerning FB incineration have been identified[50], though often there are disadvantages which balance the benefits:

- Higher electrical efficiencies are possible due to more controlled combustion conditions and lower volumes of air required per unit of waste. Despite that, greater energy inputs are required to compress air in order to fluidise the bed, and significantly greater experience and engineering refinements poured into MG technologies often means that real world performance of FB falls short compared to the more conventional mass burn incineration.
- A lower quantity of bottom ash residues and emissions produced (NOx, SO_2) when compared to MG systems due to the removal of non-combustibles prior to combustion, and more controlled burn out of the waste. Greater ash may be carried into the gas stream though, which requires filtering, clean-up and disposal (noting that most air pollution control residues typically constitute hazardous waste).
- The requirement for pre-processing means that front-end recycling comes as part of the solution. Higher overall process costs accrue, however, when pre-treatment is required.
- Refuse derived fuel (RDF) (with a potentially higher calorific value than is compatible with MG systems) is suitable as a feedstock.

3.2.3 Characteristics

WtE incineration facilities vary in size considerably, with the smallest operating plant treating about 25,000 tonnes per annum (tpa) and the largest about 600,000 tpa. The size of the facility is dependent on several factors including cost, waste catchment area, distance from wider waste sources and site constraints. Most modern WtE plants, when operating at scale (>200,000 tpa), can achieve net electrical export efficiencies of around 30%[51]; though some smaller facilities operating in practice generate far less (for instance a recent 90,000 tpa plant in the UK known to the authors of this document is known to operate at under 20%). It is

---

[49] https://doi.org/10.1016/j.wasman.2020.04.050

[50] Enzygo Ltd (2010) The energy impact of waste management: recycling and energy from waste, Report for WRAP. Unpublished.

[51] Lombardi, L., Carnevale, E. and Corti, A., (2015). A review of technologies and performances of thermal treatment systems for energy recovery from waste. *Waste management*, 37, pp.26-44.

difficult for the facilities to achieve much higher efficiencies because of the toxicity of the flue gases increases corrosion and fouling problems[52]. This sets a ceiling on the temperature at which combustion processes treating MSW can operate, so a 2010 WRAP report indicated that steam temperature is often reduced to maintain plant availability.[53]

The same report suggests that for plants above 300,000 tpa or 25MW, reheat turbines can become economic giving significant power efficiency advantages. Lower efficiencies are observed in older plants; an average efficiency of 21.7% was reported by the Confederation of European Waste-to-Energy Plants (2012)[54] for facilities recovering only electrical energy. For those operating in CHP mode, average electrical and heat recovery efficiencies of 15% and 37.1%, respectively, were reported (2018)[55]. An incinerator will typically have a higher net electrical and thermal efficiency than comparable advanced thermal treatment (ATT) processes that also generate steam for power generation or direct heating. This is mainly due to the energy required to sustain the gasification or pyrolysis process.

One major by-product of the WtE incineration is residue ash, with the total amount of ash generated typically ranging from 15 to 25% (by weight) and from 5 to 15% (by volume) of the MSW processed. This combustion residues consists of two types of material: fly ash and bottom ash. Fly ash refers to the fine particles that are removed from the flue gas and includes residues from other air pollution control equipment. Fly ash typically amounts to 10 to 20% by weight of the total ash. The rest of the MSW combustion ash is called bottom ash (80 to 90% by weight). The chemical composition of the ash usually comprises non-combustible materials (e.g., metals, glass) that contain a small amount of residual carbon, but composition varies depending on the original MSW feedstock and the combustion process.

Both bottom and fly ash are recyclable, and in the EU are increasingly used in other applications under the Green Deal agreement[56]. Once treated to remove remaining metals, bottom ash can be suitable for applications such as in concrete or for use in construction works. Fly ash residues are typically more contaminated with heavy metals, dioxins, and other persistent organic pollutants (POPs) than bottom ash, but can be subsequently used in the manufacture of cement, landfill, or deposited in deep underground voids. However, these residues can represent a serious threat to both the environment and human health as they contain high quantities of unintentionally produced POPs that exceed the safety limits recommended by scientific research and the amended Basel Convention[57].

MSW burned in incineration facilities can produce hazardous air pollutants including particulate matter (PM2.5 and PM10), carbon monoxide, acid gases, nitrogen oxides and cancer-causing dioxins and furans. There is relatively little in the way of research specifically focused on incinerators, air quality, and related health impacts, with studies producing variable results:

---

[52] Wang W and Liu Z (2020) Principle and Protective Measures of High temperature Corrosion of Garbage Incineration Boiler, Journal of Physics doi:10.1088/1742-6596/1635/1/012087

[53] Poyry (2010) Energy from Waste Technologies and Feedstocks, Report for WRAP

[54] https://www.cewep.eu/wp-content/uploads/2017/09/13_01_15_cewep_energy_report_iii.pdf

[55] ISWA (2018), *Effectiveness of municipal solid waste incinerators in replacing other fuels. A primary energy balance approach for the EU28*, https://doi.org/10.1177/0734242X18785737

[56] ToxicoWatch (2019). The hidden impacts of incineration residues. Report for Zero Waste Europe. Available: https://zerowasteeurope.eu/wp-content/uploads/2019/11/zero_waste_europe_cs_the-hidden-impacts-of-incineration-residues_en.pdf

[57] https://ipen.org/sites/default/files/documents/After_incineration_the_toxic_ash_problem_2015.pdf

- The results of a major study on modern municipal waste incinerators (MWIs) have been published by the Small Area Health Statistics Unit (SAHSU) at Imperial College London - 2 papers found no evidence of an increased risk of infant mortality for children living close to MWIs[58], and
- A recent study undertaken for the Greater London Authority[59] was one of the first to attempt to quantify the impact on health of both particulate and NOx pollution from incineration. The authors concluded that 15 deaths of London residents per year were associated with emissions of nitrogen oxides and particulate matter from the city's five WtE facilities.

However, it should be noted that modern WtE incinerators have sophisticated abatement equipment and are normally continuously monitored in terms of emissions, with access to that data by regulatory agencies. A typical facility will have a range of systems in place to mitigate environmental impacts including equipment to control and improve the quality of combustion, remove acid gases (hydrogen chloride, sulphur dioxide), nitrogen oxides (NOx), and dioxins, and filter out particulates and particle-bound pollutants such as many heavy metals. Such modern incinerators with advanced combustion and pollution control measures will incur significant capital costs. For example, in 2015, the first new incinerator built in 20 years in the USA was constructed in Palm Beach County (Florida) and is considered the most advanced and cleanest WtE plant in North America. However, the construction of this 100MW facility came at a significant capital cost, with a total project cost of US$672 (NZ$1,059) million[60].

3.2.4 Economics

The economics of conventional mass burn incineration are well established and understood. Due to the relatively low efficiency, and to being exceptionally large capital investments, conventional moving grate incineration facilities are dependent on large scale operation and high gate fees (costs per tonne). While incineration is proven WtE technology, a key drawback is that MSW incineration facilities are very expensive to build and operate. Recent example estimates and actual costs for the construction of incineration plants fall in the range of NZ$290m – NZ$400m for moving grate WtE facilities of 150,000 tpa to 350,000 tpa capacity[61]. Therefore, landfilling in countries such as the United States is often considered a more viable option, especially in the short term, due to the low economic cost of building an MSW landfill verses an MSW combustion facility[62]. The high upfront cost means that incineration facilities often require public sector support to underwrite private investments that can lock municipalities into a future of waste incineration.

The referenced source[63] provides a typical capex for a modern 350,000 tpa plant at around NZ$430m (NZ$145/tonne costed over 20 years, with a weighted average cost of capital at 10%), while operational costs per tonne are NZ$24m/annum (NZ$70/tonne). This approximately aligns with publicised costs of NZ$350m for Project Kea's proposed 365,000 tonne facility in Waimate, South Island.

It should also be noted that the EU is bringing fossil emissions from WtE into scope of its emissions trading scheme (ETS) in the coming years (2030 at the latest)[64], and the UK is expected to follow suit – which will markedly increase the costs of WtE. The price of EU ETS allowances topped €100/tonne (NZ$180/tonne) for

[58] https://www.gov.uk/government/publications/municipal-waste-incinerators-emissions-impact-on-health/phe-statement-on-modern-municipal-waste-incinerators-mwi-study
[59] Air Quality Consultants (2020) Health Effects due to Emissions from Energy from Waste Plant in London, Report for the GLA
[60] https://www.energy.gov/sites/prod/files/2019/08/f66/BETO--Waste-to-Energy-Report-August--2019.pdf
[61] Defra (2013) Incineration of Municipal Solid Waste - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf
[62] https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw
[63] Catapult Energy Systems (2020) *Energy from Waste Plants with Carbon Capture*, May 2020
[64] https://www.letsrecycle.com/news/municipal-incinerators-included-in-eus-emissions-trading-scheme/

the first time in 2023. With WtE emitting about 0.5 tonnes of fossil carbon per tonne of waste, and allowances on a generally upward trajectory, the future cost of carbon emissions for WtE facilities in Europe can be expected to exceed €50/tonne (NZ$90/tonne).

3.3 Advanced Thermal Treatment (ATT) - Pyrolysis and Gasification

3.3.1 Technology Overview

Gasification involves the partial oxidation of a substance at elevated temperature (typically ≥ 600°C) in a low oxygen environment to produce a combustible synthesis gas (or 'syngas' which) which can be used for energy generation, alongside other by-products (solid residues, oils and tars – some of which often remain uncondensed within the syngas).[65] Pyrolysis involves thermal degradation (typically at temperatures ≥ 450°C) in the absence of oxygen, and is less used for energy generation (due to reduced thermal cracking of hydrocarbons) but more for the synthesis of chemicals. Many variants and configurations of these technologies exist. All these technologies can be categorised under the umbrella term 'advanced thermal technology' (ATT).

Unlike incineration, untreated MSW is inappropriate for gasification or pyrolysis because the required thermochemical conditions within the facility need to be more precisely controlled. Facilities are sensitive to inputs outside of a strict material specification (including moisture content, CV, particle sizing, material types, and chemical contents). Therefore, feedstock preparation i.e., the removal of non-combustible materials and recyclables (e.g., metals, glass, etc.) is generally done prior to the thermal treatment stage. In addition, the waste feed may require processing to remove excess moisture, shredding to reduce size, and blending to achieve the required fuel specification. As a result of the requirement for pre-treatment in ATT WtE plants, such units often form part of a wider residual waste management strategy in conjunction with other waste treatment technologies such as mechanical biological or mechanical heat treatments or are built with their own front end processing equipment.

ATTs offer several different options for energy conversion from the oils, tars, and syngas, including use for heating, power generation, industrial applications, and liquid fuels production. The most common configuration in WtE applications is to combust the syngas in a boiler to generate steam, with this being used to generate power via standard turbo-generator equipment, or for heat supply to industrial/commercial/residential users, or for both. The nature of the syngas produced differs between gasification and pyrolysis technologies. In gasification systems, the gas element is maximised to be used for energetic purposes, though in cases where air is used as the gasifying medium the net calorific value (NCV) of the syngas can be lower than with pyrolysis. In pyrolysis systems, the higher oils outputs lend the technology more towards chemicals industry purposes. Pyrolysis can be considered as two sub-sets: slow and fast pyrolysis. Fast pyrolysis is generally employed to maximize the liquid bio-oil product yield, while slow pyrolysis processes are tailored to maximize the yield of

---

[65] Defra (2013) Advanced Thermal Treatment of Municipal Solid Waste

the solid product[66]. Where slow pyrolysis processes exist, these are often combined with a gasification stage to increase the syngas yield.

3.3.2 Technical Viability

While gasification and pyrolysis technologies have been around for some time for use with various traditional fuel (such as coal), these technologies have more limited track record with handling residual wastes, and a litany of costly failures have brought doubt on their commercial and operational viability. Compared to mass burn incineration, only small numbers of ATT facilities have been commercialized, and in relatively few countries worldwide (the UK, Sweden, Germany, Canada, the United States, and Japan).

The key challenge for gasification/pyrolysis technologies are making them cost competitive with other waste practices. Tarring (the deposition of tars) in ATT facilities can cause blockages and reduced operational efficiencies. This has been associated with plant failures and inefficiencies at several pilot and commercial scale facilities due to failures in meeting projected energy generation, revenue generation, and emission targets. It has been estimated that worldwide a total of US$2 (NZ$3.2) billion has been invested before in failed ATT facilities before they were shut down or cancelled before commencing operations[67]. One such example of this is when the company Air Products abandoned its energy-from-waste projects in the Tees Valley (UK) in 2016, blaming design and operational challenges for a failure set to cost the company as much as £700m. The two plants were expected to process 700,000 tonnes of feedstock every year, using plasma gasification technology to convert RDF into gas for the national grid. Many other examples of failed gasification and pyrolysis plants are found in the referenced literature.[67, 68]

Such high-profile failures of gasification plants in the UK over the last decade have shattered confidence in ATTs by investors, so that currently the UK only has two fully operational, commercial-scale gasification plants[68]. Even so, publicly released data for one of these plants reveals problematic performance (multiple plant shutdowns over several months), and the developer of the other plant publicly stated it will not attempt gasification a second time[69]. As a result of repeated failures, the UK market is generally moving away from ATTs, with multiple developers applying to change granted planning permissions from gasification to incineration.

Similarly, to gasification, plant failures and few commercially operating waste pyrolysis facilities around the world means the technical and commercial viability of pyrolysis systems for WtE remains unproven, and risk laden. Pyrolysis systems are also restricted in size because pyrolysis is an endothermic process (a closed system that absorbs heat/thermal energy from its surroundings) so its use for large scale application within the waste sector is unlikely to be technically or commercially feasible.

In Aotearoa New Zealand, the application of ATT for WtE is very limited for waste treatment projects. Most projects are focused on research and development rather than commercial application, while most known gasification and pyrolysis technologies utilise wood or other forms of biomass as feedstocks rather than MSW[70]. The company Bioplant is seeking to develop its first pyrolysis plant in in either Australia or Aotearoa

---

[66] https://doi.org/10.1016/B978-0-12-386505-2.00002-X
[67] https://www.no-burn.org/wp-content/uploads/Waste-Gasification-and-Pyrolysis-high-risk-low-yield-processes-march-2017.pdf
[68] https://www.endswasteandbioenergy.com/article/1740906/gas-went-wrong-uks-gasification-industry
[69] https://www.endswasteandbioenergy.com/article/1676045/no-new-gasification-facilities-expanding-viridor
[70] Perrot, J.F. and Subiantoro, A., (2018). Municipal waste management strategy review and waste-to-energy potentials in New Zealand. *Sustainability*, 10(9), p.3114.

New Zealand[71], though this is yet to progress and Bioplant recently withdrew its resource consent application. While ATTs have lost much of their credibility and bankability as a WtE solution, resulting from operational problems and multiple plant failures, interest in pyrolysis as a solution for 'chemical recycling' of plastics is gaining ground in Europe due to high recycling targets and the current high proportion of hard-to-recycle plastic packaging. Even so, rules around the calculation of recycling remain to be defined, and the commercial, technical and environmental viability of pyrolysis as a recycling technology remains uncertain.

3.3.3 Characteristics

Gasification technology providers claim the possibility for using a wide range of feedstocks including biomass, residual MSW, plastics, RDF, and tyres as fuel. However, they are far more sensitive to the composition of waste than conventional mass burn incineration meaning that pre-treatment of wate streams is required. Therefore, gasifiers have tended to focus on biomass or RDF as the primary feedstocks. In the most efficient gasification systems, 65% to 75% of the energy contained in the feedstock is converted to chemical energy in the syngas[72]. The remaining energy is lost as heat, unconverted carbon in the residual char and as chemical energy in long chain hydrocarbon compounds. One of the notable ambitions for ATT systems is the higher efficiencies perceived if syngas can be combusted through gas engines (most that have tried have failed) or as an intermediate to produce liquid fuels and chemicals. This adds complexity, however, and has not been achieved at commercial scale in Europe.

A review and benchmarking of ATTs used for production of alternative fuels, as commissioned by BEIS (2021)[73], found that several technologies exist, but these are at various stages of development with many still in the demonstration phase. Some key technical findings include:

- Alternative fuel production ATTs are being developed for operation mainly on biomass or RDF, but most projects in development are focussed more on waste streams than biomass for economic reasons. However, most of the systems in development can process biomass which is likely to be an easier feedstock to process than waste, and
- ATT facilities currently tend to be smaller than conventional mass burn incinerators (typically processing 30,000 to 60,000 tpa). But once technologies are demonstrated, it is likely that systems can be scaled up to larger units, well in excess of 100,000 tpa.

In contrast, existing pyrolysis technologies used to produce fuels are generally smaller with throughput capacities of 7,000 to 10,000 tpa and can be fuelled by tyres, waste plastics and RDF as feedstocks. The BEIS report states that, fundamentally, these small-scale systems can be considered for the conversion of niche waste or the production of niche fuels rather than large-scale production of replacement fuels.

3.3.4 Economics

The cost of pre-treatment will vary widely depending on the feedstock and the AGT process requirements, with some of the potential feedstocks such as waste wood, waste plastics or agricultural waste streams needing little pre-treatment. The IEA Bioenergy report[74] estimates the mechanical treatment of MSW in

---

[71] http://www.bioplantenergy.com/projects
[72] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1023792/agt-benchmarking-task-2-report.pdf
[73] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1023792/agt-benchmarking-task-2-report.pdf
[74] https://www.ieabioenergy.com/wp-content/uploads/2019/02/CS3-MSW-pretreatment-for-gasification.pdf

Germany to produce a rough RDF cost of €5/t to €15/t of incoming waste. However, given the litany of failed and poorly performing plants linked to fuel quality, these RDF preparation costs may be more suited to incineration than for ATTs, and higher fuel preparation costs would be more appropriate.

To meet net zero carbon emissions targets, CCUS will be required for all processes. This will incur additional costs.

3.4 Anaerobic Digestion (AD)

3.4.1 Technology overview

Anaerobic digestion (AD) refers to the breakdown of organic matter in anaerobic conditions (without oxygen) to produce part biogas, and part digestate (the remainder of the waste that can be applied to land). The AD technology for MSW developed from the systems used to treat sewage sludge and animal slurries from farms.

Biogas has various uses; for example, it can be burnt directly to generate electricity, or the biogas can be scrubbed and treated further to produce a vehicle fuel, which can be substituted for fossil serviced fuels. Alternatively, the biogas can be fed into a gas grid. As noted earlier, Aotearoa New Zealand has a single pipeline network, operated in the North Island by Firstgas, which is looking to make its gas renewable to assist in Aotearoa New Zealand's 2050 net zero carbon commitment.[75] In doing so, it is envisioned that hydrogen gas will fully replace natural gas in the grid by 2050. Between now and then, it is likely that biogas will be used in advance of or alongside any hydrogen transition.[76] This presents a challenge to how the South Island will decarbonise its gas use, where there is no current gas grid.

The Ecogas AD Plant at Reporoa

The first large scale AD facility at Reporoa, near Taupō in the centre of the North Island, has recently been developed by Ecogas and is now moving into the production phase, taking waste. Once fully operational, it is expected to treat 75,000 tonnes of organic wastes from both households and businesses, largely from Auckland kerbside food scraps collections. For comparison it is estimated that[77] during 2020 in Aotearoa New Zealand, households and businesses sent more than 300,000 tonnes of food to landfill, and hence Aotearoa New Zealand would only need four AD plants the size of Reporoa to deal with all the food scraps currently going to landfill.

Ecogas notes that:

- 200 tonnes of nitrogen-rich digestate will be produced annually, which will be applied to surrounding farmland. The digestate (called 'biofertiliser' by Ecogas) is screened (2mm) and pasteurised prior to distribution.

---

[75] https://gasischanging.co.nz/assets/uploads/Firstgas-Bringing-Zero-Carbon-Gas-to-You-and-Aotearoa.pdf

[76] https://www.newshub.co.nz/home/new-zealand/2021/03/firstgas-group-announces-plan-to-decarbonise-gas-pipeline-network-in-new-zealand.html

[77] https://www.mpi.govt.nz/food-safety-home/reducing-food-waste-at-home/?stage=Live

- Trucks delivering into Auckland will be used to back haul the food waste to Taupō, eliminating some transport impacts.
- The plant will burn some biogas to generate electricity and heat for its own internal demand.
- Some of the renewable heat will be supplied to local growers, T&G, for growing tomatoes in greenhouses.
- The remaining gas will be upgraded (2024) to pipeline-specification renewable gas and injected into the gas grid.
- The CO_2 from the upgrading process/combustion will be partially supplied to the T&G glasshouse. It is also likely that the remaining CO_2 will be bottled for market distribution and use, e.g. in the food and drink industry for carbonation.

The process will therefore not only produce electricity, fertiliser and biogas, but also offset the requirement for importing industrial CO_2 . The plant is designed and operated to meet the UK BSI:PAS110 standard regarding its digestate, one of the most globally-recognised standards for AD facilities treating source-separated organic waste.

There are two main types of AD; wet AD and dry AD, with the main differences between the technologies summarised as follows:

- Wet AD systems were first developed by the wastewater industry to treat organic sludge from treatment. In some countries, there is now a reasonably large industry which focus on the treatment of food waste. Wet AD systems generally process organic matter with a 10% to 20% dry matter content. The infrastructure is usually more energy intensive than dry AD, requiring mass reactors that are continuously mixed and can be found in sequence to reach full digestion. Additionally, the pre-treatment necessary to condition solid wastes into a slurry of adequate consistency, and without coarse or heavy contaminants, can be complex involving screens, pulpers, drums, presses, breakers, and flotation units.
- Dry AD, on the other hand, treats organic matter with generally >20% dry matter, and typically the composition of the waste includes garden wastes mixed with food wastes. Dry systems generally are less energy intensive, with less pre-treatment stages required. It is akin to in-vessel composting, but in a low-oxygen environment, with the focus more on the digestate (see below) than energy generation from the biogas.

Concerns over the use of the fraction of the waste that remains after digestion, known as the digestate, include the potential for available nitrogen (nitrogen that is not bound up with other elements and moves freely) within the digestate to leach from land. Nitrogen leaching can cause water course eutrophication and is a common concern with the over-application of artificial fertilisers on agricultural land.

Food wastes are relatively high in nitrogen compared to garden wastes and when digested, either through AD or composting (of all types), the nitrogen is preserved. However, because the materials generally found in garden wastes have a large proportion of lignin[78] which decomposes very slowly over time, the resulting material contains a higher proportion of carbon compounds and biomass that the available nitrogen is able to bind to. On the other hand, AD of food wastes has low carbon content because most of the food is degraded, with less than 10% typically remaining un-degraded. This means that there is far less material that available

---

[78] Lignin is a class of complex organic polymers that form key structural materials in the support tissues of most plants. Lignins are particularly important in the formation of cell walls, especially in wood and bark, because they lend rigidity and do not rot easily. https://en.wikipedia.org/wiki/Lignin#:~:text=Lignin%20is%20a%20class%20of,and%20do%20not%20rot%20easily.

nitrogen can bind to and so it is readily available for uptake by plants, making it more akin to a synthetic fertiliser but also raising concerns regarding over-application.

To combat this, in-vessel composting (IVC) of the AD digestate, along with garden wastes, can be introduced as a second stage. This increases the nutrient content of the compost and also ensures there is sufficient carbon and other biomass left to help bind the nutrients to the compost. This creates a compost with high nutrient levels that are not easily leached. This is the approach taken in Italy, which is described further below.

3.4.2 Technical Viability

AD has been proven to be an effective organic waste treatment method. The UK now has approximately 642 operational AD plants, 446 farm-fed, and 196 waste-fed; with over 4.9m tonnes of food waste being treated this way each year[79]. 536 of the sites are combined heat and power (CHP) units (i.e. generating electricity and heat), and 94 are biomethane-to-grid (BtG) plants, directly supplying the UK gas grid, offsetting natural fossil gas use.

In best cases, the concern over digestate application to land have been addressed by effective legislation applying tight controls to the quality of outputs. Italy, which sees the highest food waste capture rates in the world, has introduced effective management structures to control the quality of soil amendments that are produced through AD. Italy current collects approximately 6m tonnes of food and garden waste (100kg per capita) per year, around half of which goes to AD as opposed to composting facilities (which will mostly take garden waste). As of 2015, 47 AD plants in Italy collectively had the capacity to digest 3 million tonnes of food waste (69% of the total), sludge (15%) and garden waste (10%). There is increasing demand for these facilities in the southern regions as most existing facilities are concentrated in the north (CIC, 2017).

In January 2011, Italy instituted a non-compostable plastic carrier bag ban, which led to a progressive reduction in use of non-compostable plastic shopping bags in retail stores and a significant increase in use of certified compostable shopping bags for collecting food scraps. A study in 2012 showed that an optimised plant that targets the removal of non-compostable liners, after the ban on non-compostable plastic bag ban, resulted in in very low contamination levels and well composted materials.[80]

It must be noted, however, that the widespread use of compostable packaging (beyond bio-bags for food waste collection) can lead to micro-plastic contamination of the compost/digestate; both in terms of incompletely digested compostable and conventional plastics that have mistakenly been placed in food waste collections.[81]

3.4.3 Qualitative comments – AD vs Composting

The success of organic waste treatment technologies depends on the feedstock composition and quality, local setting, and management of end products. Where optimised, with food waste as the main feedstock, AD can perform very well, although composting (vermicomposting, in-vessel composting, or windrow) can be more

---

[79] Data from the UK National Non-Food Crops Centre (NNFCC)

[80] Managing compostable bags at anaerobic digestion plants, C Garaffa and R. Yepsen (2012). Available at: https://www.biocycle.net/managing-compostable-bags-at-anaerobic-digestion-plants/

[81] Microplastics identification and quantification in the composted Organic Fraction of Municipal Solid Waste - ScienceDirect, Microplastics in composts, digestates, and food wastes: A review - Porterfield - 2023 - Journal of Environmental Quality - Wiley Online Library

appropriate for some settings and feedstocks that have a wider range of organics, for example including woody garden waste.

It is worth noting that AD can provide continuous and controllable energy, which is not the case for some renewable technologies like solar and wind. Energy generation through AD can be seen as a form of renewable energy generation if the carbon in the feedstock was recently sequestered from the atmosphere. As noted in 3.3.1, biogas produced through AD can also have various uses aside from electricity generation, including heat generation (often through a CHP plant), direct injection into the gas grid (offsetting fossil gas use), and conversion into a transport fuel.

Where the AD digestate is composted with garden waste prior to being applied to land, it can provide a suitable alternative to synthetic fertiliser use, which is a highly carbon intensive material to produce. Sceptics of AD may argue that composting of food wastes to begin with is a more valid approach, eliminating the requirement for AD. However, this approach has drawbacks from a climate change perspective. Firstly, allowing food to decay through composting will release much of the same carbon to the atmosphere as is released during the AD energy generation process using biogas[82]. Studies[83] have shown that, overall, AD of food waste in most scenarios creates a carbon sink (i.e. the net carbon emissions balance is negative when taking into account avoided emissions, e.g. from other sources of electricity and heat, and fertiliser production). In comparison, there is a small net-positive impact for composting (where CO_2 is released, but the only avoided emissions are in relation to avoided fertiliser production).

Secondly, the CO_2 released through AD can more easily be captured and used by surrounding industrial sites, as is the case for the Reporoa AD plant. Additionally, AD allows for industrial food waste to be treated which might not compost so well: e.g., high lipid content waste appears to be problematic for vermicomposting whilst AD would handle this well.[84]

The location of the organic waste treatment infrastructure is also important. In Auckland, where space is limited, finding locations for large-scale composting facilities (such as windrows) could be difficult, although in-vessel-composters (IVC) can provide a relatively compact solution. AD is, however, less at risk of adverse effects on local receptors, such as odour pollution and leachate impact, compared to composting sites. Currently the separately collected food waste from Auckland is sent to the Reporoa facility in the centre of the North Island. While the transport impacts of this are reduced through the use of back-loading; transport impacts would be reduced if the Reporoa site was to source feedstock from more local suppliers, for example in the Waikato region.

The use case for AD is likely to be different in more remote areas. AD can be deployed at small scale on farms to process manures or agricultural residues, as is commonly done across the UK for example where there are literally hundreds of farm AD plants, many generating gas or electricity for the respective national grids, or on-farm heat and power uses. Where gas grids are not established, or heat and gas off-takers are not positioned, AD is likely to be less attractive in carbon benefit terms. In these areas, composting of garden and food wastes may be a more beneficial treatment option. Additionally, smaller community-scale composting projects that

---

[82] Provided the feedstock for energy generation was only produced a short time ago, there is relatively little difference – from the perspective of the carbon cycle – of using this to generate energy or allowing it to decay.

[83] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics/emissions-impacts-of-food-waste-recovery-technologies

[84] Wu, Z et. Al, (2019) Effects of different lipid contents on growth of earthworms and the products during vermicomposting, https://journals.sagepub.com/doi/full/10.1177/0734242X19861683

require very little infrastructure or technical expertise may be more able to handle the smaller waste volumes arising locally.

AD and composting are not mutually exclusive and, as noted above, the use of AD with a secondary composting stage, in many ways offers the best of both worlds in terms of biogas production combined with a high-quality compost.

We would emphasise that the comments above are general, focused on carbon/climate change impacts, and not based on quantitative analysis. Further analysis in the Aotearoa New Zealand context is required to establish the optimum organic waste treatment method in each particular setting, for example, North Island vs South, rural vs urban.

3.4.4 Economics

As noted earlier, the UK built significant AD treatment capacity (predominantly consisting of wet AD) for food waste through the first half of the previous decade. At the time it was estimated that typical capital costs of AD infrastructure were roughly £40/tonne (NZ$80) for annualised CAPEX costs and £36/tonne (NZ$72) for annualised OPEX costs.[85] To give one example, the anaerobic digestion (AD) plant built at Bygrave Lodge Farm, in Hertfordshire, in 2014, was developed by Biogen and cost £12m (NZ$24m), and will process 45,000 tonnes per year of food waste from retailers, manufacturers and households. Such facilities are expected to be viable for around 20 years.[86]

3.5 Facilities Producing Refuse Derived Fuels (RDF)

3.5.1 Technology Overview

As well as traditional recycling methods, MSW can be used to create an energy source known as refuse-derived fuel (RDF). RDF is typically pre-treated, baled residual waste, which is exported for use in suitable WtE facilities such as incinerators, gasification/pyrolysis and cement kiln co-incineration. RDF is often utilised as a fossil fuel replacement in cement kilns or power plants because it is easy to transport and store, has a relatively high net calorific value (NCV), and can reduce CO_2 compared to fossil fuel combustion alone. Solid recovered fuel (SRF) is also a fuel produced by shredding and dehydrating solid commercial and industrial waste but can be distinguished from RDF in the fact that it tends to be drier, with a higher NCV, and is produced to reach a specific quality standard. Therefore, more advanced waste treatment facilities are configured to produce SRF. Pre-treatment processes producing RDF/SRF include:

---

[85] WRAP (2013) *A survey of the UK Anaerobic Digestion industry in 2013*, 2013, http://www.organics-recycling.org.uk/uploads/article2927/ASORI%202013%20report.pdf

[86] Department for Business, and Energy and Industrial Strategy (2021) *Final Stage IA: Green Gas Support Scheme/Green Gas Levy*, September 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1018133/green-gas-impact-assessment.pdf

- **Material recovery facilities (MRFs)** – These may be either ‘clean MRFs’ which sort materials from mixed recycling collections, or ‘dirty MRFs’ which sort, shred and sometimes bale household or similar commercial residual waste. This non-recyclable material from dirty MRFs, when prepared for thermal treatment, is referred to as RDF. A third category of MRF are those facilities which deal with construction and demolition (C&D) waste. While these ‘C&D MRFs’ often produce some combustible output streams, these may be quite different in character to RDF derived from household-like residual wastes.
- **Mechanical-biological treatment facilities (MBTs)** - MBT is a generic term for the integration of several mechanical and biological processes. MBT plants may be configured in a variety of ways to sort and partially treat residual waste. The process involves size reduction and sorting of the residual waste into different components, which are typically separated into recyclable fractions by mixed waste sorting (MWS), RDF, contaminants, and organic-rich fractions. There are multiple variants of MBT including biodrying, which prioritises the production of RDF, and biostabilisation, which prioritises stabilisation of organics prior to landfill to reduce the landfill gas.

A key element in both pre-treatment processes is the recovery of materials for recycling. This has scope to reduce emissions of waste that would otherwise be burnt, in particular where the plastics are recovered for recycling. In practice, however, material recycling rates from most MRFs and MBT facilities are quite low, with very few targeting plastics for recycling. Facilities primarily target metals because they are relatively easy to sort and have a high cost-value.

In Aotearoa New Zealand, much timber used in the construction industry is treated with compounds that are problematic for energetic recovery (e.g., chromated copper arsenate [CCA] and boron-based preservatives). It can be quite difficult to visually identify this timber from non-treated or lesser treated timber, which creates problems when recovering construction waste for use in RDF production. Arsenic in particular from CCA-treated wood is a problem since it is both highly toxic, and has a low boiling point, so is amongst the first of the metalloids and metals to be released during CCA combustion. In the UK, CCA or creosote-treated wood is categorised as hazardous waste and can only be disposed of though specialist incineration plants or hazardous waste landfill.[87] No conclusion is provided here on appropriate routes for this material in an Aotearoa New Zealand context, but the issue is raised that treated waste wood may not be suitable for conventional WtE or Class 2 landfill disposal.

3.5.2 Technical Viability

Regulatory restrictions on landfill space, subsequent landfill bans, the search for alternatives to incineration, and increased costs of alternative disposal have been the major drivers for the development of MBT technologies in the EU. European markets for established MBT plants include Germany, Austria, Italy, Switzerland, and the Netherlands. As of 2017, Europe had a total of about 570 active MBT plants with a treatment capacity of 55 million tons, with another 120 facilities with an estimated capacity of almost 10 million annual tons to be commissioned between 2017 and 2025. [88]

In the UK, towards about 20% of residual waste which is sent for combustion first undergoes preparation into RDF, most of which is produced through basic MRFs. In contrast to the EU, relatively little RDF has been produced through MBTs. A number of UK MBT facilities have experienced operational and commercial difficulties, many have closed ahead of time, and few remain. This is primarily due to high disposal prices for

---

[87] UK Environment Agency (2014) Briefing on regulation of wood, http://www.organics-recycling.org.uk/uploads/article2892/Wood%20Briefing_28Aug2014V1%20final.pdf
[88] https://www.ecoprog.com/fileadmin/user_upload/pressemitteilungen/pr_MBT_ecoprog_2017.pdf

stabilised waste or RDF (due to high landfill tax and high WtE gate fees), as well as various problems over storage of RDF which can cause environmental problems such as leaching, odour and pest issues.

3.5.3 Characteristics of MBT plants

RDF is typically made through the use of MBT plants, the main advantage of which is the high flexibility to the changing requirements of the waste markets. The MBT plants can be optimized to meet the specific requirements of the market through increased recovery of recyclables, RDF, and potentially also biogas production (in AD-based MBT systems). By reducing the biodegradable fraction in the MSW destined for landfilling, the MBT concept helps minimize the greenhouse gas (GHG) emissions from landfilling untreated MSW. Ultimately, the MBT concept minimises the overall amount of waste being landfilled, while some MBT facilities (and all dirty MRFS) also produce RDF.

The capacity of MBT facilities can vary substantially, with very small plants treating 25,000 tpa or less, to large scale integrated facilities with capacities of over 200,000 tpa[89]. Given the variety of systems available, capital costs in the UK have been shown to vary widely in the range of £50 million (NZ$100m) to £125 million (NZ$250m) for facilities with capacities of 80,000 tpa to 225,000 tpa[90].

The drawbacks of MBT include low recovery rates of recyclables (compared to kerbside collections, for instance) and poor quality of the biostabilised organic fraction. This can be used to reduce landfill methane emissions, but being from mixed residual waste it is too polluted and should not be used as soil improver. Pre-treatment of the waste is relatively simple and, as such, technical risks associated with treatment are relatively low. There can be risks associated with fuel off-takers no longer accepting the material, which has been the case in the past with shipment to cement kilns during economic downturns.

3.5.4 Economics

Experience of MRFs operating in the UK indicates that residual waste can be sorted, baled and wrapped as basic RDF at a cost equivalent of about NZ$20 to $30 per tonne. This should be suitable for incineration, co-incineration, or cement kiln use. However, costs will be significantly higher if the requirement is to produce fuel to a tight specification, and warnings from the ATT section above should be heeded as numerous facilities have failed, linked to inadequate fuel preparation.

---

[89] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221039/pb13890-treatment-solid-waste.pdf

[90] *ibid*

3.6 Cement Kilns / Process Co-Incineration

3.6.1 Technology Overview

Cement kilns typically require high NCV fuels to reach the desired temperature of operation, therefore the fuel mix needs to be designed appropriately ahead of time. Traditionally, fuels used in cement kilns were coal, oil, petroleum coke, and natural gas, as these have high NCVs. In the case of coal use for cement production (which has very high carbon emissions), quite significant GHG benefits can be achieved by substituting with RDF, produced through an MBT or other pre-treatment type processes (see Section 3.1.4). However, where a cement kiln's fuel mix is already made up of significant alternative fuels such as waste tyres or biomass, it may need to be blended with fossil fuels to reach the required NCV.

The extent to which a GHG benefit is generated by co-processing RDF in a cement kiln depends on the kiln's marginal fuel, i.e., the fuel which would have been used if it had not been displaced by RDF. Fossil fuels (such as coal, natural gas and oil) have a high percentage share in global kiln fuel mixtures and can be displaced by the introduction of RDF or waste wood, resulting in GHG benefits. Conversely, introducing RDF into a cement kiln that already has a large thermal energy contribution from non-fossil carbon fuels may not yield as large a benefit, as the displaced fuel may be a mixture of fossil carbon sources and non-fossil carbon sources.

It should be noted, however, that co-incineration of waste can have significant impacts on health and the environment due to the polluting nature of the associated emissions.[91] In some jurisdictions there are higher emissions thresholds for cement kilns compared to dedicated waste incineration plants, which in Europe, for example, are subject to tight emission controls under the Industrial Emissions Directive.

3.6.2 Technical Viability

The cement industry is said to have the capacity to burn all the plastic waste the world currently produces, and the United Nations Environment Programme (UNEP) estimates that figure to be 300 million tonnes annually. This capacity is far greater than the world's plastic recycling capacity, estimated to be 46 million tonnes a year, according to a 2018 estimate by the OECD.

Benefits of use of RDF in cement kilns include the high efficiency utilisation of the generated heat (90% of energy in the RDF is released). However, generally only a limited fraction of the total energy requirement of the cement kiln can be provided by RDF. While high substitution rates have been achieved in some kilns (80% to 100% in the pre-calciner, and 50% to 60% in the kiln burner itself), in others, local waste markets and permitting conditions do not allow for higher rates of alternative fuels. Operational issues are faced with high

---

[91] The health impacts of waste incineration: a systematic review - Tait - 2020 - Australian and New Zealand Journal of Public Health - Wiley Online Library

rates of substitution, such as incomplete combustion, increased specific heat consumption, reduced flame temperature, and kiln coating build-up.[92]

3.6.3 Economics

The initial driver for using RDF in cement kilns was fuel costs, and it still is. Without the use of waste derived fuels, cement plants in most European countries are simply no longer competitive. Using RDF as a supplemental fuel in cement production is an economically viable option to minimise fuel costs and landfill disposals.

3.6.4 Aotearoa New Zealand Plant Experience

The Golden Bay Cement plant, a 0.9Mtpa plant based in Portland, Whangārei, has been upgraded so that tyre-derived fuel (TDF) can be used to make cement. The upgraded plant opened in 2021 and once fully operational will take ~3.1 million shredded tyres a year. This is estimated to result in a 15% reduction in coal use. In addition, the suspension preheater tower was modified to allow construction and demolition waste and natural wood biomass substitution to be introduced as a further coal replacement fuel. This has increased coal substitution to above 30%.

The facility is looking to drive substitution rates up to 80%, although which source of alternative fuel would be used is not clear. However, we note that the Ministry for Environment's marginal abatement cost curves analysis report[93] states that RDFs have not been incorporated into the abatement option for cement, as the tyre-derived fuel option is proceeding and is estimated to have lower abatement cost. Less is known to the authors of this report about the potential for fuel substitution at the cement grinding plant at Tauranga, though it is presumed that if there was potential for RDF substitution then this would have been covered within the Ministry for Environment's report.

3.7 Carbon Capture, Utilisation and Storage (CCUS)

3.7.1 Technology Overview

CCUS is a set of technologies aimed at capturing, transporting and either permanently storing or using CO_2 that would otherwise be released into the atmosphere. CCUS involves the following steps:

- **Capturing** CO_2 from power plants or industrial processes using a chemical reaction. Once captured, CO_2 is then compressed into a liquid state for transportation.
- **Transporting** the CO_2 (via pipelines or ships) to deep geological storage points, such as depleted oil and gas fields or deep saline aquifers.
- **Storing** the CO_2 in these sites permanently.

---

[92] Sharma P. et al (23 June 2022) *Recent Progress in Refuse Derived Fuel (RDF) Co-processing in Cement Production: Direct Firing in Kiln/Calciner vs Process Integration of RDF Gasification*, Journal of Waste and Biomass Valorization

[93] https://environment.govt.nz/publications/marginal-abatement-cost-curves-analysis-for-new-zealand-potential-greenhouse-gas-mitigation-options-and-their-costs/

- **Utilisation.** As an alternative to storage, this involves the use of CO_2 in industrial processes, particularly in carbonation of beverages, glasshouses, and in modified atmosphere packaging. Currently Aotearoa New Zealand has a CO_2 compressed gas shortage issue for industry who use it, especially the food and beverage industry. Most used to be generated from the Marsden Point refinery but with its closure, supply is mostly being imported from overseas. Carbon miles can therefore also be reduced, making Aotearoa New Zealand utilisation more attractive.

For WtE, the most suitable capture technology is post-combustion (removal of CO_2 from flue gases). The most promising and mature technology is the absorption process based on a chemical solvent, such as monoethanolamine (MEA). This can be included within new facilities or retrofitted to existing waste treatment facilities.

Although the capture and compression of CO_2 incurs an energy loss (additional parasitic load) in the form of the provision of steam and power, the sequestration of biogenic carbon emissions, in addition to fossil carbon, can result in a net drawdown of emissions, so industry claims are that net negative emissions are possible from use of CCUS.

3.7.2 Technical Viability

Post-combustion CO_2 capture is a mature technology having been used effectively for many years outside of Aotearoa New Zealand; there are already three incineration facilities in Europe incorporating CCUS at a significant scale.[94] After capture, carbon either needs to be utilised by an industry partner or transported and stored. At a small scale, the Ecogas AD facility at Reporoa is providing CO_2 (as well as power and heat) for utilisation in T&G Fresh tomato greenhouses. However, as mentioned above, while useful for the horticultural process, this only provides temporary delay to release of CO_2 emissions (within the growing tomato plants) and does not provide a net greenhouse gas reduction. Long term underground storage solutions are needed to achieve GHG reductions from CCUS systems.

Any meaningful deployment of CCUS in Aotearoa New Zealand would be reliant on the availability of transportation and storage infrastructure, brought to life through various industry partnerships. Recent work by Eunomia on behalf of Viridor in the UK stated that *"The barriers to deploying CCUS projects in the UK, and globally, are said to be primarily commercial, rather than technical."*[95] The report then flags that financial viability is reduced for smaller facilities due to [dis-] economies of [small-] scale; an assumption was taken that CCUS was not deemed financially viable on plants smaller than 100ktpa capacity. Furthermore, the analysis undertaken demonstrates that while the size of facility is important, co-location near other large CO_2 emitters (which may then be able to form a CCUS 'cluster' that can share transport and storage solutions) is also a critical factor in determining the practical application and cost effectiveness of CCUS on WtE.

The availability of well-located storage options located within reach of high carbon emitting producers for Aotearoa New Zealand are also believed to be problematic. A report by the Ministry for Environment raises issues both for steel and cement plants that *"it is not clear that the carbon capture and storage option is practicable as there are no underground formations nearby (such as a depleted oil and gas reservoir) where the* CO_2

---

[94] AVR Duiven and Twence Hengelo in the Netherlands, and Fortum Oslo Varne in Norway

[95] Eunomia (2021) *CCUS Development Pathway for the EfW Sector*, Report for Viridor, https://www.eunomia.co.uk/reports-tools/ccus-development-pathway-for-the-efw-sector/

could be stored, and developing infrastructure to transport the CO to the Taranaki region would materially increase the cost of this option”. [96]

There are no clear clusters of industrial emitters that would benefit from CCUS. Eunomia research shows that stand alone emitters that are a significant distance from existing infrastructure will see this highest CAPEX and OPEX per tonne of product output. Therefore, the construction of WtE facilities that wish to integrate CCUS will also likely see high costs associated, unless they are positioned close to existing transport and storage infrastructure.

3.7.3 Economics

Costs for capture, transport and storage of CO_2, as applied on WtE technologies, will incur additional costs (levelized over a 25-year period including the CCUS CAPEX and OPEX costs) estimated at between NZ$130 to NZ$230 per tonne of treated waste.[97] These costs are relevant for minimum plant sizes of 100,000 tpa in a UK setting where large clusters of technologies make use of shared infrastructure. However, the discussions above suggest that clusters of technologies adopting CCUS are unlikely to be possible in the Aotearoa New Zealand situation, and this cost would be higher. Furthermore, the small and dispersed nature of residual waste generation in Aotearoa New Zealand (outside of the very largest urban areas of Auckland, Christchurch and Wellington for example), coupled with future changes in line with a circular economy, are likely to limit the suitability of large-scale WtE plant for individual local councils, further pushing up the cost of CCUS if applied on smaller WtE facilities.

---

[96] Ministry for the Environment (2020) *Marginal abatement cost curves analysis for New Zealand: Potential greenhouse gas mitigation options and their costs*. Wellington: Ministry for the Environment, https://environment.govt.nz/assets/Publications/Files/marginal-abatement-cost-curves-analysis_0.docx

[97] Eunomia (2022) Eunomia Incineration Review Report - Opportunities to Decarbonise the Waste Treatment Infrastructure, https://www.gov.scot/publications/stop-sort-burn-bury-independent-review-role-incineration-waste-hierarchy-scotland-second-report-decarbonisation-residual-waste-infrastructure-scotland/documents/

4.0

Impact of WtE in the Aotearoa New Zealand Context

4.1 Carbon Performance – Landfill, Thermal Treatment, AD and Co-Processing at Cement Kilns

4.1.1 Key Assumptions

Previous Eunomia projects investigating the carbon impacts of different waste technologies that are in scope of this analysis have been used to base the carbon modelling outputs for this report. Common assumptions are used across all models, such as capture rates of materials during pre-treatment, landfill gas capture efficiency and carbon capture efficiency of CCUS technology. Where the modelling requires assumptions specific to the Aotearoa New Zealand context, these have been outlined here and in Appendix A 2.0.

4.1.1.1 Marginal Emissons Factors

The marginal grid electricity emissions factor for Aotearoa New Zealand is assumed to be 130 gCO_2/KWh, which has been averaged over the previous 5 years.[98]

4.1.1.2 Residual Waste Composition

This residual waste composition used in this analysis is based upon a Aotearoa New Zealand compositional analysis carried out in 2018 for material entering class 1 landfills. We have modified this compositional dataset to account for two relative extreme compositions which might be accepted at proposed WtE facilities in Aotearoa New Zealand. These two compositions are intended to cover the range of composition feedstock scenarios that could eventuate in the future. Composition 1 represents a ‘low organic’ waste to landfill scenario. This corresponds to a future where policy measures have been relatively successful at reducing organic wastes to landfill. Scenario 2 represents a ‘high organics’ waste to landfill scenario. This corresponds to a future where policy measures have been less successful at reducing organic wastes to landfill.

The first composition (**Composition 1**) modelled assumes that half of the accepted waste comes from household sources and the remaining half comes from commercial and industrial sources, which are themselves assumed to be predominantly plastics and rubber. For the purposes of this study, we assume that typical ‘household like’ wastes (such as paper, plastics and metals) from the landfill composition study will remain at the same proportions. The hazardous elements of the Class 1 landfill composition are assumed to be from sources which would not go to WtE and are therefore removed, along with the majority of the non-combustible elements. Organic wastes make up roughly 15% of the waste mix, of which 6% is garden waste and 9% is food waste.

The second composition (**Composition 2**) assumes that the majority of the waste that is sent for incineration will be from household sources, plus elements of combustible construction waste (assumed to contain high

---

[98] Data from Statistica.com, https://www.statista.com/statistics/1299734/new-zealand-emissions-intensity-from-electricity-generation/

proportions of wood). Organic wastes make up a larger proportion of the mix, at about 25% of the composition. Roughly 10% is garden waste and 15% is food waste.

See Appendix A 4.1 for full details of waste compositions modelled.

It is important to note that residual waste compositions are changeable, depending on the time of year, location of arisings, waste policies, and diversion initiatives that are in place. For example, in a scenario where separate food waste collections are introduced, the proportion of fossil carbon materials in the remaining residual waste stream will increase proportionally. This will also increase the direct emissions per tonne of waste treated by a treatment technology. Conversely, where interventions are introduced that remove other materials from the residual waste stream such as waste reduction policies and increases to recycling rates, the relative proportions of the targeted materials will drop.

4.1.1.3 Treatment specific assumptions

Key points to note on treatment specific assumptions taken within our modelling are:

- Landfill modelling is largely in line with the national methane emissions model used in the NZ Government submission to the UNFCCC, with a ‘sequestration’ credit applied for the storage of 50% of biogenic carbon,
- operational data relating to the energy generation performance of incineration, combined heat, and power (CHP) and advanced thermal technologies (ATT) plants in Aotearoa New Zealand is not available as there are no such plants in the country treating household waste. Energy generation efficiencies for proposed facilities were based on data obtained from newer European facilities, which were considered alongside data on the intended energy generation performance of the proposed facilities for NZ, and
- AD impacts are modelled under a wet AD system where the digestate is stabilised and used as soil fertiliser.[99] Two models have been given for the treatment of the generated biogas, the first where the biogas is combusted on site and the electricity added to the grid and the second where the biogas is used in vehicle fuel production. Due to the rather restricted nature of the gas grid in Aotearoa New Zealand, direct gas injection was not considered, although this is possible (and planned for Reporoa) in the North Island.

4.1.2 Results

The results presented below are shown as carbon emissions per tonne of waste treated - either one tonne of residual waste, where treatment considers incineration and landfill, or one tonne of food waste where treatment considers AD. The results of the modelling for both Composition 1 and Composition 2 are presented in Figure 4-1: and Figure 4-2, respectively.

---

[99] Wet AD was modelled as there are operational and planned facilities in New Zealand. Although dry AD would be technically feasible in NZ the project team is not aware of any planned facilities using this technology. The use case is also likely to be less favourable as dry AD would compete directly with in vessel composting which is able to operate at lower cost.

Figure 4-1: Carbon Impacts of unabated WtE treatment Methods Using Residual Waste Composition 1 (tonne CO_{2eq} per tonne waste)

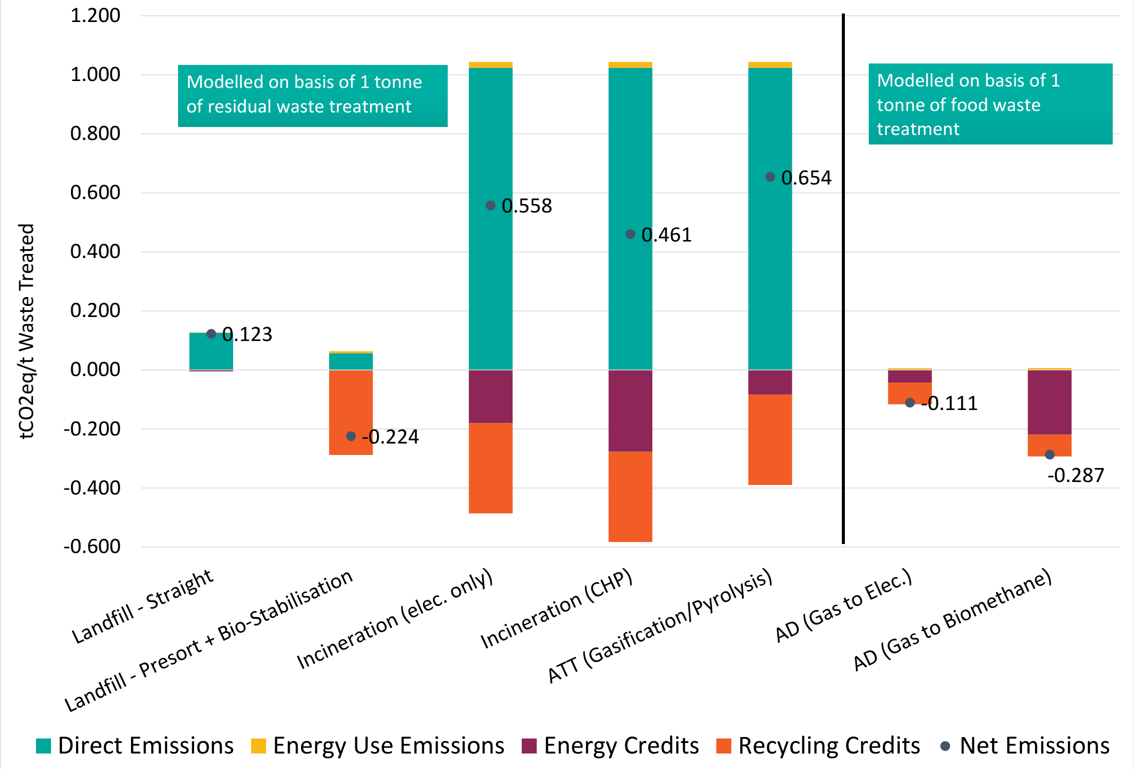
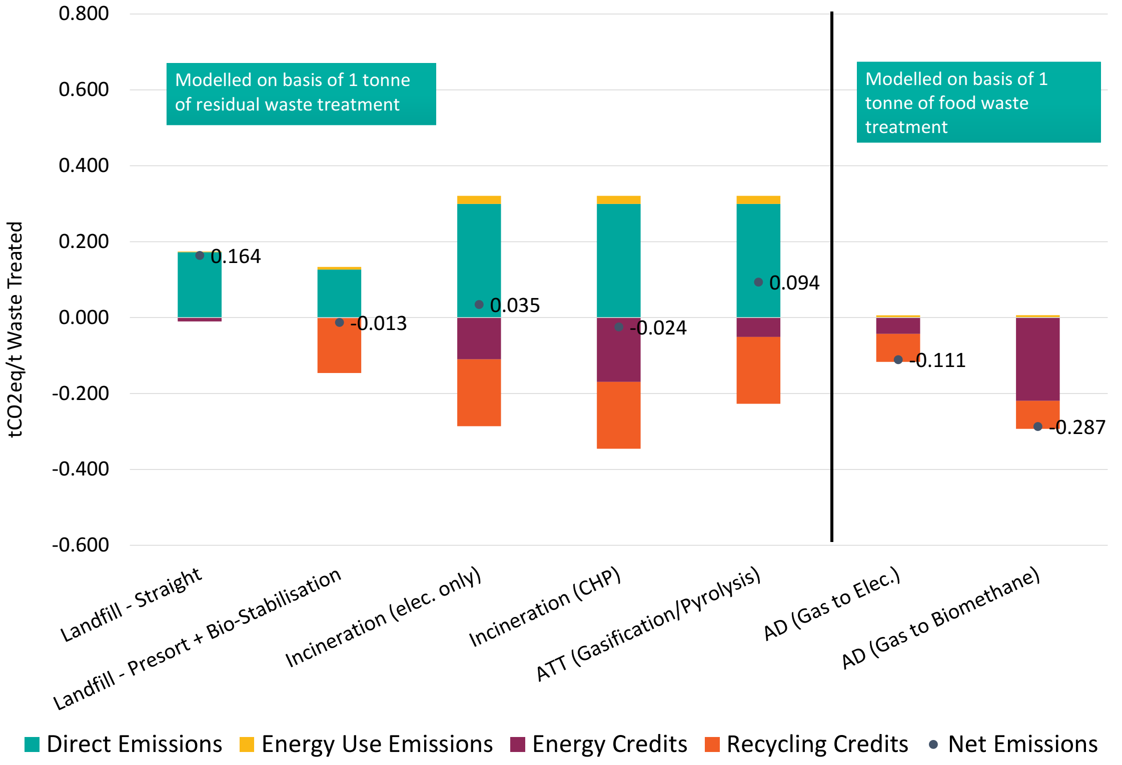


Figure 4-2: Carbon Impacts of unabated WtE treatment Methods Using Residual Waste Composition 2 (tonne CO_{2eq} per tonne waste)



4.1.2.1 Results Discussion on Landfill, Incineration and ATT

The results indicate that, compared to WtE technologies that incinerate residual waste, directly landfilling waste as is currently done in Aotearoa New Zealand shows a much better carbon performance, on a per tonne basis for Composition 1 (see Figure 4-1:). This is because of the much higher fossil carbon (in the form of plastics) content of Composition 1 residual waste creating far more direct emissions when it is incinerated.

In comparison, landfilling waste based of Composition 2 nature has the worst net performance of all treatment technologies (see Figure 4-2). This is because the high biogenic carbon fraction of the waste, mainly food and garden waste, which degrades within landfill and produces methane which has a far more damaging GWP than CO_2. [100] These emissions can thus be reduced by the introduction of food organics and garden organics (FOGO) collection systems. Separate food (and garden) waste collections, on the other hand, will both reduce landfill methane emissions and provide additional benefits from the electricity or biogas produced from anaerobic digestion of food waste.

Applying a degree of pre-sorting and bio-stabilising the waste before it is landfilled (through Mechanical Biological Treatment (MBT) technologies) significantly reduces the net emissions to close to or just under zero net emissions. Again, FOGO or separate food waste collection systems will have an interaction with this residual treatment option (landfill emissions would be reduced further still, since there will be less organics in the residual waste).

The incineration technologies for Composition 2 look comparatively well off compared to landfill because of the high biogenic carbon content, the emissions from which are ignored in this analysis, as outlined in in Section A 3.0. Indeed, incineration using CHP shows net negative carbon emissions. The performance of CHP plants are dependent on those facilities generating and utilising a significant amount of heat, and this heat being used to displace gas (or other similarly carbon intense fuels). This benefit also requires an off taker to be close to the facility so that the least heat loss is achieved. Therefore, the achievability of the negative net emissions seen for CHP incineration with Composition 2 (Figure 4-2) may not be possible in reality.

Furthermore, it must be considered that the energy generation emissions credits (i.e., reductions in emissions occurring elsewhere) associated with thermal treatment will be mostly gone after 2030, and no benefit will be seen by 2050. As such, the electricity-related energy credits (presented as purple bars) within the charts are expected to shrink and potentially disappear in the coming years. This is assuming that Aotearoa New Zealand achieves a fully renewable electricity supply by this time. This is not the case for AD to biomethane however, from which emissions credits may remain more significant assuming they continue to reduce requirements for gas heating or fossil-based transport fuels.

4.1.2.2 Results Discussion on Anaerobic Digestion

The modelling highlights that adopting AD currently would result in net negative carbon emissions. A facility that directly burns the gas generated from digestion results in a less beneficial outcome than if the gas generated was used to produce bio-methane that displaces diesel in heavy goods vehicles (HGVs). This is because the energy generation offset associated with electricity generation is already low due to the largely decarbonised electricity grid in Aotearoa New Zealand. Whereas displacement of diesel in HGVs, a highly

---

[100] Methane has a global warming potential which is 34 times higher than CO_2 over a 100-year timescale.

carbon intensive fossil fuel, sees a high emission saving. In addition, it is expected that the net environmental benefit of producing vehicle fuels through AD will last longer because the progression towards decarbonising large vehicles is slower than the decarbonisation of the electricity grid.[101]

As discussed in Section 3.4, there is some opportunity to develop AD where the biogas produced is injected into the gas network where the gas would offset natural gas use. While this has not been specifically modelled here, the overall net benefits would likely sit somewhere in between AD with electricity generation and AD producing biomethane that is used in vehicle fuel.

As highlighted previously, the modelling is based on one tonne of food waste treatment, instead of one tonne of residual waste treatment as is the case for the incineration technologies. Therefore, the results above cannot be directly compared on a like-for-like basis. Instead, we provide a supplementary investigation into overall waste system emissions in the section below.

4.1.2.3 Indicative results for the overall waste system

To highlight how a whole waste system would look like when considering landfill against WtE technologies, both compositions in this analysis has been modelled under three alternative options, based on the assumption that 100,000 tonnes are treated, and also averaged across the two compositions:

- **Option 1:** Landfill 100% residual waste (as current practice),
- **Option 2:** Send 100% residual waste to incineration with energy recovery,
- **Option 3:** Assuming 75% of the food waste arisings are capture and sent to AD, with the remainder of the residual waste being landfilled; and,
- **Option 4:** Assuming 75% of the food waste arisings are capture and sent to AD, with the remainder of the residual waste being incinerated with energy recovery.

The results of the analysis are presented in Table 4-1.

Table 4-1 Overall Waste System for Treatment of 100kt of Residual Waste, Assuming Composition 1 and 2

tCO_{2e}	Composition 1 (high fossil content)	Composition 2 (high wood content)	Average of both
Option 1: Landfill all residual waste	12,251	16,390	14,321
Option 2: WtE for all residual waste	55,761	3,480	29,621
Option 3: AD for 75% capture of food waste, landfill remaining residual waste	7,402	8,478	7,940
Option 4: AD for 75% capture of food waste, WtE remaining residual waste	51,380	2,202	26,791

The results show that for each composition:

---

[101] The approach used for AD emissions modelling is based upon a wet AD process as we currently do not have sufficient data to accurately model a dry AD process.

- It is always more beneficial to capture food waste for AD rather than it being sent to landfill or incineration,
- The substantially higher fossil carbon content of Composition 1 means that incineration of this type of waste stream results in significantly higher total carbon emissions than Composition 2, even when food waste is effectively captured; and,
- The higher biogenic carbon content of Composition 2 (in the form of garden waste, paper and card) means that landfilling this waste stream, even after effective food waste capture, there are higher carbon emissions than sending this waste stream directly to WtE.

The two waste compositions considered here may be considered an extreme range of residual waste compositions considered for WtE, and therefore we also provide an average of the two within the right-hand column of the table. Taken as a whole, these carbon modelling results indicate that an order or preference (from most to least preferable) is as follows:

1. Separate food waste for AD, landfill for the remainder.
2. Landfill all residual waste.
3. Separate food waste for AD, WtE for the remainder.
4. WtE all residual waste.

Thermal treatment (incineration) plants are expensive investments (see Section 3.1) and the results currently show that a more beneficial environmental outcome could be achieved by authorities developing bio-stabilisation plants alongside the existing landfill capacity, or, ideally, phasing out the landfilling of organic waste and collecting it separately for treatment in AD plants (food) and composting plants (other organic waste). It should be noted that the wider negative environmental impacts of landfill, which are well documented and can be significant, are not explored in this study.

Additionally, continuation of landfilling would not be conducive to a zero-waste society where circular economy solutions are considered above all disposal and recovery technologies. It should be noted that the same degree of environmental benefit (to bio-stabilisation) can be made through recycling, by increasing the capture rates of materials at the kerbside before the material enters the residual waste stream. Indeed, it will be more beneficial to concentrate on circular economy solutions in Aotearoa New Zealand, including reuse and remanufacture, which have better carbon and pollution reduction outcomes, and benefit society far more, in terms of jobs and economic growth, than other waste treatment options.

4.1.2.4 Co-Processing at Cement Kilns

Previous work undertaken by Eunomia has shown the net environmental benefit of co-processing refuse derived fuel (RDF) in cement kilns can yields large net positive outcomes where the fuel being displaced was coal.[102] The same approach to the modelling has been adopted here to estimate the net carbon impacts of co-processing RDF in a typical cement kiln. In each case the production method of RDF was the same as previous modelling, such as typical sorting efficiencies and drying conditions.

---

[102] Two projects carried out by Eunomia for confidential clients have calculated the net environmental impact co-processing RDF at cement kilns in the UK and in Malaysia. Impacts ranged from -0.550 tCO_2/t waste to -0.750 tCO_2/t waste. Common assumptions and modelling approaches were used in each case, with different specific treatment characteristics for each location applied. In each case, coal was assumed to be the marginal fuel that is displaced by RDF

The difference in environmental outcomes between results here and in previous modelling is mainly down to the following reasons:

- Difference in the initial waste compositions entering pre-treatment. In previous modelling, the analysis was undertaken for the year 2030, where each country had different assumptions in place for the capture rate of recyclables (being largely driven to current capture rates and predicted changes to capture rates due to the impacts of legislation changes).
- Different cement kiln operational assumptions, such as the clinker production thermal energy requirement.

Both Composition 1 and Composition 2 have been modelled. It is assumed that some plastics and metals are removed from the waste stream to give a net calorific value (NCV) that is considered typical for RDF co-processed at cement kilns. The results are presented in Figure 4-3 and Figure 4-4.

The modelling results present both the modelled net carbon impact for displacement of both coal and biogenic fuel. This therefore gives a full range of impacts from most beneficial, to least beneficial. It has been noted previously that the Golden Bay cement kiln in Aotearoa New Zealand operates with high alternative fuel replacement ratios, a large proportion coming from both used tyres and waste timber from the construction industry.

The results show that significant net environmental benefits over both incineration and landfill can be reached by co-processing waste in cement kilns, largely due to its power production emission offset, i.e., the emissions reduction brought about by avoided power production using coal elsewhere. This, however, relies on the fuel displacing mostly fossil fuels like coal.

Where the RDF displaces biomass (or waste timber), the net environmental benefit are not seen and the relative performance would actually be more damaging than through conventional WtE technologies and landfill. This logic does also apply for incineration facilities where the marginal energy being displaced is biomass or renewable electricity generators. Displacement of fuel that is a mixture of coal, tyres or waste timber would yield a net carbon benefit somewhere between these results (i.e., if a larger proportion of the fuel being displaced was coal, then a greater benefit would be seen and vice versa).

Figure 4-3: Net Carbon Impact of Co-Processing RDF at Cement Kilns vs Landfilling and Incineration (Based on Composition 1)

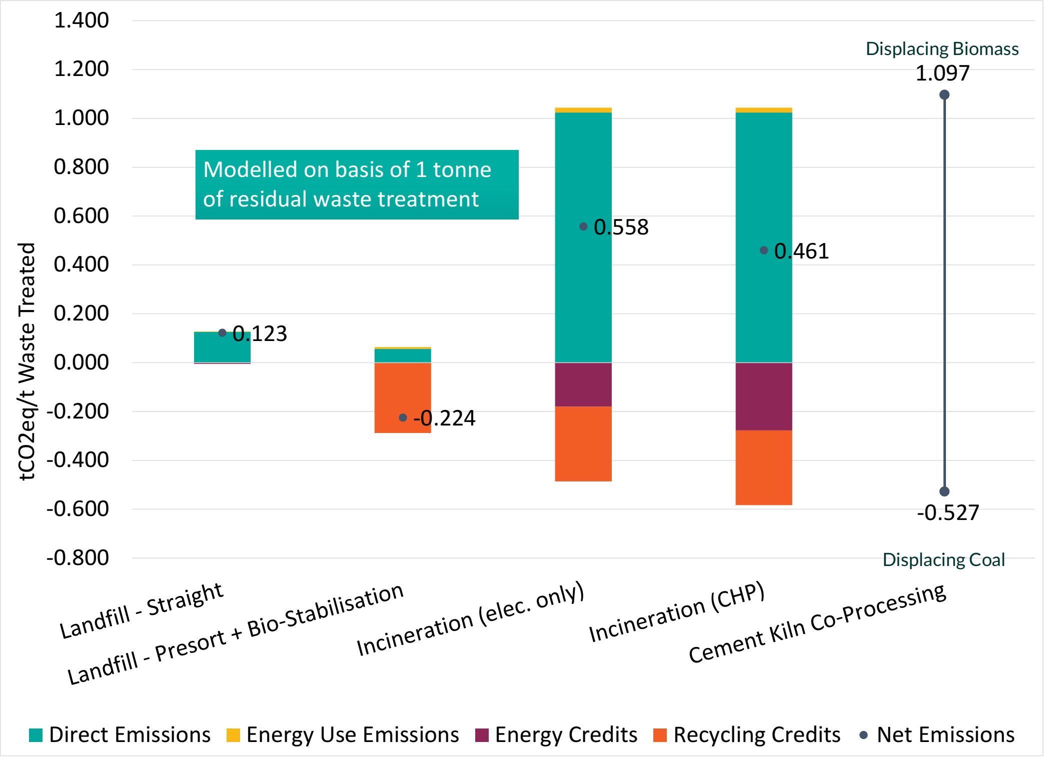
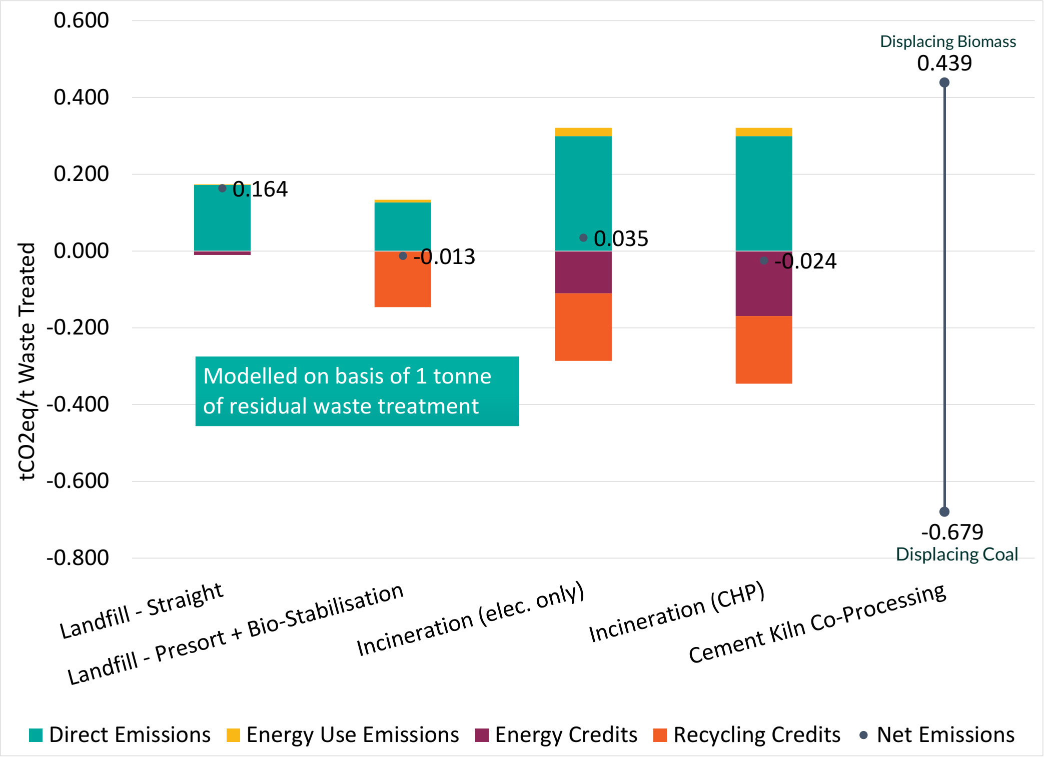


Figure 4-4 Net Carbon Impact of Co-Processing RDF at Cement Kilns vs Landfilling and Incineration (Based on Composition 2)



Co-processing of RDF in cement kilns could be seen as an attractive way, in carbon terms, for the treatment of unrecyclable wastes which avoids the substantial costs of building new dedicated MSW combustion facilities, or through continued landfilling of waste, which all show a net damaging carbon performance. RDF production would require an MBT plant, or modified MRF, to be built, however.

This treatment route would likely require establishment of an RDF export market from Aotearoa New Zealand (for which this report does not explore further) if the Golden Bay cement kiln would not be able to accept RDF, or if the RDF would displace a high proportion of alternative fuels. The cement industry is, however, taking steps to decarbonise its operations, and that in many countries, fuels other than coal are increasingly being used – such as biomass rich feedstocks, hydrogen and other waste derived fuels. Therefore, this method of treatment is unlikely to be a long-term solution for the treatment of residual waste.

It may be more likely that RDF would be burnt at the Huntly coal-fired power station in the short to medium term, displacing coal and hence offering a similar carbon benefit to burning in a cement kiln.

4.2 WtE’s Potential for Carbon capture and storage (CCUS)

4.2.1 Key Assumptions

As discussed in Section 4.1.1, modelling has been based upon previous Eunomia projects that investigated the carbon impacts of waste infrastructure in scope of this project. Marginal emissions factors and residual waste compositions remain the same.

4.2.1.1 Treatment specific assumptions

Key points to note on treatment specific assumptions for WtE with CCUS are:

- A decrease in energy generation efficiency is seen in facilities that operate carbon capture technologies. This is due to a parasitic energy requirement associated with the capture and compression of CO_2.
- 90% of flue gas CO_2 emissions are captured through carbon capture.
- A carbon emissions benefit is applied to the biogenic carbon emissions that are captured and sequestered as part of the capture system.

As with conventional WtE technologies (see Section 4.1), the modelling of CCUS emissions were carried out for both Composition 1 and Composition 2.

4.2.2 Results

As with other results, Introduction of CCUS alongside incineration has been modelled with both Compositions 1 and 2, and the results can be found in Figure 4-5 and Figure 4-6.

- CCUS results in substantial net beneficial carbon emissions for both compositions, although Composition 2 shows much larger savings in direct process emissions. These savings are a result of long-term biogenic carbon sequestration, seen as negative direct emissions, with the rest of emission savings coming from energy generation credits and recycling credits.
- Composition 1, which has proportionally much higher fossil carbon content so does not see such large carbon sequestration credits. It does receive higher savings for front-end sorting (recycling credits) and energy generation offsets, because of the higher calorific waste composition.
- Were the capture rate rates of plastics during front end sorting to be doubled for Composition 1, it would compete with the performance seen for Composition 2. This highlights that where incineration is employed, it is imperative that fossil carbon materials (and to a slightly lesser extent metals) are removed as far as possible from the waste stream before it is incinerated, so that the most benefit can be seen. This is especially important for waste streams that have a high fossil content.

As per previous sections, it is anticipated that the benefits in energy credits received by a facility will reduce into the future as the country's electricity grid decarbonises. Additionally, any improvements made to front-end sorting of the residual waste will show up as additional recycling credits, especially for further plastic and metal capture.

As noted in previous sections (see Section 3.7), CCUS is anticipated to carry high capital and operating costs, on top of the high costs associated with incineration especially for smaller facilities or facilities further away from transport and storage infrastructure. As noted by the Marginal Abatement Cost Curve Report produced for the Ministry for the Environment, CCUS is not seen as a clear practical option for heavy industry, such as steel and cement, due to there not being any depleted oil and gas fields nearby to the existing heavy industrial sites that are located in the north island. [103] Developing infrastructure to transport the CO_2 to the Taranaki region, located in the Southwestern region of the North Island, would materially increase the cost of implementing the technology. Proposed incineration facilities with CCUS which are positioned away from this region, would therefore also see large costs associated with transport and storage. Because there are few clear "clusters" of industrial emitters (as adopted in the UK's approach to the introduction of CCUS), the cost of transport and storage would likely be borne more heavily by one or two emitters that introduce CCUS, such as new WtE infrastructure.

Considering the high cost associated with CCUS, it is likely that a more economic outcome would be to treat residual waste through co-processing at cement kilns, which would also yield a similar net environmental outcome in terms of CO_2 emissions, if displacement of coal was achieved.

Finally, it is important to highlight that net negative emissions likely do not constitute a global system benefit, or an overall emissions reduction. This is owing to resource use and emissions associated with the other life stages of materials and products prior to their end of life, such as material manufacture and use. Therefore, although negative emissions can be obtained through CCUS (and other WtE technologies) from the perspective of residual waste in isolation, application of the technology relies on materials to be produced and disposed through a linear economy. As such, from the whole system perspective, global CO_2 concentrations are increased with each tonne burned. Decarbonisation on a societal level is thus better achieved through better design for recyclability, and other shifts to circular economy business models. Nevertheless, as long as residual waste exists, arguably CCUS has a role – even if the net negative claim is only applicable when focusing on a discrete part of the material lifecycle.

---

[103] Ministry for the Environment, Marginal abatement cost curves analysis for New Zealand: Potential GHG Mitigation Options and Their Costs, 2020.

Figure 4-5: Net Carbon Impact of WtE technologies with CCUS (Based on Composition 1)

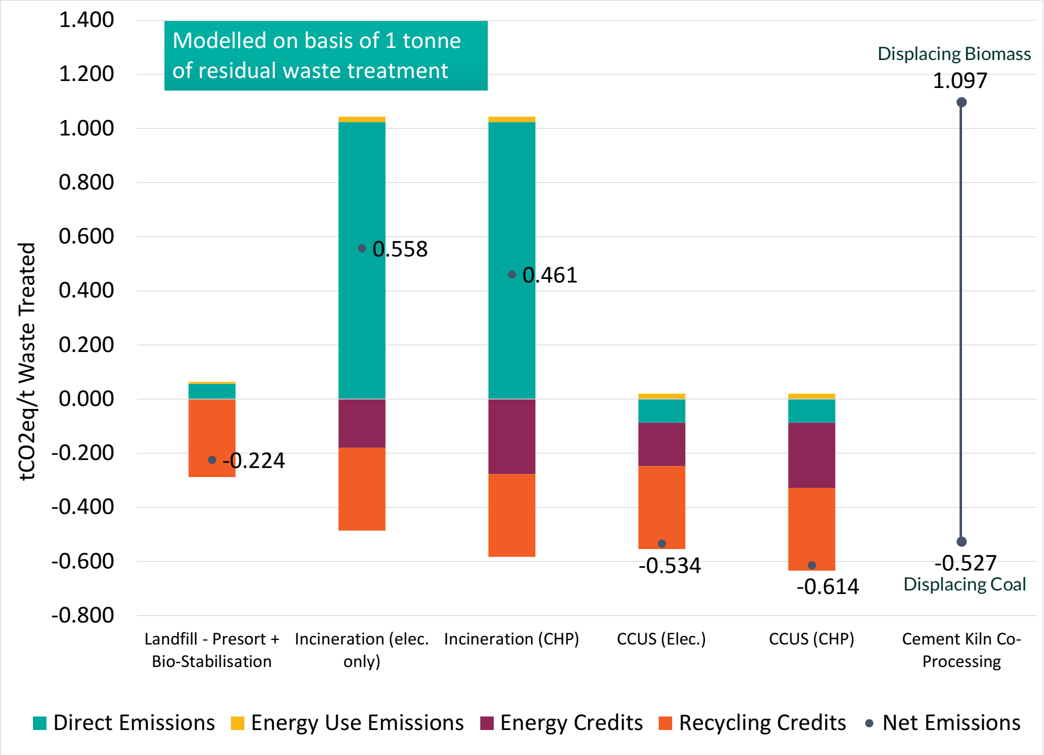
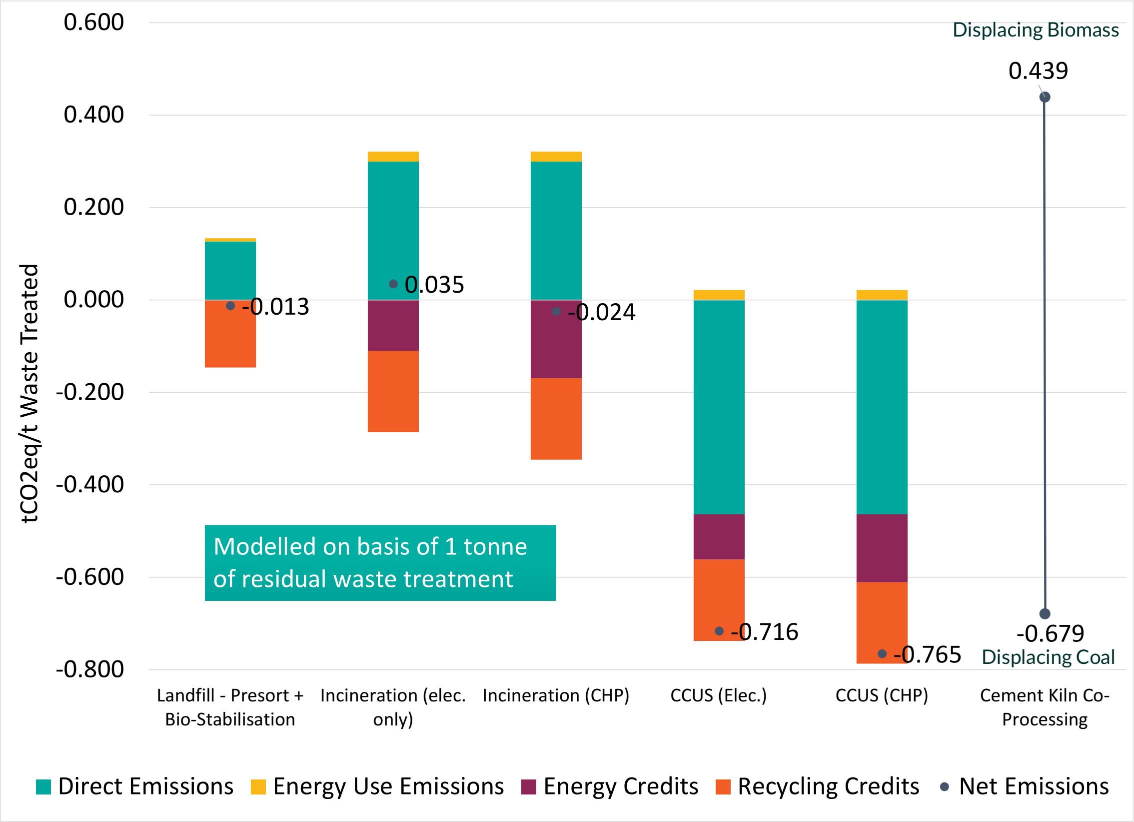


Figure 4-6: Net Carbon Impact of WtE technologies with CCUS (Based on Composition 2)



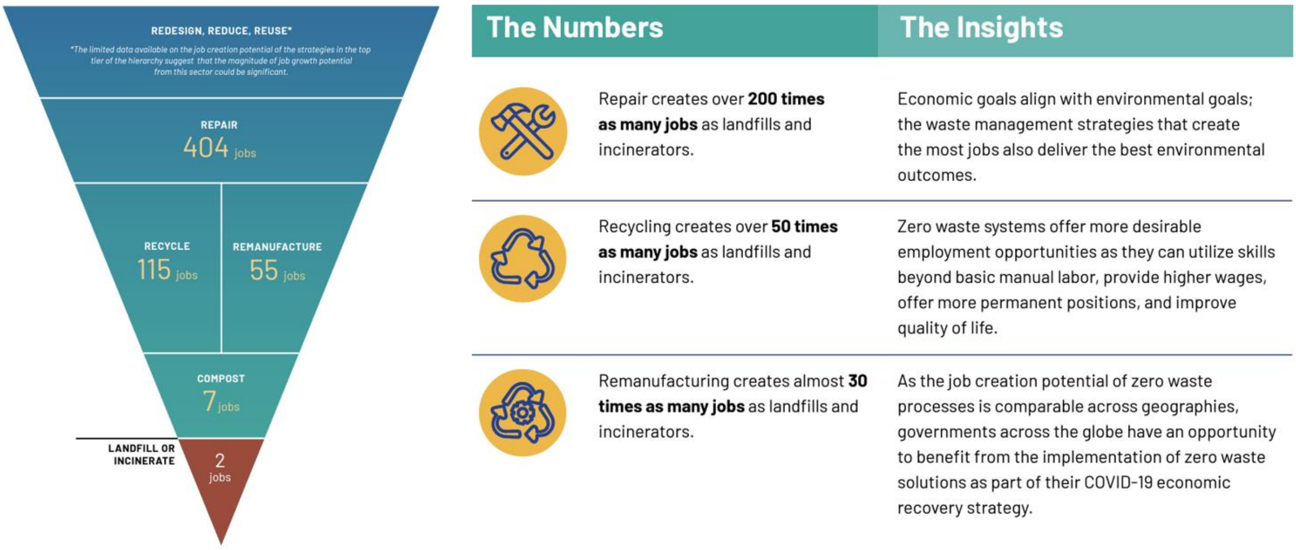
4.3 Employment Impacts

Many studies show that progressing towards a more circular economy can generate more employment opportunities than a typical linear economy (take, make, waste). In fact, the higher up the waste hierarchy the economy progresses, the more jobs are generated, sometimes in orders of magnitude; for example, jobs in repairing, refurbishing, remanufacturing, handling for direct reuse, and in recycling, anaerobic digestion (AD) and composting (collection, sorting and reprocessing).

Analysis carried out by Eunomia showed that the literature supports this hypothesis.[104] Typical WtE infrastructure (landfills and incinerators) generated 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 (IVC), 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. Jobs were most abundant in E-waste and plastics reprocessing, with over 120 and 60 FTEs per 10,000 tonnes, respectively. Employment opportunities in re-use and repair rose again by another order of magnitude, with over 500 FTEs per 10,000 tonnes.

A recent meta-analysis by the Global Alliance for Incinerator Alternative (GAIA) in 2021, that reported employment figures from multiple countries, found much the same outcomes; where higher employment opportunities are found further up the waste hierarchy.[105] The study also showed, based on incomes in 22 states in the US, that the income of jobs in the recycling sector was higher than incomes in the disposal sector.

Figure 4-7: Employment Opportunities in the Waste Hierarchy, Adapted from GAIA (2021)



The Numbers	The Insights
Repair creates over **200 times as many jobs** as landfills and incinerators.	Economic goals align with environmental goals; the waste management strategies that create the most jobs also deliver the best environmental outcomes.
Recycling creates over **50 times as many jobs** as landfills and incinerators.	Zero waste systems offer more desirable employment opportunities as they can utilize skills beyond basic manual labor, provide higher wages, offer more permanent positions, and improve quality of life.
Remanufacturing creates almost **30 times as many jobs** as landfills and incinerators.	As the job creation potential of zero waste processes is comparable across geographies, governments across the globe have an opportunity to benefit from the implementation of zero waste solutions as part of their COVID-19 economic recovery strategy.

Finally, a study by Re-London, which focussed on circular economy opportunities in London, found that if a target of 65% recycling rate by 2030 was met, then 386 jobs would be created in circular economy businesses

---

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

[105] Ribeiro-Broomhead, J. & Tangri, N. (2021). Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions.

for every 1 job lost in incineration, for every 10,000 tonnes of waste.[106] The scenario was mainly driven by increases to recycling rates, design changes that enhance repair and recyclability, and communication campaigns that drive behaviour change and waste prevention (mainly food waste). The study recognises that to reach circular economy targets, such as 65% recycling rate by 2030, large transitions in businesses need to be made. Transitioning to a circular economy will mean that equitable skills will need to be matched between workers and jobs, while investments in training and up-skilling will be required to bridge the skills gap. Overall, the transition will require collaboration between government, education systems and businesses.

A 2018 report by the International Labour Organisation (ILO) showed that if circular economy practices were introduced on a global scale, then there would be a net increase of 6 million jobs by 2030 compared to a business-as-usual trajectory.[107] Notably, the reallocation of jobs means that jobs from mining and manufacturing sectors would transition to the recycling, repair, and rental sectors.

While investment into job reallocation will be required, the movement to a circular economy is forecasted to increase prosperity. A 2016 report by Eunomia for SUEZ[108], the large European-based waste company, the UK economy could gain £9.1bn in GVA per annum by 2030, and save 4 million tonnes of CO_2eq per annum, by following an ambitious CE transition. A report issued by the European Commission showed that GDP in Europe could be increased, with a greater emphasis on CE policies, by 0.5% compared to the baseline case, whilst also reducing reliance on materials from overseas, making the pact more self-sufficient. It is important to also note that remanufacturing can re-shore jobs in manufacturing that have been previously lost to low cost and often high impact overseas operations, most notably in the Far East.

In all cases, where circular economy practices are introduced, the protection of workers health and wellbeing should be properly taken into consideration. Many jobs in the recycling sector pose a real risk to workers health and safety from physical injuries and exposure to harmful substances. As the circular economy promises to expand the employment opportunities in the waste sector globally, care should be taken to ensure that the transition is a just one and that the quality of work is high.

For Aotearoa New Zealand, a focus on transition to a circular economy (as opposed to move to WtE incineration) means higher recycling rates, separation of organic wastes from other streams and a reduced reliance on waste disposal infrastructure (incineration and landfilling). As the country is not already in a WtE 'lock-in', employment opportunities for the transition to a circular economy are abundant. Where 100 potential jobs can be created from the construction of an incinerator, for example, an order of magnitude higher number of jobs can be created by successfully introducing circular economy practices that retain the same quantity of material within the economy. These jobs can also be created where the quality of the job is kept high, and the health and safety of workers is properly managed.

---

[106] Report - Circular economy effects on waste production in London: impact assessment - ReLondon

[107] The scenario explored the impact of sustained 5% annual increases in recycling rates for plastics, glass, wood pulp, metals and minerals. Worldwide employment would grow by 0.1% by 2030, compared to a business as usual scenario, as defined by the IEA 6°C.

[108] A Resourceful Future: Expanding the UK Economy, Eunomia 2016

4.4 Landfill, Incineration and Carbon Emission Levies

As outlined throughout this report, the incineration of waste in WtE facilities produces carbon emissions that add additional CO_2 to the atmosphere because of the combustion of fossil derived products like plastics. Aotearoa New Zealand's Net Zero target of 2050 requires the right policy interventions to be able to disincentivise high carbon emitting activities. Currently, landfill waste is subject to the Aotearoa New Zealand emissions trading scheme (ETS), but the payments can be offset by use of unique emission factors (UEFs) where the operator is capturing significantly higher greenhouse gases than the assumed default.

In the EU and UK, which have both a net zero by 2050 target, carbon levies are being used to an increasingly higher degree in order to meet emissions reductions targets. The EU ETS will have incineration facilities included by 2028 at the earliest.[109] The UK ETS is likely to follow suit in including incineration infrastructure within the ETS following a call for evidence from the UK Government that consulted on expanding the UK ETS to include waste incineration. The exact way each ETS will operate is currently unknown and is yet to be decided, but it is almost certain that incinerator facilities that treat residual waste will be required to pay for the majority of emissions before the end of the next decade.[110]

Aotearoa New Zealand must be mindful that the policies that it enacts are in general alignment with these ETS', that are also working towards net zero.

There are currently provisions with the Climate Change regulations to calculate and report emissions from combusting used oil, waste oil, used tyres, or waste for the purpose of generating electricity or industrial heat[111]. While energy from waste is not noted under waste provisions, stationary energy is captured under the Aotearoa New Zealand ETS, and so energy generation from waste would also be captured under these provisions.

On the other hand, the current provisions of the Waste Minimisation Act (WMA) exclude incineration with energy recovery from classification as a disposal facility, and hence liability for the waste disposal levy[112]. It is understood that amendments to clarify the liability of WtE facilities are being considered by MfE in proposed revisions to the WMA.

Proposed facilities should also take account of the continued increase in carbon pricing, which has been steadily increasing since the introduction of such emissions trading schemes and is likely to increase further.

Large reductions in emissions from waste management overall can, as noted earlier, be achieved through separate collection of all organic waste, for treatment in AD and composting, and greater emphasis on circular

---

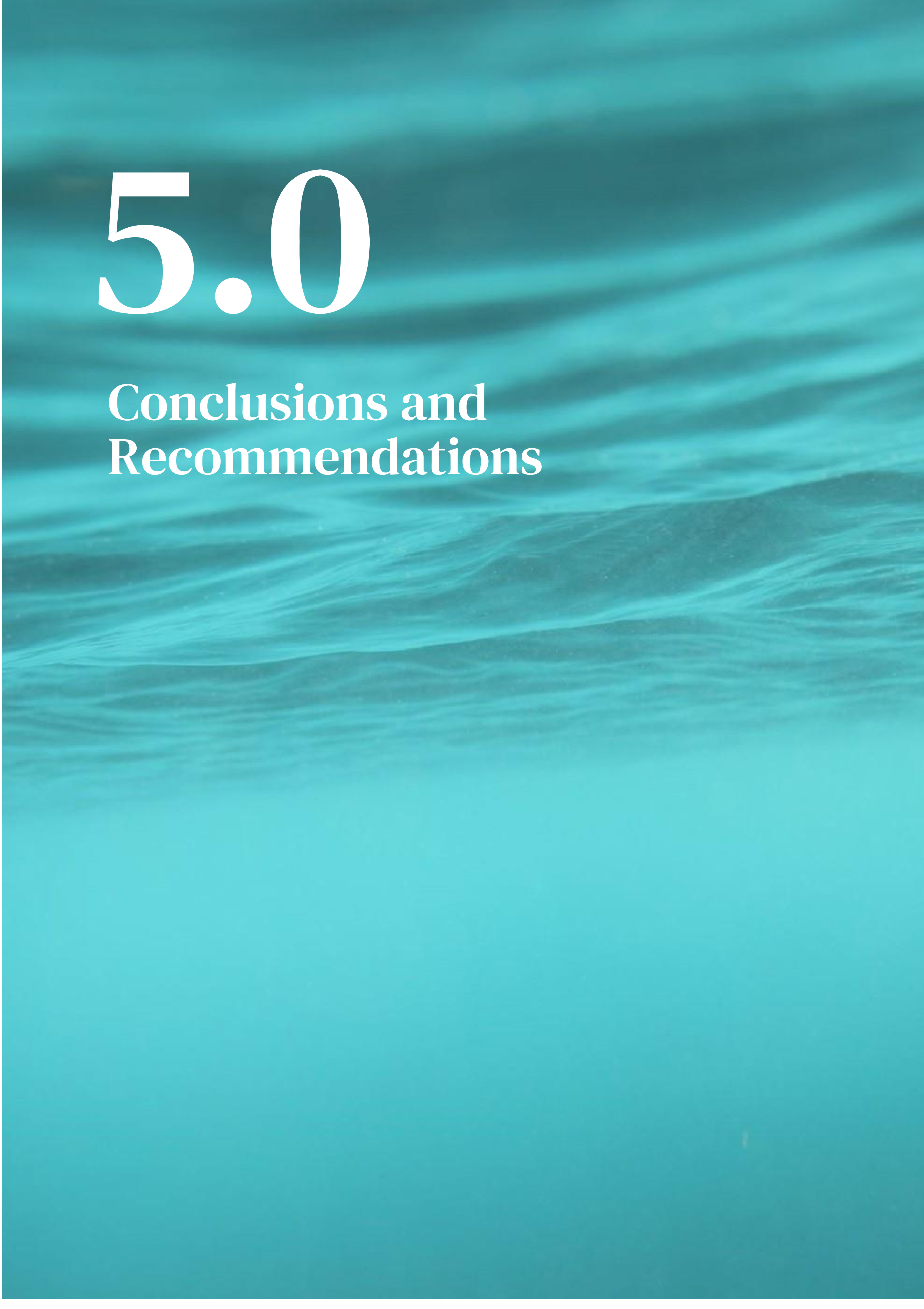
[109] Climate Change: Deal on a more ambitious Emissions Trading System (ETS), European Parliament, December 2022. Accessed March 2023. https://www.europarl.europa.eu/news/en/press-room/20221212IPR64527/climate-change-deal-on-a-more-ambitious-emissions-trading-system-ets

[110] Developing the UK Emissions Trading Scheme (UK ETS), UK Government, March 2022. Accessed March 2023. https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading-scheme-uk-ets

[111] Climate Change (Stationary Energy and Industrial Processes) Regulations 2009, Section 21

[112] Waste Minimisation Act 2008, Section 6.

economy measures at the top end of the hierarchy, along with improved segregation and/or separation of recyclables from residual waste.



5.0

Conclusions and Recommendations

5.1 Discussion and Conclusions

5.1.1 Introduction and historical context (Europe)

WtE technologies of various kinds have been widely used in Europe since the 1960s, a trend that accelerated in the 1990s and early 2000's with the introduction of landfill diversion targets and landfill levies/taxes. These technologies were, in particular, large incineration plants, designed to meet new and relatively strict emission control standards. At this time, it generally made some sense to incinerate waste for energy recovery rather than landfill it, since a) the waste contained reasonably high levels of energy, (although lower than pure fossil fuels due to water content etc.), b) some of it was biogenic (adding less fossil-based 'new' carbon to the atmosphere), and c) the CO_2 emitted overall was lower than that emitted otherwise to generate electricity (i.e. where there was a high proportion of coal and oil use).

Waste management has, however, moved on dramatically in the last 15 to 20 years in Europe, driven by European Directives. Recycling rates in the EU have risen to 64% for packaging and 49% for municipal solid waste (MSW) (EU27) [113], and organic waste is now commonly collected at the kerbside (this being mandated in the EU from the end of 2023) to be composted, or in the case of food, to be anaerobically digested. The MSW that remains tends to be increasingly dominated by non-recyclable plastic packaging, and hence is more carbon intensive to burn than before. At the same time, electricity generation has steadily been decarbonising, with greater use of hydro, wind and solar power, complemented by nuclear power in some countries, with coal, oil and gas use reducing.

This makes the incineration of waste for energy generation increasingly unattractive in carbon emissions terms for most European countries. Furthermore, some evidence indicates that more than half of what is currently being incinerated in the EU could have been recycled or composted[114]; suggesting that much of Europe's WtE incineration capacity is being used to burn valuable resources that could have had a better environmental outcome.

Circular economy policies, focused at the top end of the waste hierarchy, now drive the waste management strategies in Europe; for example via the Circular Economy Action Plan(CEAP)[115]. The European Parliament own-initiative report[116] on the CEAP highlights that "Member States must strengthen prevention and preparation for reuse, increase high-quality recycling and move away from landfilling waste, while minimizing incineration, in line with the waste hierarchy."

The various technologies are discussed, qualitatively and quantitatively, in the sections below.

---

[113] https://www.eea.europa.eu/ims/waste-recycling-in-europe
[114] ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf
[115] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
[116] https://www.europarl.europa.eu/doceo/document/TA-9-2021-0040_EN.html

5.1.2 Qualitative conclusions on WtE technologies

5.1.2.1 Incineration with energy recovery

WtE incineration can be helpful in certain circumstances where the waste feedstock is low in fossil-based materials (that have their origins in geological storage, from millions of years ago) and high in bio-based materials (that have recently captured carbon from the atmosphere when growing as plant matter), and/or where the electricity grid mix is dominated by fossil-fuels. The carbon intensity of European incinerators is significant (540gr CO_2 /kWh)[117], around twice the concentration of CO_2 emissions derived from the average EU electricity grid (296gr CO_2 /kWh)[118] and significantly greater than the energy produced through conventional fossil fuel sources such as gas. Aotearoa New Zealand has a far more decarbonised electricity grid (~85% on average[119]) and hence WtE incineration only makes sense here where the waste feedstock is dominated by biogenic waste materials. The quantitative carbon modelling, reported below, confirms this.

5.1.2.2 Anaerobic Digestion (AD)

In the author's experience, AD is widely seen as the best way to deal with food waste in Europe, and perhaps the only genuinely beneficial WtE technology in a circular economy context. It is important to note that AD and composting are not mutually exclusive, and can work hand in hand, respectively with food waste and other organics. AD of food waste can also be combined with composting of garden waste to improve the quality and nutrient benefits of the AD digestate. Studies show that AD generally offers a better carbon outcome for food waste, overall, than composting[120], particularly where the biogas can be used to offset fossil fuel use in heat and power generation. However, this study does not directly compare food waste treatment in AD vs composting, as the latter is not an WtE technology. Further work would be required in the Aotearoa New Zealand setting to provide a definitive preference for food waste and other organics treatment, and it is likely that this would vary depending on local circumstances.

5.1.2.3 Alternative Treatment Technologies (ATT)

Other forms of WtE, such as pyrolysis and gasification (advanced thermal treatment), are unlikely to be viable in practice for mixed solid waste in Aotearoa New Zealand due to high technical and commercial risks. There may be some scope for burning mixed waste as refuse-derived fuel (RDF) in a cement kiln or a thermal power station as a transitional solution to further offset coal use.[121]

---

[117] ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf

[118] cdn.eurelectric.org/media/4005/power-barometer-final-lr-h-3A4C4DC9.pdf

[119] https://www.transpower.co.nz/about-us/our-strategy

[120] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics/emissions-impacts-of-food-waste-recovery-technologies

[121] Specific use of RDF in the Huntly or Golden Cement facilities was outside the scope of this report and these options were not investigated.

5.1.2.4 Carbon Capture Utilisation and Storage (CCUS)

Carbon capture utilisation and storage (CCUS), when used alongside the burning of waste (incineration or otherwise), can reduce emissions, albeit at a high cost. However, it is important to note that CCUS is still an 'end of pipe' solution, which does not deal with the very substantial upstream emissions in product supply chains.

5.1.2.5 Landfilling

Landfill, even with gas capture and electricity generation, is not considered a WtE approach; but it is currently the main waste disposal option in New Zealand and is included here by way of comparison. Contrary to popular belief, landfilling of relatively inert (non-biodegradable) material like plastic can be preferable to burning it in an incinerator; since the former will not generate landfill gas, while the latter will generate fossil-based carbon dioxide. Landfilling impacts can also be reduced by pre-treating the waste in processes such as mechanical biological treatment (MBT). This process removes recyclables and bio-stabilises the organic waste prior to landfilling so it will not generate methane in the landfill. Although landfilling scenarios generally perform well relative to WtE incineration in the carbon analysis (see below), landfilling nonetheless has significant issues; such as the loss of resources, legacy pollution concerns (e.g. from liquid leachate), and fugitive methane emissions. Because landfilling is, by definition, the end point in a linear material flow it is, ultimately, not compatible with a circular economy.

5.1.3 The Place for WtE in a Circular Economy

An important question is the extent to which WtE can play a role in a transition to a CE. In this context, it is worth noting that most leading organisations on the subject, including the Ellen MacArthur Foundation (EMF), do not regard incineration with energy recovery as CE; but rather as 'leakage' from the system, alongside landfill. Similarly, the EU has excluded WtE incineration from a list of economic activities (under the EU Taxonomy[122] and other financial instruments including The Just Transition Fund and The Recovery and Resilience Facility [123]) considered suitable for 'sustainable finance'. By comparison, AD is considered CE by EMF and the European Commission and is included under the EU Taxonomy and other financial instruments, given its role in the bio-economy, alongside composting.

It is worth noting that the EU-defined Waste Hierarchy was only ever a guide, and where a clearly better environmental outcome could be shown, it was acceptable to depart from the hierarchy. In fact, in a partially decarbonised electricity generation scenario, like the UK; landfilling of 'difficult to recycle' fossil-based plastics, which are essentially inert, would lock-up carbon. In comparison, incineration of those plastics would release net carbon at a level comparable to gas-fired electricity production. This is not to say, of course, that reuse and recycling/composting are not preferable to both incineration and landfill.

Scotland's stance on WtE incineration offers a good summary of the issues from a UK carbon perspective. Zero Waste Scotland's October 2020 report 'The climate change impact of burning municipal waste in Scotland'[124] found that: "Burning residual municipal waste in WtE plants in Scotland in 2018 had an average carbon

---

[122] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[123] https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en
[124] The climate change impacts of burning municipal waste in Scotland. Zero Waste Scotland, June 2021

intensity of 509 g CO_2/kWh. The average carbon intensity for electricity-only incinerators and gasifiers burning residual waste was 524 g CO_2/kWh. This is nearly twice as high as the average carbon intensity of the marginal electricity grid in the UK, which was 270 g CO_2/kWh in 2018. Converting these plants to combined heat and power systems would lower their carbon intensity but not to the level of the UK grid. As a result, in Scotland, WtE [incineration] can no longer be considered a source of low carbon energy within a UK and Scottish context."

Another issue is the impact large scale WtE facilities can have on further development of reuse and recycling. Large facilities, such as waste incinerators, need 'feeding'; and contractual supply of the necessary waste to run them, and the involvement of public funding to build them, can lead to 'lock-in' if waste policies and economic incentives are not designed effectively. Such 'lock-in' can mean that waste that was suitable for reuse, recycling or composting can be diverted to WtE. This needs to be avoided for technologies, such as WtE incineration, that do not offer good carbon performance in the long run; or those that may hinder good circular economy practices.

Denmark, Wales (part of the UK), and Germany offer interesting case studies. Denmark has a long tradition in WtE incineration and the highest municipal waste generation rate per capita (781kg) in the European Union, burning over 50% of its waste. Its current waste policies, however, require it to reduce its incineration capacity by 30% over the next decade and remove 80% of plastic waste from incineration plants by 2030 compared to 2020. To cut overcapacity, seven incinerators nationally will need to close.

Wales has long been a stand-out performer in the UK with a recycling rate of 65%. The country only has two existing MSW WtE incinerators. In the wake of its Beyond Recycling strategy[125], the government announced details of a moratorium[126] on new WtE plants, to cover facilities with capacities of 10MW or greater. Small scale WtE plants of less than 10MW will also only be allowable if the applicant can demonstrate the need for such a facility for the non-recyclable wastes produced in the region. Small plants would also need to supply heat and be carbon-capture and storage enabled where possible.

Germany is a very unusual case, with a high recycling rate (67% for MSW) and WtE incineration now dominating residual waste disposal over landfill (the recovery rate, including recycling, is ~97%). While Germany shows that it isn't impossible to have high levels of WtE incineration as well as high recycling rates; this has only been possible because of a combination of stringent policy measures and targets, including the use of deposit return scheme (DRS) for containers, and an energy context (mainly fossil-fuel based electricity grid generation) that makes the burning of waste make sense in carbon terms.

Finally, it is important to note that circular economy solutions (including reuse, repair and remanufacture), in addition to recycling, are also able to offer far more (generally by an order of magnitude) and better-quality jobs and training opportunities than other waste management options. As the country is not already in a WtE incineration 'lock-in', employment opportunities for the transition to a circular economy are abundant and

---

[125] Beyond Recycling, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/beyond-recycling

[126] Wales Takes Action on Circular Economy with Funding, Upcoming Reforms on Plastic and a Moratorium on Large-Scale Waste Energy, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/wales-takes-action-circular-economy-funding-upcoming-reforms-plastic-and-moratorium-large-scale

many of these opportunities have the potential to support disadvantaged groups and local community economic development in New Zealand.[127]

5.1.4 Te Ao Māori complexities

There are varying levels of understanding of, and attitudes to, WtE technologies in Māori iwi, and they do not generally have the resources and expertise to focus on these issues above all other pressing issues. Organisations such as Para Kore, who have a clear understanding of the issues associated with waste-to-energy, and who have the expertise to engage, are not supported or mandated to hold these conversations, as they are not an iwi and have no legislated mechanisms to engage in the consenting process.

5.1.5 Quantitative Carbon Assessment

The study modelled carbon emissions in four scenarios, three for WtE and one for landfill, in the New Zealand context. The use of WtE in these scenarios was focused on residual waste that would normally go to Class 1 or Class 2 landfill disposal. These scenarios were as follows:

- **Option 1:** Landfill 100% residual waste (as current practice);
- **Option 2:** Send 100% residual waste to incineration with energy recovery[128];
- **Option 3:** Assuming 75% of the food waste generated is captured and sent to anaerobic digestion (AD), with the remainder of the residual waste being landfilled; and
- **Option 4:** Assuming 75% of the food waste generated is captured and sent to AD, with the remainder of the residual waste being incinerated with energy recovery.

Before discussing the conclusions, it is important to remember that the potential impact of WtE, in carbon terms, is highly dependent on two factors; a) the energy generation that would be displaced by it, and b) the composition of the waste feedstock.

On point a), a benefit of WtE is its ability to generate power (and in some cases heat). Electricity generation in New Zealand, as noted earlier, is predominantly (~87%[129]) from renewable sources (hydro, geothermal and wind), with the aim of moving to 95 per cent by 2035 and 100% by 2050 [130]. Gas and coal (predominantly Huntly power station) make up the remainder at present, but are only used for peak demand (mainly gas) and when hydro sources are diminished, e.g. during dry winter periods when hydro power is low and demand is high (coal boilers take a while to get up to temperature and so are used for 'slow peaking' during these periods). An incinerator cannot be easily turned on and off, and would therefore, in the main, be providing baseload power and substituting a very low carbon source (i.e. renewables). Burning of waste is also less efficient than burning gas to generate electricity, and so would not be more efficient even if it were able to be used to help address peak load issues currently provided by burning gas.

---

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

[127] Ribeiro-Broomhead, J. & Tangri, N. (2021). Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions.

[128] The performance of 3 configurations of EfW were modelled: Incineration with energy recovery, incineration with energy and heat recovery (combined heat and power or CHP), and gasification/pyrolysis (collectively known as 'thermal' EfW). The best performing from a carbon perspective was incineration with CHP. However, because of the need to co-locate a facility with a user of the heat, this was considered less likely to be implemented, and so the scenario modelling used incineration with energy recovery as the default form of EfW.

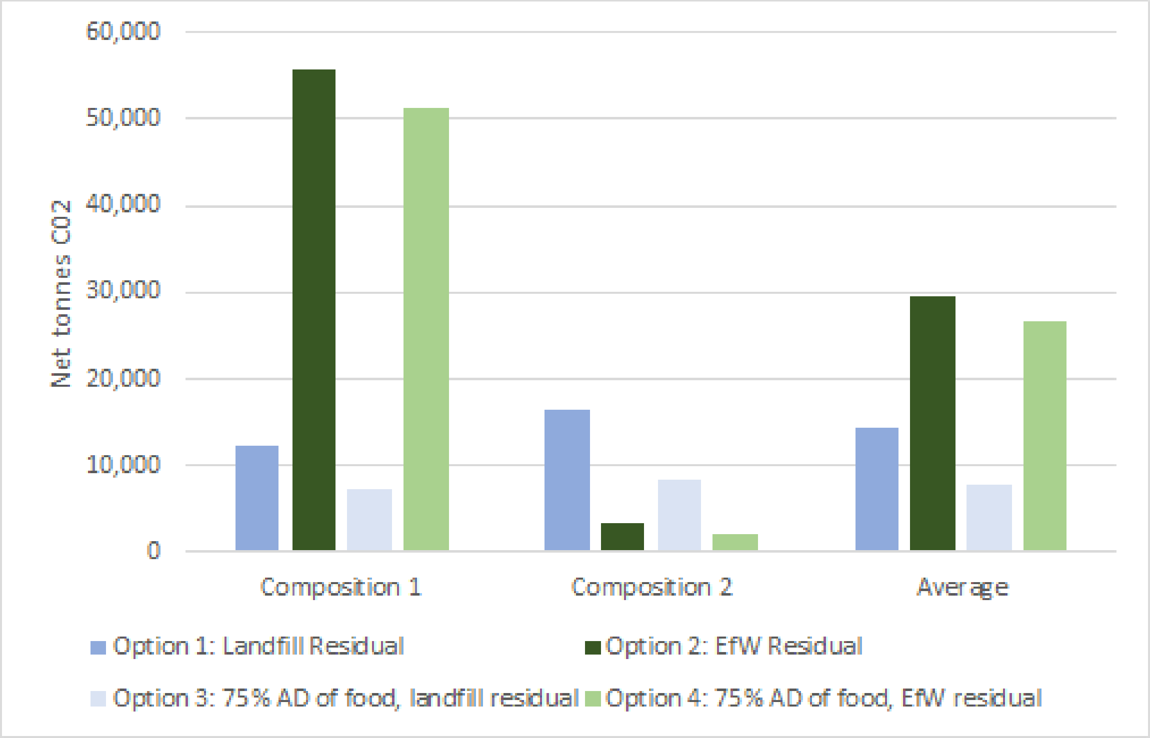
[129] https://www.transpower.co.nz/about-us/our-strategy

[130] The water pumped storage 'battery' scheme (www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/low-emissions-economy/nz-battery/), and the increase in other renewables, will further reduce demand for coal and gas as the decade progresses.

A feedstock that has a high fossil carbon content will generate higher net CO_2 emissions in a WtE process than a feedstock with low fossil carbon content (i.e. more biogenic carbon). Therefore, in each of the scenarios we modelled two compositions – one with a high fossil carbon content (Composition 1), and one with a high biogenic (natural materials) carbon content (Composition 2), together with an average of the two. Compositions 1 and 2 may be considered an extreme range of residual waste compositions considered for WtE, with the results for the Average composition essentially representing a typical composition for Aotearoa New Zealand. This is therefore considered the default. [131]

The key results of the analysis are presented in the figure below:

Figure 5-1: Overall Waste System Carbon Emissions (per 100kt of Residual Waste)



The results show that:

- It is always more beneficial to capture food waste for use in AD rather than it being sent to landfill or incineration.
- The substantially higher fossil carbon content of Composition 1 means that incineration of this type of waste stream results in significantly higher total carbon emissions than Composition 2, even when food waste is effectively captured.
- The higher biogenic carbon content of Composition 2 (in the form of garden waste, paper, and card) means that landfilling this waste stream, even after effective food waste capture, results in higher carbon emissions than sending this waste stream directly to WtE.

---

[131] It should be noted that the study has not attempted to model actual emissions from 'real' facilities, but has taken into account the New Zealand context in terms of two likely extremes of waste composition for EfW feedstock; and the emissions that would be avoided/offset if waste were to be utilised in an EfW plant.

Based on the modelling, the following general order of preference (from most to least preferable in terms of total carbon emissions) is likely to apply for typical compositions for mixed municipal solid waste (as shown by the average of the two extremes noted above):

1. Separated food waste for anaerobic digestion (AD), landfill (with gas capture) for the remainder.
2. Landfill (with gas capture) for all residual waste.
3. Separate food waste for AD, incineration with energy recovery for the remainder.
4. Incineration with energy recovery for all residual waste [132].

It should be noted, however, that the actual outcomes will be heavily dependent on the feedstock. If there are low levels of fossil carbon and high levels of biogenic carbon in the feedstock, then WtE incineration is likely to perform better, and be a good complement to AD for food waste. Current and proposed future policy settings, which focus on removing organic waste from disposal and directing to higher value uses, are, however, likely to operate against this outcome. If the feedstock includes significant quantities of waste timber, a method that removes the treated timber (particularly CCA-treated timber), and manages the resulting contaminants in emissions and ash, would be required before an EfW solution is appropriate.

In terms of Priority 1 above, it is worth noting that when food waste is removed from the residual waste (i.e. is sent to AD or composting), the greenhouse gas emissions from landfill reduce dramatically. By contrast, in terms of Priority 3, removing food waste from incineration removes some of the low carbon biogenic element from the residual, and hence makes the incinerator emissions more carbon intensive.

Finally, it is important to note that in carbon emission terms, prevention (reduction and reuse) is almost always preferable to all other waste management options, including recycling. In general, recycling is preferable to both landfilling and WtE incineration in most scenarios, although these wider comparisons and scenarios have not been specifically modelled in this study.

5.2 Recommendations

When considering the appropriate method for treatment of residual waste, care must be taken that the technology, or set of technologies, provide not only the best carbon performance outcome, but also contribute to circular economy targets set by the country that they are operating in. Based on these considerations, the report recommends that, for the Waikato region and Tauranga city, and indeed Aotearoa New Zealand more generally:

- Food waste should be separated for anaerobic digestion (AD), and/or composting with other organics, and this should be mandated nationwide.
- WtE 'incineration'[133] for mixed waste and fossil-based materials should be avoided unless there is strong evidence that:
    - fossil fuel use will be directly offset, with a clear carbon benefit; and
    - drives to increase circularity (as part of a circular economy) will not be impeded by the technology, in the short to medium term.

---

[132] We would note that we use the average electricity grid emissions as the marginal avoided emissions reference in modelling, which is actually understating the impact of incineration since it would largely be used as baseload, offsetting very low carbon generation from renewables.

[133] The term incineration is used here to mean burning of waste with energy recovery, as opposed to the definition in the Waste Minimisation Act 2008, which defines incineration as burning waste without energy recovery.

- In our view, if WtE for uses other than the above is to be effectively avoided, this will potentially require a strong level of sanction, and legislative and/or regulatory instruments should be considered.
- Advanced thermal treatments, such as pyrolysis and gasification, should be avoided as these technologies are unlikely to be viable in practice for mixed solid waste due to high technical and commercial risks.
- That burning mixed waste as refuse derived fuel (RDF) only be allowed in co-processing, e.g., in a cement kiln or a thermal power station, as a transitional solution where offsetting the burning of coal or oil.[134]
- That landfill (with optimised gas capture and energy generation, to limit methane emission impacts) be used as the only waste management approach for genuinely residual waste (i.e., that cannot be reused, recycled, anaerobically digested or composted) in the transition to a CE. It is important to note that waste to landfill can be gradually reduced in that transition, whereas waste to incineration can only realistically be reduce by closing whole facilities.
- That Māori are proactively engaged in WtE matters. Options for this include establishing a representative iwi body for waste issues, providing iwi with the resources for well-informed decision making, engaging through genuine relationships and partnerships, and empowering councils to provide resources to support iwi and Māori to engage.

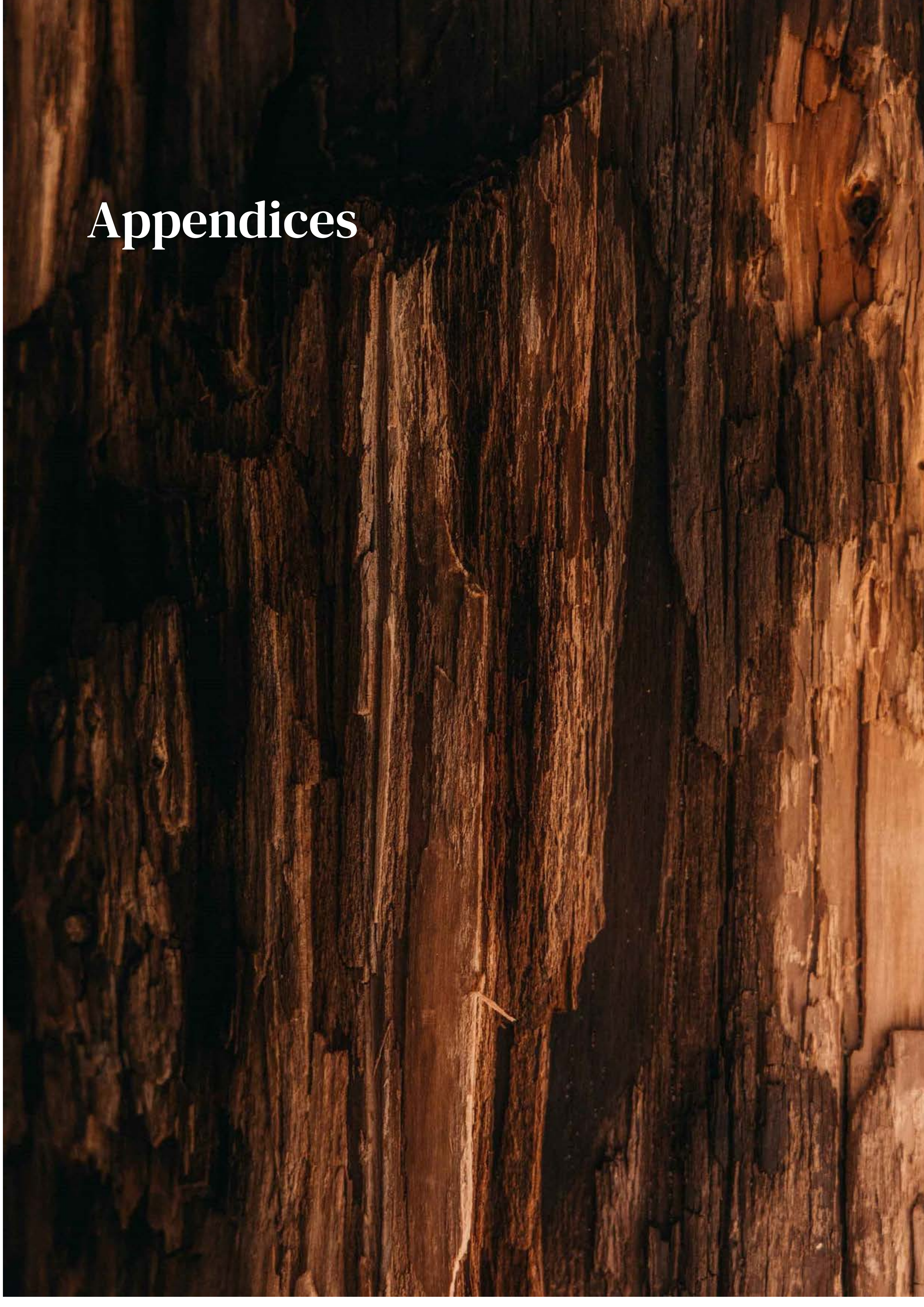
While wider issues around circular economy have not been specifically covered by this report, or the impacts modelled, we would also recommend that Aotearoa New Zealand should also do the following to help meet CE ambitions and Emission Reduction Plan goals:

- Phase out biodegradable waste from landfill as new CE infrastructure is developed, and support/incentivise AD (for food) and composting (for other organics), for example by utilising an increasingly high waste disposal levy, with a nationally mandated year on year increase.
- Focus on higher levels of paper/cardboard, wood and textiles reuse and recycling (i.e. largely biogenic materials), to remove further biodegradable waste from landfill in the meantime (before the biodegradable waste phase out makes its full impact).
- Focus on higher levels of separation of other reusable and recyclable materials from the residual waste stream - at material recovery facilities (MRFs), or mechanical biological treatment (MBT) facilities as landfill pre-treatment.
- Actively support further genuine waste prevention and circular economy approaches, including direct re-use, preparing for reuse, repair, refurbishment and remanufacture.

---

[134] Specific use of RDF in the Huntly or Golden Cement facilities was outside the scope of this report and these options were not investigated.

Appendices



A 1.0 Te Ao Maori View of WtE – Peer Review by Whetu Consultancy

WHETŪ
Consultancy Group
BRINGING TWO WORLDS TOGETHER

Review of Waste-to-Energy Project Report

Context

This study of technical implications of 'waste-to-energy' technologies within the Waikato and Tauranga regions is an important and timely topic, given the recent development around 'energy from waste' (EfW) technology. Although the study conducted by Eunomia provides many great general recommendations that can guide the implementation, regulation, or moratorium of EfW technologies within Aotearoa, there are some critical aspects that need attention. These wider aspects are in relation to Te Ao Māori, as well as statutory obligations to engage with Māori. This document explores and summarises key considerations for a 'Te Ao Māori' approach to EfW, that elucidates potential risks and uncertainties that are not recognised within the report.

Te Tiriti o Waitangi

Te Tiriti o Waitangi (The Treaty of Waitangi) is a treaty signed in 1840 between the British Crown and several Māori chiefs in New Zealand. Te Tiriti is the founding document of New Zealand, and it outlines the rights and obligations of both the British Crown and the Māori people. One of the key provisions of the Treaty of Waitangi is the recognition of Māori rights and interests in their traditional lands and resources. This includes the right to participate in local decision-making processes that affect these lands and resources.

Many strides have been made within the context of local government and resource management to uphold the principles of Te Tiriti. This includes the establishment of Māori wards and seats on local councils, the development of Māori relationship agreements with iwi, and the incorporation of Māori perspectives and values into local decision-making processes, strategies and frameworks.

Iwi Settlement Legislation

Many of these engagements are statutory requirements set out in legislation; ratified agreements that seek to reconcile the past grievances and breaches of Te Tiriti by the Crown. The various Acts refine engagement with 'Māori' to engagement with 'iwi'; these are Māori groups that are inextricably tied to shared human and non-human ancestors.[1] Iwi settlement acts are therefore locally, regionally and nationally applicable legal instruments that inform territorial authorities how to appropriately engage with iwi operating as representative Māori authorities within their respective areas. There are several Treaty of Waitangi settlements (as evidenced through Settlement Acts and Bills) and the subsequent mechanisms that are applicable within the Waikato Region and Tauranga City area. These include:

- Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010
- Ngāti Tūwharetoa, Raukawa, and Te Arawa River Iwi Waikato River Act 2010
- Ngā Wai o Maniapoto (Waipā River) Act 2012
- Ngāti Koroki Kahukura Claims Settlement Act 2014
- Ngāti Hauā Claims Settlement Act 2014
- Ngāti Tamaoho Claims Settlement Act 2018
- Ngāti Maniapoto Claims Settlement Act 2022

---

[1] Hoskins, T. K., & Jones, B. (2017). Non-human others and Kaupapa Maori research. *Critical Conversations in Kaupapa Maori.*

- Ngāti Rangi Claims Settlement Act 2019
- Waitaha Claims Settlement Act 2013
- Ngāi Te Rangi and Ngā Pōtiki Claims Settlement Bill
- Ngāti Pūkenga Claims Settlement Bill
- Tauranga Moana Iwi Collective Redress and Ngā Hapū o Ngāti Ranginui Claims Settlement Bill

Understanding the scope of meaningful engagement with iwi on issues relating to EfW requires considerations of these legislative frameworks. This includes understanding the aspirations of iwi as stated in their statutory settlement legislation (such as Te Ture Whai Mana)[2], matters that legally require engagement with iwi via local government mechanisms (such as Joint Management Agreements), or local government documents and policies that have been informed by iwi. Further, many iwi have developed their own Environmental Management Plans setting out their own aspirations for the management of resources within their rohe. These should all be reviewed and taken into account in the relevant spatial areas where resource consent applications are lodged and where Decision Makers are considering applications.

Engagement with iwi is not merely an aspirational exercise borne out of goodwill and the benevolence of territorial authorities. It is not a weakness to engage with local iwi that can be mitigated, avoided or minimised for the sake of efficiency and cost-effectiveness. It should be recognised first and foremost as the legal obligation of councils to integrate iwi into decision-making as part of legislated acts founded on the principles of Te Tiriti. Failure to do so is in breach of legislation set out above that formalises iwi partnership and participation in various decision-making processes. Further, in many situations, it broadens opportunities and understanding within projects, which benefits all parties involved.

A note on the RMA Reforms

As some regulatory authorities are becoming more adept and clearer in their understanding of the roles that iwi play in resource management processes, the existing legal and political landscape is set to rapidly change with the current RMA Reforms. The reforms seek to deliver significant change and further deepen obligations to engage with Māori throughout the consenting process. It is important to note that these reforms will bring significant changes across the resource management landscape.

The reforms are also an opportunity for advancing and enabling climate-focused regulatory frameworks to deliver more efficient processes with improved environmental outcomes. Depending on the outcomes and recommendations from this report, the findings should help inform and streamline resource consenting processes as these evolve through the RMA reforms. These policies and practices may not be clear until after the reforms process is completed.

Māori views on waste

Many Te Ao Māori concepts cross into the discourse around waste management: practices of stewardship, sustainable management of ecosystems, and various protocols that are governed by cultural relationships with ancestral geographies. As mentioned in the report, the Para Kore organisation and its champions are leading thinkers in the field of waste management that connect the waste to the wider concepts of the failure of the linear and globalised economy, the role of exploitative and extractive impacts of multinational corporations, and the emphasis on local economies and community solutions.

This is one of the few places where Māori concepts can be discussed with a salient understanding of upstream issues and necessary systemic changes required for action. It should be noted that Para Kore is a national Māori organisation as opposed to an iwi with authority and mandate to represent the views and opinions of its people. However, Para Kore have iwi constituents. This creates dichotomies and complexities when engaging on the topic of EfW.

---

[2] Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, https://www.legislation.govt.nz/act/public/2010/0024/latest/DLM1630107.html

Complexities when engaging

The complexities when engaging on waste proposals are considerable. This is notably captured in the recent EfW application for consent in Te Awamutu, and the complexities around Te Ao Māori representation in the waste discussion were evident. The EfW proposal was as follows:

- Global Contracting Solutions proposed a 15MW waste-to-energy facility to step away from "fossil-fuel energy sources" and with it create 420 new jobs.
- Global Contracting Solution is a subsidiary of Global Metal Solutions - the largest Māori owned and operated scrap metal recycler. Further, the owner has a genealogical connection to Ngāti Apakura, one of the mana whenua of the Te Awamutu area.
- Engagement with Ngāti Apakura took place and they provided their support for the project, outlined in an email attachment to the consent application.

In response, Zero Waste Network, Para Kore and Go Eco coordinated an effort to discuss concerns in opposition to the proposal. Para Kore's position statement on waste-to-energy technologies is clear:

> *"Incinerating waste has perpetual negative impacts on the environment and creates pollutants such as greenhouse gasses and toxic ash. Investing in long-term incineration contracts is harmful to our natural world, instead, we must ensure investment is redirected regionally to local people to build a Tiriti-led, zero waste, zero carbon future."*[3]

Ngāti Apakura has no available Environmental Management Plan, however, Ngāti Apakura has expressed shared interests in the Maniapoto & Waikato rohe.

Within the Maniapoto Environmental Plan, section 24.4.2.1 declares support for actions that:

> *"incentivise systems that promote waste minimisation or deal with waste as close to point of origin as possible" and "promote product stewardship initiatives where the costs of waste disposal are met by product manufacturers (imported materials are taxed to cover eventual disposal costs) and other waste generators at source."*[4]

The Environmental Management Plan of Waikato Tainui - Tai Timu Tai Pari section 26.2.9 states:

> *"Waikato-Tainui generally do not support any form of energy generation unless it is sustainable and renewable, or any form of energy generation that has adverse social, cultural, spiritual, or environmental effects that cannot be managed to meet the requirements of this plan. For clarity, Waikato-Tainui does not consider containment hydro dams suitable as a form of sustainable renewable energy generation, due to the adverse environmental, cultural, spiritual, and social effects of such dams."*[5]

This is a brief example of competing interests, varying levels of understanding, and the complexities of navigating Te Ao Māori and iwi considerations in the EfW space. This demonstrates that some iwi have specified their aspirations in the waste space, while others may not. Moreover, it doesn't address whether Māori and/or iwi have the resource, expertise and capacity to focus on waste, specifically EfW, above all other pressing issues. Organisations such as Para Kore, who have a clear understanding of the issues associated with waste-to-energy and who have the expertise to engage, are not supported or mandated to hold these conversations, as they are not an iwi and have no legislated mechanisms to engage in the consenting process.

To further complicate issues, there is currently no dedicated collective iwi body specifically focused on waste management, such as there are with freshwater, climate etc. This example presents the complexities of engaging with Māori. The current lack of understanding, clarity and definition for what constitutes waste to energy, further muddies the water for those taking part in resource management processes for these projects. It also

---

[3] Waste to Energy, Para Kore, 2022 https://www.parakore.maori.nz/waste-to-energy/

[4] Maniapoto Environmental Plan, section 24.4.2.1 https://www.maniapoto.iwi.nz/wp-content/uploads/2020/09/0525318-Maniapoto-Enviro-Manag-Plan_Cvr_Tabs.pdf

[5] Waikato-Tainui Environmental Managament Plan – Tai Tumu, Tai Pari, Tai Ao. 2013. Section 26.2.9 https://waikatotainui.com/wp-content/uploads/2022/08/Waikato-Tainui-Environmental-Plan-2013.pdf

proffers little guidance for territorial authorities through navigating the complexities of consultation on these projects. Implementation of EfW solutions and engagement with iwi and Māori must ensure that Māori interlocutors are equipped with the best understanding of the wider issues, such as those presented in the report.

Conclusion

This report provides a summary of the challenges encountered when engaging with iwi on waste-related matters and the aspects of energy-from-waste technologies. Although certain groups, such as Para Kore, possess an understanding to address these issues they are not engaged, nor supported to provide a Māori perspective within the consideration of these technologies. Further, mandated authorities and iwi entities that have formalised mechanisms to engage may not have the time to focus on energy from waste or the capacity to prioritise them over other concerns of well-being. Furthermore, the recent resource reforms have exacerbated the complexities and have not yet provided clear guidance for territorial authorities to navigate engagement with iwi in this context.

To support the analysis by Eunomia and provide Waikato Regional Council and Tauranga City Council, with the best tools to engage with EfW proposals that are being put forward by proponents of EfW technologies, further analysis is required. In addition, it is important to note that addressing the issues outlined in this report requires genuine relationships and partnerships, to support further analysis on the matter. This may entail Councils' providing resources to support iwi and Māori to engage, formalise mechanisms to engage, or jointly develop an approach to EfW technologies, that involves iwi and Māori interests.

Authored by:
Tamoko Ormsby and Amy Whetu
Whetū Consultancy Group

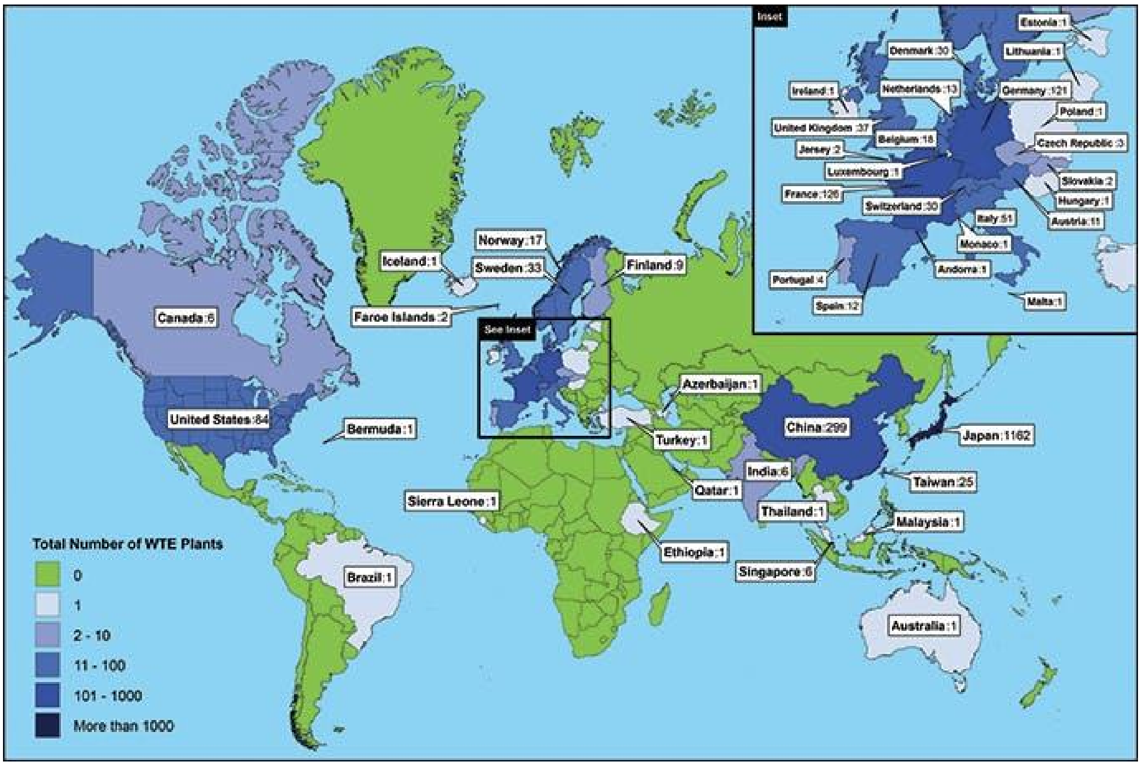
This brief has been prepared for Eunomia Research and Consulting NZ for the purpose of considering te ao Māori contexts for the Waste to Energy Project for Waikato Regional Council and Tauranga City Council. It is not intended for general use and application within other projects and contexts, without further discussion with Whetū Consultancy Group.

A 2.0 Use of WtE and Impact

A 2.1 International Use of WtE

Today, there are an estimated 2,600 WtE incineration plants active worldwide processing estimated 460 million tonnes annually.[135] Most of the plants are concentrated in a few countries, with Japan alone accounting for approximately 45% of the plants, while China has approximately 300 plants. The total number of incineration plants in Europe is thought to be over 500, with the amount of Municipal Solid Waste (MSW) incinerated in the EU doubling to 60 million tonnes annually between 1995 and 2019.[136] The tolerance of moving grate (MG) systems to heterogeneous waste streams (i.e. those of a variable nature in terms of an uneven mix of types; i.e. the opposite of homogenous) means this form of the technology represents the largest share of the global incinerator market[137], with MG incineration widespread in Europe, the US and beyond. The use of fluidised bed (FB) technology for MSW incineration remains much more limited than MG technology globally, with these systems requiring a significant level of pre-treatment of mixed waste.

Figure 5-2: Map of WtE Plant Concentrations Globally



Source: https://www.mswmanagement.com/collection/article/13036128/the-current-worldwide-wte-trend

---

[135] https://www.ecoprog.com/publications/energy-management/waste-to-energy.htm#:~:text=Today%2C%20more%20than%202%2C600%20WtE,capacity%20of%2044.4%20million%20tpy.

[136] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Municipal_waste_landfilled,_incinerated,_recycled_and_composted,_EU-27,_1995-2019.png

[137] Incinerator Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027

Figure 5-2, while a little out of date (2019), indicates the relative rate of adoption. Generally, regions of the world where economies are well-developed, populations are dense and land is limited (e.g., some European countries, and Japan) have greater adoption of WtE; in part due to high waste generation levels combined with space constraints regarding landfill.

A 2.2 The European Context

While WtE technologies have found worldwide application, we have given a particular focus to the European context; principally because European policy and practice is most closely aligned with The New Zealand Waste Strategy's stated ambition to move towards a low emissions CE. Consequently, how WtE is viewed in the European context is likely to be most instructive as to the stance that Aotearoa New Zealand should adopt in relation to WtE.

A 2.2.1 The changing face of electricity generation

WtE technologies of various kinds have been widely used in Europe since the 1960s, a trend that accelerated in the 1990s with the introduction of landfill diversion targets and landfill levies/taxes. These were, in particular, large incineration plants, designed to meet new and relatively strict emissions standards. At the time, European recycling and composting rates were low, with large quantities of plastic, food waste and other organics going to landfill, generating methane-rich landfill gas with very high global warming potential (84 times that of CO_2 over a 20 year timeframe[138]). This move away from landfill was further driven by the 1999 EU Landfill Directive and its requirement to gradually phase out the landfilling of biodegradable municipal [139]waste (BMW); to avoid methane emissions that were difficult to fully capture, even in a well-engineered landfill.

At the same time, much of the electricity generation in Europe was coal-fired; with only a relatively small proportion of low-carbon energy, mostly from nuclear power and hydro. It was in this context that the general order of preference for waste treatment, the waste hierarchy (first introduced in the EU Waste Framework Directive; WFD), was established. In the waste hierarchy recovery (of energy) is above landfilling, but below prevention, reuse and recycling. Although the directive does note that *"When applying the waste hierarchy [..] Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life cycle thinking on the overall impacts of the generation and management of such waste"*.

In the late 1990s and early 2000s, it generally made sense to combust residual waste rather than landfill it, since a) the waste contained reasonably high levels of energy, (although lower than pure fossil fuels due to water content etc.), b) some of it was biogenic, and c) the CO_2 emitted overall was lower than that emitted otherwise to generate electricity (i.e. where there was a high proportion of coal use). At the time, it was thought that recycling rates may be limited in practice to perhaps 40% to 50%, with a further 40% WtE, and a balance of 10% to 20% landfill. The United Kingdom only achieved the European Union average of a 23% dry recycling rate for municipal solid waste (MSW) in 2008, according to figures published by the European

---

[138] https://earthobservatory.nasa.gov/features/MethaneMatters

[139] In Europe, municipal solid waste is used to refer to household waste and waste from other sources that is similar in nature and/or composition

Commission[140]. As a consequence, many European economies, including Germany, the UK and Denmark, moved to large-scale incineration of waste as an alternative to landfill, and to complement recycling/composting.

The last 15 years has seen major changes in waste management (described in the next section) and at the same time, electricity generation has gradually been de-carbonised in many countries including the UK. This means that burning waste, and in particular burning waste plastic (essentially a fossil fuel made of oil), is actually offsetting a combination of renewable electricity and gas in the UK and hence is far more carbon intensive, relatively speaking, than it was two decades ago[141]. Furthermore, unlike power stations in the UK, waste incinerators are not part of the UK Emissions Trading Scheme and do not pay any sort of environmental impact levy (unlike landfill which is taxed).

Zero Waste Scotland's October 2020 report 'The climate change impact of burning municipal waste in Scotland'[142] found that: "Burning residual municipal waste in WtE plants in Scotland in 2018 had an average carbon intensity of 509 g CO_2/kWh. The average carbon intensity for electricity-only incinerators and gasifiers burning residual waste was 524 g CO_2/kWh. This is nearly twice as high as the average carbon intensity of the marginal electricity grid in the UK, which was 270 g CO_2/kWh in 2018. Converting these plants to combined heat and power systems would lower their carbon intensity but not to the level of the UK grid. As a result, in Scotland, WtE can no longer be considered a source of low carbon energy within a UK and Scottish context."

It is worth repeating that the waste hierarchy was only ever a guide, and where a clearly better environmental outcome could be shown, it was acceptable to depart from the hierarchy. In fact, in a partially decarbonised electricity generation scenario, like the UK, landfilling of fossil-based plastics, which are essentially inert, would lock-up carbon. In comparison, incineration of those plastics would release net carbon compared to gas-fired electricity production. This is not to say, of course, that reuse, and recycling/composting are not preferable to both incineration and landfill.

A 2.2.2 The Circular Economy

In recent years the concept of a circular economy (CE) has come to the fore, where products and materials are kept in use for far longer due to their durability and through reuse, repair, remanufacture, and, as a last resort, recycling of material. This thinking is expressed below (Figure 2) in the well-recognised 'butterfly' diagram from the Ellen MacArthur Foundation (EMF). The EU has recognised CE as a key means to reduce waste and reduce carbon emissions, with the (revised) Circular Economy Action Plan of 2020[143] one of the main building blocks of the European 'Green Deal'. The Green Deal aims to reduce pressure on natural resources and to create sustainable growth and jobs, whilst aiming to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. Other global initiatives include the Global Alliance for Circular Economy and Resource Efficiency, and the G7 Alliance on Resource Recovery.

An important question is the extent to which WtE can play a role in a transition to a CE. In this context, it is worth noting that most leading organisations on the subject, including the Ellen MacArthur Foundation, do not regard incineration / energy recovery (apart from AD) as CE; but rather as 'leakage' from the system, alongside

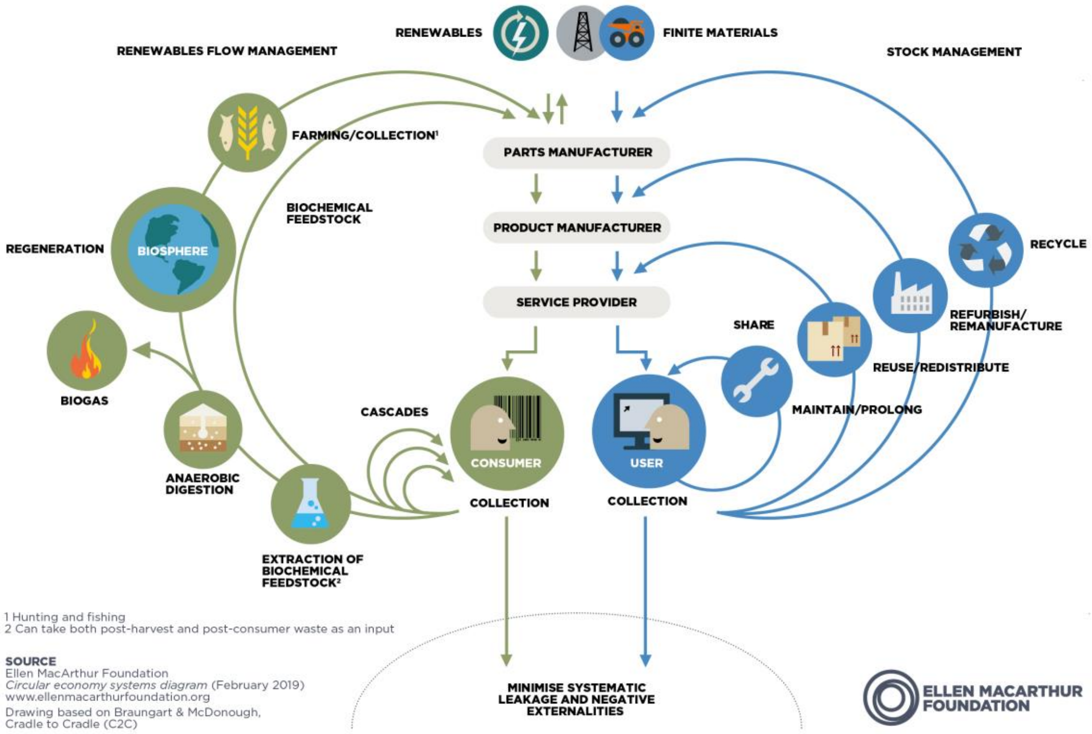
---

[140] Eurostat data
[141] Greenhouse Gas and Air Quality Impacts of Incineration and Landfill, Eunomia for Client Earth, Dec 2020
[142] The climate change impacts of burning municipal waste in Scotland. Zero Waste Scotland, June 2021
[143] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

landfill. Similarly, the EU has excluded WtE incineration from a list of economic activities (the EU Taxonomy[144]) considered suitable for 'sustainable finance'; i.e. those that can make a substantial contribution to climate change mitigation and which do no significant harm to other environmental objectives such as the transition to a circular economy.

AD is treated separately as part of the biological cycle, since this type of energy recovery is a by-product of the process of returning organic material to the soil[145], via digestate, and is able to generate biogas efficiently (without loss) and for direct use in replacing fossil gas for heating – a far bigger issue for decarbonisation than electricity generation. AD is, consequently, considered suitable for sustainable finance under the EU taxonomy.

Figure 5-3: Circular Economy 'Butterfly' Diagram (Ellen MacArthur Foundation)



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Finally, it is worth explaining the link to net zero carbon strategies. The Ellen MacArthur Foundation paper, 'Completing the Picture: How the Circular Economy Tackles Climate Change'[146], argues that, while moving to renewable energy sources can address 55% of global GHG emissions, to achieve UN climate goals it is imperative to tackle the remaining 45% (from food and other products) and that the bulk of this can be done through CE initiatives in five key material types - cement, plastics, steel, aluminium, and food. This study indicates that designing out waste, keeping materials in use, and regenerating farmland can reduce GHG emissions globally by 9.3 billion tonnes per annum: equivalent to eliminating current emissions from all forms of transport globally. According to a recent Biffa study, and in line with previous Eunomia work, the UK has an

---

[144] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[145] https://ellenmacarthurfoundation.org/articles/the-biological-cycle-of-the-butterfly-diagram
[146] https://ellenmacarthurfoundation.org/completing-the-picture

opportunity to unlock circa £18bn in investment in the circular economy that will create more than 16,000 jobs, while contributing to a reduction of circa 7.1 million tonnes of CO_2e[147].

A 2.3 The impact of WtE on moves towards a Circular Economy

When considering the appropriate method for treatment of residual waste, care must be taken that the technology, or set of technologies, provide not only the best carbon performance outcome, but also contribute to circular economy targets set by the country that they are operating in. Waste prevention, and effective recycling, always bring about the highest energy savings and reductions of GHG emissions, above recovery, or disposal technologies.

In the EU, waste management has moved on dramatically in the last 15 to 20 years. Driven by European Directives, recycling rates in the EU have risen to 64% for packaging and MSW 49% (EU27) [148], with Germany collecting close to 70% of its MSW overall for recycling, and the UK (now outside the EU), recycling 46.0% of its MSW overall in 2019, and 64% of the packaging waste[149]. Increasingly organic waste is collected at the kerbside (this being mandated in the EU from the end of 2023 under the 2018 WFD), and the MSW that remains tends to be increasingly dominated by non-recyclable plastic packaging, and hence is more carbon intensive to burn than before.

But has the move to WtE incineration in any way inhibited growth in recycling and composting/AD? The picture is somewhat complex. In the UK, there are now around 56 WtE incineration plants, dealing with over 17 million tonnes of waste per year[150] (an average capacity of over 303,000 tonnes per site). In the UK, as landfill sites have begun to close and be phased out, incineration has picked up much of that demand; with incineration rates rising nearly four times, from 12% to 44%, over the past decade. During this same period recycling rates have only risen marginally, from 37% to 43%. Such a high level of incineration is believed by some to be constraining England's ability to meet recycling targets[151] since the incinerators need 'feeding' on a contractual basis.

Germany, however, has continued to grow its recycling and composting rates, whilst also being a very large-scale user of WtE incineration for its residual waste (see case study below). Across the EU, as a whole, recycling and composting rates had been growing as quickly as WtE incineration in the early 2000's, however the last few years has seen recycling rates almost levelling off, while composting/AD and WtE have continued to grow to replace landfill (Figure 5-4)[152].

---

[147] From Waste Hierarchy to Carbon Hierarchy: Biffa's Blueprint for Waste Net Zero, Biffa 2022

[148] https://www.eea.europa.eu/ims/waste-recycling-in-europe

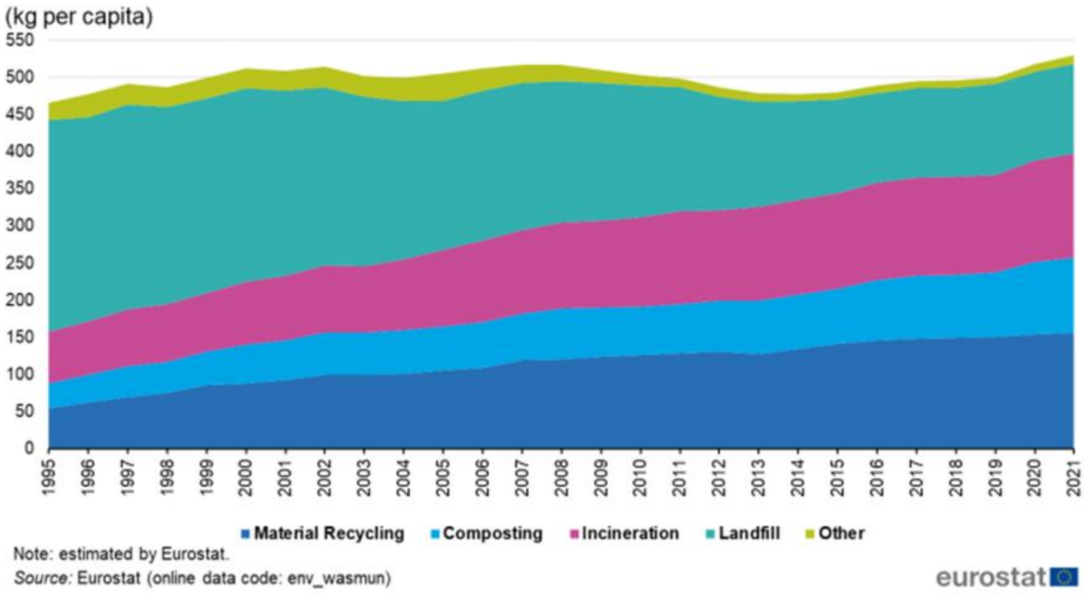
[149] https://www.gov.uk/government/statistics/uk-waste-data/uk-statistics-on-waste

[150] UK Energy from Waste Statistics – 2021, Tolvik Consulting, May 2022

[151] https://ukwin.org.uk/facts/

[152] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics#Municipal_waste_treatment

Figure 5-4: Municipal waste treatment, EU, 1995-2021



Note: estimated by Eurostat.
Source: Eurostat (online data code: env_wasmun)

New ambitious EU targets, such as halving the quantity of municipal waste that is not recycled or prepared for reuse by 2030[153] , and achieving carbon neutrality by 2050[154], have meant that the main European governing institutions - and an increasing number of EU Member States - have been withdrawing support for incineration on the basis of it being too carbon-intensive and misaligned with a transition to a circular economy. Instead, new prevention, preparation for reuse and recycling measures, alongside mandatory recycled content targets, are the key drivers in the EU's transition to a circular economy. Consequently, several EU countries (see Denmark example below) are currently experiencing an overcapacity of residual WtE infrastructure. Meeting the contractual obligations to reach required throughputs at these facilities, for the duration of their operational lifetime, can seriously discourage efforts to implement effective waste prevention, re-use, and recycling measures.

The revised 2018 EU WFD notes that Member States should make use of economic instruments and other measures to provide incentives for the application of the waste hierarchy, such as landfill and incineration charges, and extended producer responsibility schemes. The European Commission, in the Circular Economy Strategy, outlined that WtE through incineration (electricity, CHP or ATT) should not interfere with circular economy objectives:

> "the role of waste incineration – currently, the predominant waste-to-energy option - needs to be redefined to ensure that increases in recycling and reuse are not hampered and that overcapacities for residual waste treatment are averted."

---

[153] 2020 EU Circular Economy Action Plan, European Commission. Accessed March 2023 https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

[154] The European Green Deal, European Commission, 2019. Accessed March 2023. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

The drive to move material from residual waste up the waste hierarchy to more circular practices is reflected in calls (such as a recent report produced for Reloop[155]) to introduce mandatory pre-sort in the forthcoming update to the EU Waste Framework directive.

Mindful of the EU's climate and energy targets for 2030, the European Commission has established an "EU taxonomy for sustainable activities"[156]. This intends to inform companies, investors and policymakers which economic activities can be considered environmentally sustainable. Any technology which undermines climate change mitigation objectives or harms other specific environmental objectives is judged to be excluded from the Taxonomy. Such technologies can expect higher interest charges and reduced access to investors, in addition to being judged not sustainable.

Treatment of separately collected biowaste through anaerobic digestion is judged within the EU Taxonomy as a sustainable activity, worthy of investment, on the basis that it substantially contributes to climate change mitigation. Incineration of non-hazardous waste and the use of refuse derived fuels for cement production are, however, both specifically excluded.

The EU Taxonomy's Technical Expert Group deliberations on incineration provide balanced views which say on the one hand that it *"has a role to play even in an increasingly circular economy, as not all residual waste can be reused or recycled"*, but ultimately reject its inclusion within the taxonomy. The reasons given relate to the large portion of waste currently incinerated that could be recycled, a reliance on incineration within some Member States, and that it can result in lock-in effects, discouraging recycling which would deliver higher climate mitigation benefits.[157] Commentary on this from Zero Waste Europe provides a warning to countries in Aotearoa's situation that *"transition to a low carbon economy will involve the phase-out of […] waste-to-energy incineration"*.[158]

The Taxonomy conclusion to exclude the use of RDF for cement manufacturing is based on the reasoning that *"Co-incineration of waste has significant impacts on health and the environment due to the polluting nature of the associated emissions, and higher emissions ceiling for cement plants in comparison with dedicated waste incineration plants[159]. Furthermore, promoting waste as an eligible fuel source may undermine waste minimisation efforts in other sectors."*

Consequently, some European countries are moving away from incineration (see Denmark case study below), as well as landfill (which has to reduce to 10% of MSW by 2035 under the revised Landfill Directive). WtE 'Lock-in' should certainly be avoided for technologies that do not see a good carbon performance in the long run, or those that may hinder good circular economy practices. Denmark, Wales (part of the UK), and Germany offer interesting case studies which are described further below, alongside Australia.

---

[155] The case for Sorting Recyclables Prior to Landfill and Incineration, Reloop, 2022. Accessed March 2023. https://www.reloopplatform.org/wp-content/uploads/2022/06/D-HOGG-_Reloop_FINAL_June2022-1.pdf

[156] EU Taxonomy for Sustainable Activities. Accessed March 2023. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en#documents

[157] EU Technical Expert Group on Sustainable Finance: Technical annex to the TEG final report on the EU taxonomy, European Commission, 2020. Accessed March 2023. https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf

[158] Waste-to-Energy is not Sustainable Business, the EU says, Zero Waste Europe, 2019. Accessed March 2023. https://zerowasteeurope.eu/wp-content/uploads/2019/09/zero_waste_europe_policy_briefing_sustainable_finance_en.pdf

[159] subject to tight emission controls under the Industrial Emissions Directive.

A 2.3.1 Denmark

Denmark has a long tradition in WtE incineration and according to Eurostat's data[160], the country has the highest municipal waste generation rate per capita (781kg) in the European Union, burning over 50% of its waste. However, Denmark has become 'locked-in' to WtE technologies that are relied upon to reduce the national dependency on landfills[161]. The major issue encountered is that the country does not generate enough waste to power its 23 WtE incinerators, which are capable of burning 3.8 million tons of waste a year. As a result, Denmark imported nearly 1 million tonnes of waste (as RDF) in 2018, mainly from the U.K. and Germany[162].

A reliance on WtE does not align with Denmark's National Plan for Prevention and Management of Waste 2020-2032[163], that outlines the government's vision to achieve a climate-neutral waste sector by 2030. This includes targets to reduce its incineration capacity by 30% over the next decade and removal of 80% of plastic waste from incineration plants by 2030 compared to 2020. To cut overcapacity, seven incinerators nationally will need to close. However, because many of the facilities were financed by loan guarantees and are owned by local municipalities, central government are having to offer financial incentives to incinerators to close.

A 2.3.2 Wales

Wales has a population of just 3.1m in 2021 in a total area of 20,779 km², c.f. to New Zealand with 5.1m people in an area of 268,021 km².

Wales has long been a stand-out performer in the UK when it comes to recycling rates. The Welsh Government's £1 billion investment since devolution (semi-autonomous with its own parliament) in household recycling has helped see its rates rise from just 4.8% in 1998-1999, to over 65% in 2020-21. Wales is ranked third in the world behind Germany and Taiwan on the global recycling leaderboard[164]. The Welsh Government unveiled its Beyond Recycling strategy[165] in 2021 which sets out a number of objectives aimed at making the circular economy a reality. The strategy sets out a target of a 70% recycling rate by 2025, alongside the longer-term goal of making Wales a zero-waste nation (i.e., 100% recycling, including composting and AD) by 2050; embedding circular economy business models into resources and material utilisation.

The country only has two existing EfW incinerators, and in the wake of this strategy, the government announced details of a moratorium[166] on new WtE plants, indicating that it will cover those facilities with capacities of 10MW or greater and come into effect immediately. The statement added that small scale WtE plants of less than 10MW will also only be allowable if the applicant can demonstrate the need for such a

---

[160] 480 kg of Municipal Waste Generated per Person in the EU, Eurostat, 2018. Accessed March 2023. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20180123-1

[161] Denmark's Devilish Waste Dilema, Politico, 2020. Accessed March 2023. https://www.politico.eu/article/denmark-devilish-waste-trash-energy-incineration-recycling-dilemma/

[162] Waste Statistics, Ministry for Environment Denmark, 2018. Accessed March 2023. https://www2.mst.dk/Udgiv/publikationer/2020/05/978-87-7038-183-3.pdf

[163] Action Plan for Circular Economy, Ministry for Environment Denmark, 2021. Accessed March 2023 https://en.mim.dk/media/224197/alle-faktaark-engelsk-nyeste.pdf

[164] Recycling – Who Really Leads the World? Eunomia, March 2017

[165] Beyond Recycling, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/beyond-recycling

[166] Wales Takes Action on Circular Economy with Funding, Upcoming Reforms on Plastic and a Moratorium on Large-Scale Waste Energy, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/wales-takes-action-circular-economy-funding-upcoming-reforms-plastic-and-moratorium-large-scale

facility for the non-recyclable wastes produced in the region. Small plants would also need to supply heat and be carbon-capture and storage enabled where possible.

A 2.3.3 Germany

Germany is an unusual case, with a high recycling rate (67% for MSW) and WtE incineration now dominating residual waste disposal over landfill (the recovery rate, including recycling, is ~97%). In the face of it, this suggests that WtE and high recycling rates are not incompatible. The high recycling rate has been driven by a number of factors:

- Landfill gate fees are amongst the highest in Europe despite having no landfill tax.
- An incredibly effective and comprehensive deposit return scheme (DRS), with a return rate of around 98%, and covering almost all beverage containers including glass and milk drinks.
- Very strong and long-standing government policies and very high recycling and reuse targets, ahead of European targets under the Waste Framework Directive (WFD) (MSW 55% by 2025, 60% by 2030, and 65% by 2035), for municipal recycling; e.g. the Circular Economy Act of 2012, set a 65% recycling rate, surpassed in 2019 and the 2019 Packaging Act, which contains new, more ambitious recycling rates and targets – 90% by 2022 for glass, metals and paper, 80% for cartons, 70% for composites, and 63% plastics. There is also a ban on disposal without pre-treatment.
- Ingrained public awareness and compliance regarding recycling, with clear and standardised recycling systems across the country.
- Germany has been doing all this for a very long time, with recycling a part of German culture for several decades, and gradual refinement - Recycling of municipal waste was already 56% in 2002[167].

It is also important to remember the energy context for Germany. WtE incineration covers just a few % of electricity generation in Germany, and they still use mainly coal, oil and gas for electricity grid generation, so burning waste to generate energy offsets higher carbon emissions, far more so than the UK for example, which is now only burning about 3% coal in its electricity generation. Germany also has good opportunities and incentives (since 2008) for district heating from WtE, which makes the incinerators more efficient overall (50% cf ~30% UK)[168].

It's worth noting that Germany has been building WtE incinerators since the 1960s for waste and the last one was built in 2008, although more recent RDF power plants have been built since. It isn't clear that more incinerators as such will be built – the targets and economics may well work against their replacement.

So, while Germany shows that it isn't impossible to have high levels of WtE incineration as well as high recycling rates, this has only been possible because of a combination of stringent policy measures and targets, including the use of DRS, and an energy context that makes the burning of waste make sense in carbon terms.

A 2.3.4 Australia

---

[167] https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-recycling-municipal-waste#assessing-the-development

[168] https://www.umweltbundesamt.de/en/topics/waste-resources/waste-disposal/thermal-treatment#thermal-treatment-of-municipal-waste-

To date there has been no WtE deployment in Australia on a commercial scale. While certain plans and policies seek increased recycling, circular economy ambitions remain low, and commitments to large scale waste incineration are starting to be made.

The National Waste Policy Action Plan has set several targets (including achieving an 80% average recovery rate from all waste streams by 2030 and a 50% reduction in organic waste to landfill by 2030), there is no specific national WtE policy guidance published, with individual States and Territories in the process of developing their own policy positions. At a federal level, the impetus for the development of the energy from waste sector is being driven by the energy sector; this includes the Clean Energy Finance Corporation (CEFC) supported by the Australian Renewable Energy Agency (ARENA). In 2015 CEFC published a market report that identified up to AUS$3.3 (NZ$3.5) billions of potential investment in urban WtE. It also noted that generating electricity and heat from waste resources could be cost competitive with other new-build energy generation in terms of capital expenditure.

Some federal government documents do however make recommendations on national policy, with approaches generally limiting the thermal recovery of energy to residual waste streams which currently have no viable alternative to landfilling. Meanwhile, certain national plastic and other waste management policies appear to have been designed to provide business and economic support and incentives, particularly for plastic reprocessing, RDF and WtE incineration. As a result, there has been significant recent investment in WtE facilities.[169] These include:

- CEFC provided AUS$90 million (NZ$95.6 million) as part of a AUS$400 (NZ$424.7) million debt syndicate for the 400,000 tpa Kwinana WtE plant located in Western Australia. ARENA also contributed a further AUS$23 (NZ$24.4) million in grant funding to the project.
- CEFC has also committed AUS$57.5 (NZ$61.1) million in funding (by way of subordinated debt) and ARENA AUS$18 (NZ$19.1) million (in recoupable grant funding) towards the construction of the 300,000 tpa East Rockingham WtE project, also located in Western Australia.

Overall, around 12.5 million tpa of municipal waste is created in Australia, of which 7.5 million tpa is managed as residual waste (data within the latest national waste report puts municipal waste recycling at 41%)[170]. Data from Zero Waste Australia indicates that, including facilities in planning, the country could be heading towards 4mpta of incineration capacity.[171] The voluntary sector is seeking to counter the industry claim that incineration is a green renewable form of energy generation.

---

[169] Energy From Waste – A Load of Rubbish or a Viable Solution to Landfill, Gilber and Tobin, 2021. Accessed March 2021. https://www.gtlaw.com.au/knowledge/energy-waste-load-rubbish-or-viable-solution-landfill

[170] National Waste Report, Blue Environment, 2020. Accessed March 2023. https://www.dcceew.gov.au/sites/default/files/env/pages/5a160ae2-d3a9-480e-9344-4eac42ef9001/files/national-waste-report-2020.pdf

[171] Map of Incineration Facilities in Australia, Zero Waste Australia. Accessed March 2023. https://zerowasteaustralia.org/incineration/

A 3.0 Carbon Accounting Fundamental Principles

A 3.1 Carbon Emissions Accounting

When considering the carbon impacts of a waste treatment system, there are several ways in which carbon emissions can be presented, depending on the audience or the decisions that have to be made as a result of the calculations. All emissions directly being emitted within a country's border, otherwise known as territorial emissions, are reported to the United Nations Framework Convention on Climate Change (UNFCCC) as a measure of their direct global carbon footprint. While useful in helping a country identify decarbonisation priorities in some areas, such as transport or energy generation emissions, it does not paint a full picture of the carbon impact of waste management structures.

In this report, the carbon emissions system boundary considers the direct emissions from the process, or emissions caused by the process, as well as any reduction in emissions which occur elsewhere (including internationally) as a consequence of the process ('emissions offsets' - as detailed in Section A 3.2 immediately below). This way the total, or "net", emissions impact of a technology is appraised. The emissions accounting does not, however, include the emissions associated with the primary production of the materials which are used up in the process (e.g., the waste which is combusted, landfilled etc.).

A 3.2 Emissions Profile of Waste Treatment Infrastructure in This Study

When considering the total impacts of waste treatment infrastructure, the net emissions should be taken into account when considering the differences between the technologies. The categorisation of emissions for waste treatment infrastructure is given below.

Direct emissions – Emissions resulting during any stage of the treatment process, including stack emissions from combustion of waste and/or fugitive emissions of methane from landfill and AD facilities. As highlighted in Section A 3.3, a carbon credit should be applied to landfill emissions if short cycle biogenic emissions from other forms of treatment are discounted. Research shows that roughly 50% of all organic carbon will be semi-permanently stored within landfill; the remaining 50% of organic carbon being emitted, in line with the assumptions used in the IPCC Landfill Tier 1 Model, which is now embedded into the Aotearoa New Zealand Ministry for Environment's Greenhouse Gas Model.

Energy use – emissions associated with any energy used during the treatment process, such as maintaining correct operating conditions within a cement kiln.

Energy generation offset emissions (also referred to as energy credits) – Carbon benefits that are equal to the amount of energy produced by the WtE facility multiplied by the marginal energy source emissions factor (see Section 4.1.1.1 and Appendix A 4.2).

Recycling emissions offsets (also referred to as recycling credits) – Both pre-sorting and thermal treatment technologies separate, process and send certain amounts of material for recycling. This includes a range of possible material separated for recycling during pretreatment processes (e.g., metals and plastics), metals separated from ash following thermal treatment, and compost and soil improvers following organic treatment. The recycling of the material displaces emissions associated with primary production of the material, or of fertilisers in the case of digested/composted organic waste. Theoretically, the emission factors for recycling will be specific to the recycling process and will include consideration of the emissions associated with the primary production (which will depend on the country and efficiency of the process) and the emissions associated with the recycling process (which will depend largely on the countries average grid emissions factor). This study uses a simplified approach using generic UK sourced assumptions for avoided emissions related to recycling of different materials, as listed in Appendix A 4.5.

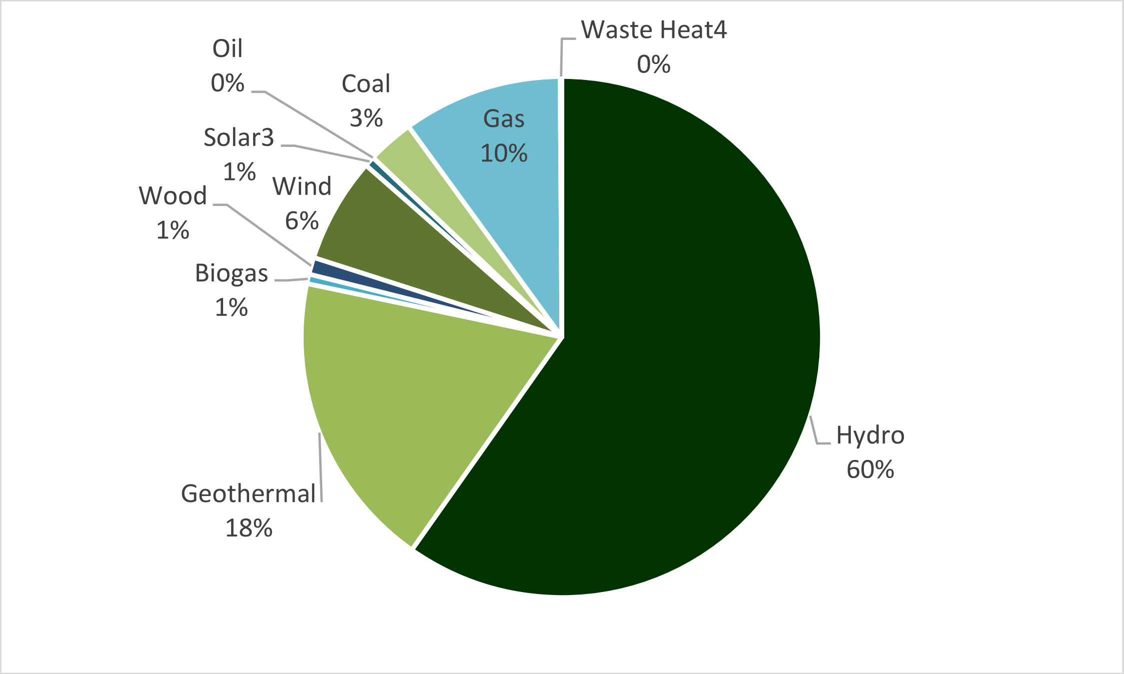
Marginal energy sources - When measuring the impacts of a waste management technology, consideration should be made for the energy source emissions that the technology is displacing, also known as the marginal source of electricity supply. For example, an incineration facility generates electricity which is fed to the grid, adding to the total grid supply. This increase in electricity supply from the WtE facility will displace the marginal energy supplier elsewhere in the system. The marginal source of electricity is the source of electricity that would be brought offline due to this small increase in energy supply from the incinerator. Therefore, this marginal source of energy generation's carbon intensity is what WtE infrastructure must be compared against. This method is used to appraise all types of WtE infrastructure in this study.

In the UK, the approach to forecasting the marginal emissions factor is that the marginal source of electricity should trend towards the average grid mix over time, as the transition away from fossil fuel energy generation progresses.[172] This approach is also adopted in estimating waste infrastructure's net impact in Aotearoa New Zealand. As discussed in Section 2.1, Aotearoa New Zealand has an already largely (>80%) decarbonised electricity grid, with ambitions to have electricity generation supplied by 100% renewables by 2030, although this ambition may not be fully realised.[173] Unlike the UK, Aotearoa New Zealand does not forecast the marginal emissions factor, so it is difficult to say for certain exactly what this marginal emissions factor is likely to be in the future.

[172] Treasury Green Book, Department for Business Energy and Industrial Strategy Tables 1-19. Accessed March 2023. https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[173] Transgrid however estimate that the grid could feasibly be 95% renewable by 2035 and 100% by 2050.

Figure 5-5: Assumed Electricity Grid Mix (2022)



Source: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

Considering Aotearoa New Zealand's ambition to have a fully decarbonised electricity supply by 2030 and the already low average grid emissions factor (130 gCO_2/kWh), it is likely that the marginal source of energy being displaced by WtE is already equivalent to the average grid emissions factor. In fact in reality, apart from in dry winters when demand is high and hydro supply diminished, WtE will almost always displace renewables, which provide the baseload. As noted earlier, fast-reacting gas turbines are currently used for genuine 'peaking' supply, with coal only for more predictable 'slow peaking' supply, Use of gas and coal for baseload is a reasonably rare occurrence in dry winters, and the occurrence will decrease into the future as more energy storage capability is introduced into Aotearoa New Zealand, e.g. through the development of the water pump storage 'battery', and distributed energy generation (photovolatics and wind) combined with chemical battery energy storage systems (BESS), the use of which is steadily increasing. Use of the grid mix noted above, is therefore considered an optimistic one for WtE incineration, since the net carbon impact of burning waste will be reduced compared to what might be considered a more realistic scenario, i.e. displacement of renewable generation only.

Where heat as well as power is generated through WtE, as if often the case in Europe, it has been assumed that natural gas is the marginal heat source, as natural gas forms the highest proportion of energy consumption in the country (38%).[174] However, local circumstances dictate the exact marginal fuel; this is particularly the case in Aotearoa New Zealand where heat is more likely to be used for industrial purposes. Where the fuel displaces a heat source less carbon intensive than natural gas, the carbon benefit will be lower, and where it displaces a more carbon intensive source such as coal, the benefits are greater.

---

[174] Decarbonising Process Heat, Ministry of Business, Innovation and Employment New Zealand. Accessed March 2023 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/low-emissions-economy/

As discussed in Section 3.6, in circumstances where RDF is competing with other fuels in a mixture, such as co-processing of waste in cement kilns, the marginal source of energy is the fuel, or fuel mixture, that is being displaced by the RDF (e.g. often coal in cement kilns).

A 3.3 Fossil and Biogenic Sources of Carbon

A fossil source of carbon is part of a much longer carbon cycle; one which has taken millennia for the carbon to become the state that it is (oil or gas) and has therefore not been present in the atmosphere for that amount of time. By burning fossil sourced carbon, additional carbon is released into the atmosphere in addition to the naturally occurring carbon cycle. As carbon dioxide is a GHG, increased levels then absorb more solar energy and cause the climate changes we see today.

Biogenic carbon emissions are those that originate from organic material like food and garden waste. It is often considered that biogenic carbon emissions do not need to be incorporated into total emissions, because they are 'short cycle', i.e. "only relatively recently absorbed by growing matter". Note that methane emissions from organic material are included because they are considered to be anthropogenic in nature, whereas biogenic CO_2 emissions are in effect viewed as similar to or part of the natural carbon cycle as discussed subsequently. [175]

This perspective follows the approach taken in developing the national inventories for climate change emissions, which countries submit on an annual basis to the UNFCCC. Biogenic CO_2 emissions occurring from, for example, the combustion of wood and other organic items, as well as that arising from the organic decay in ecosystems, are excluded from these annual inventories. The carbon incorporated within these items is assumed to have been sequestered from the atmosphere into the plant within the previous years' growth. Inclusion of both impacts is therefore considered to result in a double-counting of impacts. A similar approach has been taken in life-cycle assessments, which consider the global warming potential of systems over a 100-year period.

However, application of the above approach is problematic when accounting for landfill impacts, as a significant proportion of the biogenic carbon is not released as biogenic CO_2 (or as methane) but instead remains sequestered in the landfill; in this way, landfills act as imperfect 'carbon capture and storage' for the non-reactive biogenic fraction of the waste. In contrast, all of the biogenic CO_2 emissions are released from incineration at the point of combustion. As such, the two systems are not being compared on a like-for-like basis where this approach is applied to considering emissions from residual waste treatment systems.

Therefore, this omission of short cycle biogenic carbon emissions is acceptable as long as a carbon credit is applied for the biogenic carbon which is stored in a landfill. If no adjustment is made, the exclusion of the biogenic CO_2 emissions will overestimate landfill impacts relative to other forms of treatment in which all the

---

[175] DEFRA (2014) Energy from Waste: A Guide to the Debate, Revised Edition, February 2014. Accessed March 2023. https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate

biogenic carbon is released as CO_2 into the atmosphere. This carbon sequestration credit is included in this analysis for landfill infrastructure.[176] [177]

A 3.4 Considerations Made in Waste Carbon Modelling

As discussed in previous sections, Aotearoa New Zealand's electricity grid already has a substantial contribution from renewable sources (over 80%) and over time, as the marginal emissions factor decreases through grid decarbonisation of the remaining coal and gas use (See Section 2.0), the carbon benefit from offsetting energy generation will decrease. Therefore, results presented here are relevant to today's system characteristics; net emissions will increase, or become less beneficial, over time for all technologies.

A 3.4.1 Incineration, Gasification and Pyrolysis

The main impacts on the performance of these types of treatment infrastructure are given below:

- **Composition of waste** – Proportion of fossil and biogenic carbon within the waste stream. Where food waste collections are introduced, the proportion of biogenic carbon will decrease. Separate collections of food and garden will increase the proportion of fossil carbon in the material stream and make WtE look worse *on a per tonne basis*.
- **Marginal electricity emissions factor** – Carbon performance of WtE infrastructure depends on the electricity grid marginal emissions factor. This study uses a marginal grid emissions factor of 130 gCO_2/kWh, as discussed in Section 4.1.1.1.
- **Efficiency of facility –** Facilities vary in terms of how efficient they are at converting waste into energy. Mass burn incinerators, for example, are typically only around 20% to 30% efficient in converting waste to electrical energy (although higher where heat is also utilised in combined heat and power plants – see earlier text - although these are less common), whereas a combined cycle gas turbine plant is around 50% to 70% efficient[178]. As highlighted previously, larger facilities tend to have higher energy generation efficiencies (see Section 3.1). A higher performing facility which generates more electricity on a per tonne of waste basis will have a better carbon performance.
- **Heat** – Finding a heat off-taker depends on the surrounding industrial infrastructure or whether there is established heat networks. Where a heat off-taker is found, a carbon credit will be applied for the displacement of the marginal heat generation and this will depend on the carbon intensity of that fuel. In practice, actual heat offtake which might be beneficially utilised can be much lower than the maximum efficiency of heat export reported by the WtE facility.

A 3.4.2 Anaerobic Digestion

When considering the carbon impacts of AD, the following considerations should be taken into account:

- **Use of biogas** – The carbon impact of the energy source that the biogas displaces impacts the overall carbon performance of AD. If the biogas was combusted on site and the electricity generated was fed

---

[176] Christensen, T., Gentil, E., Boldrin, A., Larsen, A., Weidema, B. and Hauschild, M. (2009) C balance, Carbon Dioxide Emissions and Global Warming Potentials in LCA-modelling of Waste Management Systems, Waste Management & Research, 27, pp707-717

[177] Department for Environment Food and Rural Affairs (2014) Energy recovery for residual waste: A carbon-based modelling approach. Accessed 31 March 2023. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

[178] https://www.statista.com/statistics/548943/thermal-efficiency-gas-turbine-stations-uk/

into the grid, the emissions offset would be dependent on the marginal source of electricity on the grid. Where the biogas is 'upgraded' (see Section 3.4) to produce a vehicle fuel, the emissions offset would be dependent on the vehicle fuel that the produced fuel is displacing. Where injected into a gas grid, it would displace the fossil gas used.

- **Consideration of the final output** – Wet and dry AD produce significantly different outputs, where wet AD is optimised for maximum biogas generation, dry AD is generally optimised for a balance between gas and digestate output. Digestate is used as a fertiliser substitute, which reduces fertiliser production emissions. The carbon benefits of digestate use can, however, be lost if the product does not meet specified requirements, and it ought not be used on agricultural land.

A 3.4.3 Co-Processing of Waste and Cement Kilns

As discussed in Section 3.6, a carbon benefit generated by co-processing RDF in a cement kiln depends on the kiln's current fuel mix and the marginal fuel that will be displaced by the RDF. Displacement of fossil fuels, such as coal and oil will yield large carbon benefits, whereas introducing RDF into a cement kiln where it displaces biomass fuels will yield no carbon benefit. Where RDF displaces fossil fuels, the net carbon impacts are generally significantly more beneficial than in WtE facilities where the energy generated displaces the marginal emissions factor that itself does not have a large contribution from fossil fuels.

It is important to consider the possibility of sending RDF to the Golden Bay cement plant. The plant has recently made upgrades to substitute 15% of coal with used tyres (Section 3.6), pushing overall coal substitution rates to above 50%. This already high substitution rate may well pose a barrier for RDF substitution of coal. An exact answer to whether RDF could continue substituting for coal at this plant, is however, out of scope of this assessment and it is recommended that stakeholders seek to understand this issue further. Again, it is always more beneficial to send RDF to a kiln where the RDF displaces coal or oil, which may require an export market to be established for RDF from NZ.

Another possibility is the RDF could be substituted for coal at Huntly power station. The plant's owners Genesis, have been investigating alternative fuel sources and have trialled biomass in one of their units[179].

Emissions from transporting the waste fuel from production site to the kiln/power plant location should also be considered. Where the majority of miles are covered by road haulage, a larger negative impact will be seen compared to if the fuel is mostly transported by ship.[180] Generally, though, transport emissions account for a very insignificant amount of the total emissions.

Finally, the small fraction from RDF production that is omitted during the fuels production requires final treatment or disposal. Consideration should be taken for the most appropriate method, in terms of carbon performance, for this unwanted fraction of material.

A 3.4.4 Carbon capture utilisation and storage (CCUS)

Where CCUS technology is applied to the above technologies, the same impacts on carbon performance should be considered, and it is assumed that 90% of stack emissions are captured by CCUS.

---

[179] https://www.genesisenergy.co.nz/about/news/genesis-biomass-trial-successful

[180] Transporting emissions from haulage equate to roughly 0.18 $kgCO_2$/km/tonne. Shipping emissions equate to roughly 0.02 $kgCO_2$/km/tonne.

In addition, an emissions credit is applied to the biogenic emissions that are captured and sequestered from the stack gases. This assumption considers that these emissions form part of the short life-cycle emissions and were recently captured from the atmosphere and stored in the material. Therefore, these emissions capture and sequestration represent a net drawdown of emissions.

A 4.0 Modelling Assumptions

A 4.1 Waste Composition

The residual waste composition for residual waste entering Class 1 landfills is presented in Table A 1. It is based upon a 2018 analysis of national average waste composition for Class 1 landfills in Aotearoa New Zealand. The analysis is confidential as it contains commercially sensitive online waste levy system data and therefore cannot be referenced here.

Table A 1: Aotearoa New Zealand Residual Waste Composition

Material	Composition
Paper and Card	6%
Plastics	8%
Textiles	5%
Glass	2%
Ferrous Metals	3%
Non-ferrous Metals	1%
Kitchen Waste	9%
Garden Waste	6%
Sanitary Products	3%
Wood	13%
Potentially Hazardous	24%
Rubber	2%
Rubble and Concrete	20%

The two residual waste compositions used in the modelling for this analysis are presented in Table A 1. For both compositions, the potentially hazardous, rubble and concrete and rubber material has been removed. For composition 1, the % of wood has been reduced down to 3.5%, similar to levels of wood waste from households in the UK. The “misc combustible” is assumed to be 4.8% to bring the total composition from household sources to 50%. It is assumed that an additional 20% plastics, 20% tyres and 10% shredder floc (rubber and plastics) come from commercial and industrial sources.

Composition 2 assumes household waste (as per Composition 1), yet wood is not reduced from the level as presented in Table A 1. This therefore assumes that C&D waste wood forms a significant part of the feedstock. The composition has then been scaled up to reach 100%.

Table A 2: Residual Waste Compositions used in Modelling

Material	Composition 1	Composition 2
Paper and Card	5.9%	10.0%
Plastics	58.3%	14.0%
Textiles	5.0%	8.5%
Glass	1.8%	3.0%
Ferrous Metals	2.7%	4.6%
Non-ferrous Metals	0.8%	1.4%
Kitchen Waste	5.7%	9.6%
Garden Waste	9.0%	15.2%
Sanitary Products	2.5%	4.2%
Wood	3.5%	21.3%
Potentially Hazardous	0.0%	0.0%
Rubber	4.8%	8.1%

A 4.2 Marginal Energy Factors

Marginal energy factors used in the modelling are shown in Table A 3. The year modelled was 2030.

Table A 3: Marginal Energy Factors Used

Energy source displaced	Year 2030 marginal energy factor
Electricity	0.130 kg CO_{2e}/kWh
Heat	0.150 kg CO_{2e}/kWh

A 4.3 Landfill

We have assumed that sequestration impacts of biogenic materials are included in landfill modelling (see Section A 3.3). The model calculates a single emissions single factor per tonne landfilled, over a 100 year time horizon. Landfill gas assumptions are presented in Table A 4.

Table A 4: Landfill Assumptions

Landfill Gas Assumption	%
Average landfill gas capture rate over 100 years	61%
Proportion of gas used to generate energy	60%
Proportion of gas flared	40%
Gas engine efficiency (to electricity)	35%

A 4.4 Incineration and CCUS and ACT Assumptions

The unabated electricity generation efficiencies used in the modelling of electricity only and CHP WtE stations are given in Table A 5.

Table A 5: Unabated Incineration Energy Generation Efficiencies

Electricity Only Generation	% Efficiency
Electrical generation efficiency (gross)	28%
CHP	% Efficiency
Electrical generation efficiency (gross)	20%
Heat generation efficiency (gross)	20%

The abated electricity generation efficiencies (CCUS) used in the modelling of electricity only and CHP WtE stations are given in Table A 5. We assume a CO_2 capture rates of **90% from flue gasses** at CCUS capable facilities.

Table A 6: Unabated Incineration Energy Generation Efficiencies

Electricity Only Generation	% Efficiency
Electrical generation efficiency (gross)	25%
CHP	% Efficiency
Electrical generation efficiency (gross)	19%

Heat generation efficiency (gross)	18%

The unabated electricity generation efficiencies used in the modelling of electricity only and CHP WtE stations are given in Table A 7.

Table A 7: Unabated Incineration Energy Generation Efficiencies

Electricity Only Generation	% Efficiency
Electrical generation efficiency (gross)	13%

A 4.5 Avoided Emissions Through Recycling

The assumptions for avoided emissions through recycling of different materials are given in Table A 8.

Table A 8: Avoided Emissions Through Recycling

Material	Avoided Emissions, tonne CO_2e/tonne
Plastics (PET)	1.400
Plastics (dense, mixed)	1.615
Plastic film	1.330
Glass (open loop recycling)	0.150
Ferrous (steel)	1.133
Non-ferrous (aluminium)	9.100
Food waste (offsetting fertiliser)	0.074

A 5.0 Glossary

Alphabetical List of Sources

1. 2019 statement; can be found here https://www.wastemanagement.co.nz/news-and-media/waste-to-energy-in-new-zealand/
2. 2020 EU Circular Economy Action Plan, European Commission. Accessed March 2023 https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
3. 2023 Draft advice to inform the strategic direction of the Government's second emissions reduction plan. April 2023. Page 154
4. A Resourceful Future: Expanding the UK Economy, Eunomia 2016
5. Action Plan for Circular Economy, Ministry for Environment Denmark, 2021. Accessed March 2023 https://en.mim.dk/media/224197/alle-faktaark-engelsk-nyeste.pdf
6. Air Quality Consultants (2020) Health Effects due to Emissions from Energy from Waste Plant in London, Report for the GLA
7. AVR Duiven and Twence Hengelo in the Netherlands, and Fortum Oslo Varne in Norway
8. Beyond Recycling, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/beyond-recycling
9. Catapult Energy Systems (2020) Energy from Waste Plants with Carbon Capture, May 2020
10. cdn.eurelectric.org/media/4005/power-barometer-final-lr-h-3A4C4DC9.pdf
11. Christensen, T., Gentil, E., Boldrin, A., Larsen, A., Weidema, B. and Hauschild, M. (2009) C balance, Carbon Dioxide Emissions and Global Warming Potentials in LCA-modelling of Waste Management Systems, Waste Management & Research, 27, pp707-717
12. Climate Change (Stationary Energy and Industrial Processes) Regulations 2009, Section 21
13. Climate Change: Deal on a more ambitious Emissions Trading System (ETS), European Parliament, December 2022. Accessed March 2023. https://www.europarl.europa.eu/news/en/press-room/20221212IPR64527/climate-change-deal-on-a-more-ambitious-emissions-trading-system-ets
14. Decarbonising Process Heat, Ministry of Business, Innovation and Employment New Zealand. Accessed March 2023 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/low-emissions-economy/
15. Defra (2013) Advanced Thermal Treatment of Municipal Solid Waste
16. Defra (2013) Incineration of Municipal Solid Waste - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf
17. DEFRA (2014) Energy from Waste: A Guide to the Debate, Revised Edition, February 2014
18. DEFRA (2014) Energy from Waste: A Guide to the Debate, Revised Edition, February 2014. Accessed March 2023. https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate
19. Denmark's Devilish Waste Dilema, Politico, 2020. Accessed March 2023. https://www.politico.eu/article/denmark-devilish-waste-trash-energy-incineration-recycling-dilemma/
20. Department for Business, and Energy and Industrial Strategy (2021) Final Stage IA: Green Gas Support Scheme/Green Gas Levy, September 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1018133/green-gas-impact-assessment.pdf
21. Department for Environment Food and Rural Affairs (2014) Energy recovery for residual waste: A carbon-based modelling approach. Accessed 31 March 2023. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Complete d=0&ProjectID=19019
22. Developing the UK Emissions Trading Scheme (UK ETS), UK Government, March 2022. Accessed March 2023. https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading-scheme-uk-ets

23. Development of a Modelling Tool on Waste Generation and Management, Appendix 9: Employment in Municipal Waste Operations. Eunomia, 2014.
24. Development of a Modelling Tool on Waste Generation and Management, Appendix 9: Employment in Municipal Waste Operations. Eunomia, 2014.
25. Energy From Waste – A Load of Rubbish or a Viable Solution to Landfill, Gilber and Tobin, 2021. Accessed March 2021. https://www.gtlaw.com.au/knowledge/energy-waste-load-rubbish-or-viable-solution-landfill
26. Enzygo Ltd (2010) The energy impact of waste management: recycling and energy from waste, Report for WRAP. Unpublished.
27. EU Taxonomy for Sustainable Activities. Accessed March 2023. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en#documents
28. EU Technical Expert Group on Sustainable Finance: Technical annex to the TEG final report on the EU taxonomy, European Commission, 2020. Accessed March 2023. https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf
29. Eunomia (2021) CCUS Development Pathway for the EfW Sector, Report for Viridor, https://www.eunomia.co.uk/reports-tools/ccus-development-pathway-for-the-efw-sector/
30. Eunomia (2022) Eunomia Incineration Review Report - Opportunities to Decarbonise the Waste Treatment Infrastructure, https://www.gov.scot/publications/stop-sort-burn-bury-independent-review-role-incineration-waste-hierarchy-scotland-second-report-decarbonisation-residual-waste-infrastructure-scotland/documents/
31. Eurostat, 2018. Accessed March 2023. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20180123-1
32. From Waste Hierarchy to Carbon Hierarchy: Biffa’s Blueprint for Waste Net Zero, Biffa 2022
33. Greenhouse Gas and Air Quality Impacts of Incineration and Landfill, Eunomia for Client Earth, Dec 2020
34. http://www.bioplantenergy.com/projects
35. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1023792/agt-benchmarking-task-2-report.pdf
36. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221039/pb13890-treatment-solid-waste.pdf
37. https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en
38. https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en
39. https://doi.org/10.1016/B978-0-12-386505-2.00002-X
40. https://doi.org/10.1016/j.wasman.2020.04.050
41. https://earthobservatory.nasa.gov/features/MethaneMatters
42. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Municipal_waste_landfilled,_incinerated,_recycled_and_composted,_EU-27,_1995-2019.png
43. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics#Municipal_waste_treatment
44. https://ellenmacarthurfoundation.org/articles/the-biological-cycle-of-the-butterfly-diagram
45. https://ellenmacarthurfoundation.org/completing-the-picture
46. https://en.wikipedia.org/wiki/Lignin#:~:text=Lignin%20is%20a%20class%20of,and%20do%20not%20rot%20easily.
47. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
48. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
49. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
50. https://environment.govt.nz/assets/Publications/regulatory-impact-statement-waste-disposal-levy.pdf p23
51. https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/energy-and-industry/
52. https://environment.govt.nz/publications/marginal-abatement-cost-curves-analysis-for-new-zealand-potential-greenhouse-gas-mitigation-options-and-their-costs/
53. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020/

54. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
55. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
56. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
57. https://fletcherbuilding.com/news/golden-bay-cement-sustainable-disposal-solution-for-waste-tyres-a-new-zealand-first/
58. https://gasischanging.co.nz/assets/uploads/Firstgas-Bringing-Zero-Carbon-Gas-to-You-and-Aotearoa.pdf
59. https://gasnz.org.nz/what-we-do
60. https://ipen.org/sites/default/files/documents/After_incineration_the_toxic_ash_problem_2015.pdf
61. https://ukwin.org.uk/facts/
62. https://waikatotainui.com/wp-content/uploads/2022/08/Waikato-Tainui-Environmental-Plan-2013.pdf
63. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/WasteandRecycling/Report/c04
64. https://www.beehive.govt.nz/release/100-renewable-electricity-grid-explored-pumped-storage-%E2%80%98battery%E2%80%99
65. https://www.carbonnews.co.nz/tag.asp?tag=Carbon+prices 14/05/23
66. https://www.cewep.eu/wp-content/uploads/2017/09/13_01_15_cewep_energy_report_iii.pdf
67. https://www.ecoprog.com/fileadmin/user_upload/pressemitteilungen/pr_MBT_ecoprog_2017.pdf
68. https://www.ecoprog.com/publications/energy-management/waste-to-energy.htm#:~:text=Today%2C%20more%20than%202%2C600%20WtE,capacity%20of%2044.4%20million%20tpy.
69. https://www.eea.europa.eu/ims/waste-recycling-in-europe
70. https://www.eea.europa.eu/ims/waste-recycling-in-europe
71. https://www.eea.europa.eu/ims/waste-recycling-in-europe
72. https://www.endswasteandbioenergy.com/article/1676045/no-new-gasification-facilities-expanding-viridor
73. https://www.endswasteandbioenergy.com/article/1740906/gas-went-wrong-uks-gasification-industry
74. https://www.energy.gov/sites/prod/files/2019/08/f66/BETO--Waste-to-Energy-Report-August--2019.pdf
75. https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw
76. https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics/emissions-impacts-of-food-waste-recovery-technologies
77. https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics/emissions-impacts-of-food-waste-recovery-technologies
78. https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics/emissions-impacts-of-food-waste-recovery-technologies
79. https://www.europarl.europa.eu/doceo/document/TA-9-2021-0040_EN.html
80. https://www.europarl.europa.eu/doceo/document/TA-9-2021-0040_EN.html
81. https://www.genesisenergy.co.nz/about/news/genesis-biomass-trial-successful
82. https://www.gov.uk/government/publications/municipal-waste-incinerators-emissions-impact-on-health/phe-statement-on-modern-municipal-waste-incinerators-mwi-study
83. https://www.gov.uk/government/statistics/uk-waste-data/uk-statistics-on-waste
84. https://www.ieabioenergy.com/wp-content/uploads/2019/02/CS3-MSW-pretreatment-for-gasification.pdf
85. https://www.legislation.govt.nz/act/public/2008/0089/latest/DLM1166800.html
86. https://www.legislation.govt.nz/regulation/public/2004/0309/latest/DLM287035.html?search=ta_regulation_R_rc%40rinf%40rnif_an%40bn%40rn_25_a&p=3
87. https://www.legislation.govt.nz/regulation/public/2010/0338/latest/whole.html
88. https://www.letsrecycle.com/news/municipal-incinerators-included-in-eus-emissions-trading-scheme/

89. https://www.mbie.govt.nz/about/news/energy-in-new-zealand-2022-shows-a-strong-share-of-renewable-energy/
90. https://www.mbie.govt.nz/about/news/energy-in-new-zealand-2022-shows-a-strong-share-of-renewable-energy/
91. https://www.mpi.govt.nz/food-safety-home/reducing-food-waste-at-home/?stage=Live
92. https://www.newshub.co.nz/home/new-zealand/2021/03/firstgas-group-announces-plan-to-decarbonise-gas-pipeline-network-in-new-zealand.html
93. https://www.no-burn.org/wp-content/uploads/Waste-Gasification-and-Pyrolysis-high-risk-low-yield-processes-march-2017.pdf
94. https://www.nzherald.co.nz/nz/plan-junked-for-power-plant-fired-by-rubbish/6JJFFIZ36CACCLOVSIXYUI5FCM/
95. https://www.projectkea.co.nz/
96. https://www.statista.com/statistics/1299734/new-zealand-emissions-intensity-from-electricity-generation/
97. https://www.statista.com/statistics/548943/thermal-efficiency-gas-turbine-stations-uk/
98. https://www.stuff.co.nz/manawatu-standard/300901213/contentious-feilding-wastetofuel-plant-proposal-withdrawn-due-to-technicalities
99. https://www.stuff.co.nz/national/111782266/why-did-west-coast-plans-for-a-wastetoenergy-plant-fail
100. https://www.transpower.co.nz/about-us/our-strategy/whakamana-i-te-mauri-hiko-empowering-our-energy-future
101. https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-recycling-municipal-waste#assessing-the-development
102. https://www.umweltbundesamt.de/en/topics/waste-resources/waste-disposal/thermal-treatment#thermal-treatment-of-municipal-waste-
103. Ināia tonu nei: a low emissions future for Aotearoa, Climate Change Commission, June 2021
104. Incinerator Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027
105. Intergovernmental Panel on Climate Change. https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change
106. Interim Climate Change Commission, Accelerated Electrification, April 2019
107. ISWA (2018), Effectiveness of municipal solid waste incinerators in replacing other fuels. A primary energy balance approach for the EU28, https://doi.org/10.1177/0734242X18785737
108. Lombardi, L., Carnevale, E. and Corti, A., (2015). A review of technologies and performances of thermal treatment systems for energy recovery from waste. Waste management, 37, pp.26-44.
109. Managing compostable bags at anaerobic digestion plants, C Garaffa and R. Yepsen (2012). Available at: https://www.biocycle.net/managing-compostable-bags-at-anaerobic-digestion-plants/
110. Maniapoto Environmental Plan, section 24.4.2.1 https://www.maniapoto.iwi.nz/wp-content/uploads/2020/09/0525318-Maniapoto-Enviro-Manag-Plan_Cvr_Tabs.pdf
111. Map of Incineration Facilities in Australia, Zero Waste Australia. Accessed March 2023. https://zerowasteaustralia.org/incineration/
112. MfE. (2020). Marginal abatement cost curve analysis for New Zealand.
113. Ministry for the Environment (2020) Marginal abatement cost curves analysis for New Zealand: Potential greenhouse gas mitigation options and their costs. Wellington: Ministry for the Environment, https://environment.govt.nz/assets/Publications/Files/marginal-abatement-cost-curves-analysis_0.docx
114. Ministry for the Environment (August 2020) A waste to energy guide for New Zealand, https://environment.govt.nz/assets/Publications/Files/waste-to-energy-guide-for-new-zealand.pdf
115. Ministry for the Environment, Marginal abatement cost curves analysis for New Zealand: Potential GHG Mitigation Options and Their Costs, 2020.
116. Ministry for the Environment. 2023. Te rautaki para | Waste strategy | Waste strategy. Wellington: Ministry for the Environment.
117. National Waste Report, Blue Environment, 2020. Accessed March 2023. https://www.dcceew.gov.au/sites/default/files/env/pages/5a160ae2-d3a9-480e-9344-4eac42ef9001/files/national-waste-report-2020.pdf
118. Nick Robertson and Merewyn Groom (for Business and Economic Research Ltd) (2019), “Waste to energy: the incineration option”, available at www.berl.co.nz

119. Perrot, J.F. and Subiantoro, A., (2018). Municipal waste management strategy review and waste-to-energy potentials in New Zealand. Sustainability, 10(9), p.3114.
120. Poyry (2010) Energy from Waste Technologies and Feedstocks, Report for WRAP
121. Recycling – Who Really Leads the World? Eunomia, March 2017
122. Ribeiro-Broomhead, J. & Tangri, N. (2021). Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions.
123. Sharma P. et al (23 June 2022) Recent Progress in Refuse Derived Fuel (RDF) Co-processing in Cement Production: Direct Firing in Kiln/Calciner vs Process Integration of RDF Gasification, Journal of Waste and Biomass Valorization
124. The case for Sorting Recyclables Prior to Landfill and Incineration, Reloop, 2022. Accessed March 2023. https://www.reloopplatform.org/wp-content/uploads/2022/06/D-HOGG-_Reloop_FINAL_June2022-1.pdf
125. The climate change impacts of burning municipal waste in Scotland. Zero Waste Scotland, June 2021
126. The climate change impacts of burning municipal waste in Scotland. Zero Waste Scotland, June 2021
127. The European Green Deal, European Commission, 2019. Accessed March 2023. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
128. The Zero Waste Network: https://zerowaste.co.nz/waste-to-energy-incineration/; also the Behaviour Change Sector Group coordinated by the Waste Management Institute of New Zealand https://www.wasteminz.org.nz/files/Behaviour%20Change/Behaviour%20Change%20WtE%20position%20paper.pdf
129. ToxicoWatch (2019). The hidden impacts of incineration residues. Report for Zero Waste Europe. Available: https://zerowasteeurope.eu/wp-content/uploads/2019/11/zero_waste_europe_cs_the-hidden-impacts-of-incineration-residues_en.pdf
130. Treasury Green Book, Department for Business Energy and Industrial Strategy Tables 1-19. Accessed March 2023. https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
131. UK Energy from Waste Statistics – 2021, Tolvik Consulting, May 2022
132. UK Environment Agency (2014) Briefing on regulation of wood, http://www.organics-recycling.org.uk/uploads/article2892/Wood%20Briefing_28Aug2014V1%20final.pdf
133. ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf
134. ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf
135. ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf
136. Waikato-Tainui Environmental Management Plan – Tai Tumu, Tai Pari, Tai Ao. 2013. Section 26.2.9
137. Wales Takes Action on Circular Economy with Funding, Upcoming Reforms on Plastic and a Moratorium on Large-Scale Waste Energy, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/wales-takes-action-circular-economy-funding-upcoming-reforms-plastic-and-moratorium-large-scale
138. Wales Takes Action on Circular Economy with Funding, Upcoming Reforms on Plastic and a Moratorium on Large-Scale Waste Energy, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/wales-takes-action-circular-economy-funding-upcoming-reforms-plastic-and-moratorium-large-scale
139. Wales Takes Action on Circular Economy with Funding, Upcoming Reforms on Plastic and a Moratorium on Large-Scale Waste Energy, Welsh Government, 2021. Accessed March 2023. https://www.gov.wales/wales-takes-action-circular-economy-funding-upcoming-reforms-plastic-and-moratorium-large-scale
140. Wang W and Liu Z (2020) Principle and Protective Measures of High temperature Corrosion of Garbage Incineration Boiler, Journal of Physics doi:10.1088/1742-6596/1635/1/012087
141. Waste Minimisation (Calculation and Payment of Waste Disposal Levy) Regulations 2009, available at www.legislation.govt.nz
142. Waste Minimisation Act 2008, Section 6.
143. Waste Statistics, Ministry for Environment Denmark, 2018. Accessed March 2023. https://www2.mst.dk/Udgiv/publikationer/2020/05/978-87-7038-183-3.pdf
144. Waste to Energy, Para Kore, 2022 https://www.parakore.maori.nz/waste-to-energy/
145. Waste-to-Energy is not Sustainable Business, the EU says, Zero Waste Europe, 2019. Accessed March 2023. https://zerowasteeurope.eu/wp-content/uploads/2019/09/zero_waste_europe_policy_briefing_sustainable_finance_en.pdf

146. WRAP (2013) A survey of the UK Anaerobic Digestion industry in 2013, 2013, http://www.organics-recycling.org.uk/uploads/article2927/ASORI%202013%20report.pdf
147. Wu, Z et. Al, (2019) Effects of different lipid contents on growth of earthworms and the products during vermicomposting, https://journals.sagepub.com/doi/full/10.1177/0734242X19861683
148. www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/low-emissions-economy/nz-battery/.
149. www.parakore.maori.nz
150. www.whetugroup.co.nz

eunomia.co.uk

eunomia