Office of the Prime Minister's Chief Science Advisor
Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

Title:

REPORT: Beyond the bin: Capturing value from food loss and waste

Author:

OPMCSA

Output type: PDF				
Pages: pp 249				
Date: Feb-2024				
Language: English				
Review: Peer reviewed				
Versions				
Record number:	*Version:*	*Date V1 created:*	*Date:*	*Printed version*
PMCSA-24-2-1-V2	V2	16-Feb-2024	14-Mar-2024	Y
DOI:	10.17608/k6.OPMCSA.25058258			
ISBN:	978-0-473-70220-5 (PDF) 978-0-473-70219-9 (Paperback)			
Archive page link: https://dpmc.govt.nz/our-programmes/special-programmes/prime-ministers-chief-science-advisor-archives/archive/gerrard-2021-2024				
Notes: Delivered in January 2024 - release in February 2024-				

Beyond the bin

Capturing value from food loss and food waste

The third report in the food waste series from the Prime Minister's Chief Science Advisor, Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia.

January 2024





January 2024 (Version 2)

ISBN:

978-0-473-70220-5 (PDF)

978-0-473-70219-9 (Paperback)

Other reports in the OPMCSA food waste series:

Food waste: A global and local problem https://doi.org/10.17608/k6.OPMCSA.20164736

Food rescue in 2022: Where to from here? https://doi.org/10.17608/k6.OPMCSA.21218243

Office of the Prime Minister's Chief Science Advisor
Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

Office of the Prime Minister's Chief Science Advisor
The University of Auckland
Private Bag 92019
Victoria Street West
Auckland 1142
Aotearoa New Zealand

Email info@pmcsa.ac.nz | **Web** pmcsa.nz

Instagram @nz_chief_science_advisor | **Twitter** @ChiefSciAdvisor

Front cover (top to bottom):

1. A variety of 'imperfect' tomatoes ready for upcycling by Rescued Kitchen
2. A household compost bin
3. Prepping anaerobic digestion tanks at Ecogas for household food waste from Auckland
4. Composting in outdoor windrows at Living Earth
5. A handful of vermicast produced by at MyNoke's Taupō worm farm

Mā tōu rou, mā taku rourou

ka ora te iwi

Foreword

Kia ora koutou,

New Zealand produces hundreds of thousands, possibly millions, of tonnes of food waste each year, much of which is landfilled, left unharvested, buried in pits, held in methanogenic stockpiles, or otherwise wasted. Industry, communities, researchers, and individuals have long been working to capture value from unprevented food waste, but there is much room for improvement.

Food waste is increasingly being recognised as a resource that can be given a second life as compost, animal feed, upcycled food products, biogas, and more. This shift is reflected in a wide variety of government workstreams, from the *Te rautaki para | Waste Strategy* and the *Emissions Reduction Plan* to MBIE's circular economy strategy work and beyond. At the local level, many councils are bedding in, rolling out, or scoping kerbside food waste solutions for households, and many support home and community composting initiatives. We hope to underpin these efforts by providing an evidence base to support change.

This report builds on our recent web resource focused on household food waste, exploring opportunities to capture value from a variety of food waste streams. It draws on the circular economy and food recovery hierarchy frameworks outlined in our overview of the food waste problem, and places a spotlight on the role of food waste valorisation in the context of the climate crisis. We cover opportunities across five tiers of the food recovery hierarchy: upcycling to new food products, conversion of food waste to animal feed, material recovery, nutrient recovery, and energy recovery. We also touch on disposal, which sits at the bottom of the hierarchy as the least-preferred option for food waste management, and how we can work to minimise food waste ending up in landfill, especially those without methane capture.

As we highlighted in our deep dive of the New Zealand food rescue sector, there is a need to ensure that efforts to capture value from food waste don't distract from or undermine efforts to prevent food waste at source wherever possible.

This report was made possible thanks to the generosity of the project reference group, whose members have hosted us at community gardens, large scale vermicomposting sites, commercial fly farms, anaerobic digestion facilities, pilot plants, and more. We have also benefitted from conferences, meetings, email exchanges, and feedback on drafts as the report has taken shape. Those who contributed to this report, as well as the wider project reference group, are acknowledged in the following pages.

To learn more about food waste, visit our webpage where you can find the project framework and publications https://www.pmcsa.ac.nz/topics/food-rescue-food-waste/. If you'd like to contribute to future work and we aren't already in touch, please contact info@pmcsa.ac.nz

Ngā manaakitanga,

Juliet Gerrard

Professor Dame Juliet Gerrard DNZM HonFRSC FRSNZ
Prime Minister's Chief Science Advisor
Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

Acknowledgements

We thank the many researchers, stakeholders, and officials in our project reference group. Our work wouldn't be possible without the expert and on-the-ground insights shared by this diverse group, who have helped to guide our approach to this project, commented on drafts, hosted us for visits, engaged in thought-provoking discussions, and shared resources and whakaaro. We also acknowledge the Chief Science Advisor Forum members for their contributions to this project.

Responsibility for any errors and omissions sits with the OPMCSA. We have done our utmost to keep track of everyone who has contributed to this project and extend our sincere apologies if we have inadvertently omitted anyone.

We also extend our thanks to everyone who has paved the way for action on food waste, both here in Aotearoa and overseas. We have discovered a rich legacy and growing momentum around food waste minimisation and management, and hope this report supports ongoing mahi.

Particular thanks to

Alzbeta Bouskova, Ecogas

Andrew Prest, Andrew Prest and Associates Ltd/AS Wilcox

Anna Yallop, BPA

Aotearoa Composters Network

Awilda Baoumgren, MPI

Barry Wards, MPI

Brett Robinson, University of Canterbury

Brian Cox, Bioenergy Association

Brittany Rymer, MfE

Carel Bezuidenhout, Massey University

Chelsea Mintrom, MPI

Cristina Cleghorn, University of Otago

Danielle Kennedy, MfE

Deepa Goswami, Porirua City Council

Diane Stanbra, Rescued

Emma Harding, Foodstuffs

Erin Young, University of Otago

Frances Clement, NZ Pork

Francesca Goodman-Smith, Fight Food Waste CRC

Gerald Rys, MPI

Gradon Diprose, Landcare Research

Harry Livesey, MfE

Hilary Sharpe, MoH

Indra Oey, Otago University

Ivan Chirino-Valle, MfE

Jacqui Todd, Plant and Food Research

Janet Lymburn, MPI

Jeff Seadon, Seadon Consulting

Jenny Marshall, MfE

Jessica O'Connor, University of Otago

Joanne Hort, Massey University

Jocelyn Eason, Plant and Food Research

Julien Heyes, Massey University

Kaitlin Dawson, NZ Champions 12.3

Katherine Silvester, MfE

Katie Bright, MfE

Lesley Ottey, EcoEducate

Liz Butcher, MfE

Margaret Thorsen, University of Otago

Marian McKenzie, Plant and Food Research

Matiu Prebble, University of Canterbury

Michael Macbeda, Waimate District Council

Michelle Blau, Fair Food

Nadine Wakim, Auckland Council

Nick Hanson, NZ Pork

Olga Pantos, ESR

Olivia Ogilvie, Opo Bio

Phil Bremer, University of Otago

Philippa Hawthorne, MPI

Qinhua Shen, MPI

Rebecca Doonan, MPI

Regina Wypych, Beef and Lamb

Rob Tinholt, Water NZ

Roderick Boys, MfE

Sarah Reader, MPI

Shawn Gardner, Enspire

Sheila Skeaff, University of Otago

Stephanie Hill, MfE

Taima Moeke-Pickering, Laurentian University

Ulrich Kornmueller, Bioenergy Association

Wender Martins, University of Auckland

Reference group

Akari Otsuka, Dunedin City Council

Alex Kirkham, Auckland Council

Ali Reza Nazmi, University of Canterbury Alison

Collins, MfE

Alison Subiantoro, University of Auckland

Alzbeta Bouskova, Ecogas

Amanda Kane, New South Wales Environment Protection Authority (Australia)

Amanda Wolf, Victoria University of Wellington

Amanda Yates, Auckland University of Technology

Amber Walter, MoE

Amir Sayadabdi, Victoria University of Wellington

Analeise Murahidy, University of Auckland

Andrew Dickson, Our Land and Water Andrew

East, Massey University

Andrew Fisher, Ecostock

Andrew McCallum, MBIE

Andrew Prest, Andrew Prest and Associates Ltd/AS Wilcox

Angela Calver, KiwiHarvest

Angela Clifford, EatNZ

Anna Yallop, BPA

Anne Wietheger, MPI

Anton Drazevic, Nelson Environment Centre

Antonia Miller, Plant and Food Research

Antony Heywood, Vegetables New Zealand

Aotearoa Composters Network

Asch Harwood, ReFED (US)

Awilda Baoumgren, MPI

Bailey Perryman, Kaiwhakatere (Nōku Te Ao Charitable Trust)

Barbara Annesley, MfE

Barry Wards, MPI

Ben Baldwin Queensland Department of Agriculture and Fisheries (Australia)

Ben Elms Biochar Network New Zealand

Ben Reddiex, DOC

Ben van den Eykel, MBIE

Benje Patterson, Independent economist

Benoit Guieysse, Massey University

Betsy Kettle, City to Farm

Bill Kaye-Blake, NZ Institute of Economic Research

Brendon Malcolm, Plant and Food Research

Brent Kleiss, NZ Pork

Brett Robinson, University of Canterbury

Brian Cox, Bioenergy Association

Bridget Murphy, MoH

Brittany Rymer, MfE

Brittney Evans, Manawatū District Council

Bruce Middleton, Waste Not Consulting

Cameron Crawley, Satisfy Food Rescue

Cara McNicol, Queensland Department of Environment and Science (Australia)

Carel Bezuidenhout, Massey University

Carolyn Lister, Plant and Food Research

Cath Gledhill, Dunedin City Council

Catherine Rosie, Auckland Council

Cecilia Manese, Foodstuffs

Chelsea Mintrom, MPI

Chen Wu, previously at FlyFarm (Australia)

Cherie Pugh, Pyrocal

Chloe Lynch, MoH

Chris Daughney, Regional and Unitary Councils Aotearoa

Chris Galloway, Massey University

Chris Henderson, Dunedin City Council

Chris Hewins, MPI

Chris Kerr, MPI

Chris Purchas, Tonkin and Taylor

Christiane Rupp, University of Auckland

Christina McBeth, Nourished for Nil

Claire Hanrahan, Compass Group

Claire Mortimer, MBIE

Cliona Ni Mhurchu, University of Auckland

Craig Bunt, University of Otago

Craig Cliff, University of Otago

Cristina Cleghorn, University of Otago

Dan Harvey, MfE

Dana Gunders, ReFED (US)

Daniel Morrimire, Manawatū Food Action Network

Daniel Yallop, Re.Group

Danielle Kennedy, MfE

Danielle LeGallais, Sunday Blessings

Darrin Hodgetts, Massey University

Dave Perkins, Waste Management

David Carlton, DOC

David Howie, Waste Management

David Jefferson, University of Canterbury

David Kettle, City to Farm

David Whitehead, Manaaki Whenua

Dawn Hutchesson, Aotearoa Food Rescue Alliance

Deborah Manning, KiwiHarvest and NZFN

Deborah Mclaughlin, Fair Food

Deepa Goswami, Porirua City Council

Denise Conroy, Plant and Food Research

Des Flynn, The Warehouse Group

Diane Mollenkopf, University of Canterbury

Diane Stanbra, Rescued

Dinarie Abeyesundere, MSD

Donnell Alexander, MPI

Dorthe Siggaard

Duncan Wilson, Eunomia Consulting

Eleonora De Crescenzo, MSD

Eli Gray-Stuart, Massey University

Elise O'Brien, Auckland Council

Elodie Letendre, Dunedin City Council

Emil Murphy, Deer Industry New Zealand

Emily King, Spira

Emma Harding, Foodstuffs

Emma Richardson, Climate Change Commission

Emma Taylor, MPI

Enda Crossin, University of Canterbury

Erin Breen, MPI

Erin Leitao, University of Auckland

Erin Young, University of Otago

Eva Gaugler, Scion

Fiona Duncan, MPI

Fliss Roberts, Greenback

Frances Clement, NZ Pork

Francesca Goodman-Smith, Fight Food Waste Cooperative Research Centre (Australia)

Freya Hjorvarsdottir, MPI

Garth Lamb, Re.Group

Gavin Findlay, NZFN

Geoff Kira, Victoria University of Wellington

Geoffroy Lamarche, Office of the Parliamentary Commissioner for the Environment

Georgina Langdon-Pole, Auckland Council

Georgina Morrison, Environment Hubs Aotearoa

Gerald Rys, MPI

Glenn Wigley, MfE

Grace Clare, University of Otago

Gradon Diprose, Landcare Research

Grant Blackwell, Climate Change Commission

Grant Verry, FoodBowl

Hadas Ore, Waiheke Resources Trust

Hans Maurer, AgriChain Centre

Harmony Ryder, KiwiHarvest

Harry Livesey, MfE

Harshal Chitale, MfE

Heather Riddell, MPI

Helen Darling, Sumfood

Hilary Sharpe, MoH

Iain Lees-Galloway, Aotearoa Food Rescue Alliance

Ian Barugh, NZ Pork

Ian Town, MoH

Indrawati Oey, University of Otago

Ingrid Cronin-Knight, Waste Management

Ivan Chirino-Valle, MfE

Ivy Gan, Plant and Food Research

Jack Heinemann, University of Canterbury

Jacqui Forbes, Para Kore

Jacqui Horswell

Jacqui Todd, Plant and Food Research

Jacqui Yip, Auckland Council

Janet Cole, Kaipātiki Project

Janet Lymburn, MPI

Jarrod Haar, Auckland University of Technology

Jeff Seadon, Seadon Consulting

Jenny Elliott, Wellington City Council

Jenny Ford, Mynoke

Jenny Grainger, Venerdi

Jenny Marshall, MfE

Jeremy Helson, Seafood New Zealand

Jesse Nichols, MSD

Jessica Hutchings, Kaupapa Māori Researcher

Jessica O'Connor, University of Otago

Jim Jones, Massey University

Jo Sharp, Plant and Food Research

Jo Wrigley, Go Eco Waikato Environment Centre

Jo Fountain, Lincoln University

Joanna Langford, Wellington City Council

Joanne Ferry, Tonkin and Taylor Consultancy

Joanne Hort, Massey University

Joanne Todd, University of Auckland

Joanne Kingsbury, ESR

Jocelyn Eason, Plant and Food Research

John Roche, MPI

John Bronlund, Massey University

John Milligan, Foodbank Canterbury

Jonathan Elms, Massey University

Jonathan Hannon, Massey University

Jonathan Middis, Fight Food Waste Cooperative Research Centre (Australia)

Josie Lambert, Food Nation

Joya Kemper, University of Canterbury

Juan Lei, FlyFarm (Australia)

Judith Goldsack, Nourished for Nil

Juhi Shareef, Project Moonshot

Julie Dickinson, Auckland Council

Julie Harris

Julie North, Foodcom

Julien Heyes, Massey University

Juliet Armstrong, MPI

Julio Bin, Auckland Council

Kaitlin Dawson, NZ Champions 12.3

Kang Huang, University of Auckland

Karen Fernandez, University of Auckland

Karen Lau, MPI

Karen Lee, Nelson City Council

Kate Meads, Waste Free with Kate

Kate Parker, Scion

Kate Porter, NZ Champions 12.3

Kate Springer, Commerce Commission

Kate Walmsley, Kaicycle

Katherine Silvester, MBIE

Kathryn Pavlovich, University of Waikato

Kathy Voyles, Waiheke Resources Trust

Katie Bright, MfE

Katie Buller, Auckland Council

Katy Bluett, Future Foods Aotearoa

Kelly Drombroski, Massey University

Kenny Lau, New Zealand Trade and Enterprise

Kim Stretton, Waikato Regional Council

Kim Hang Pham Do, Massey University

Kirra Havemann, Sunday Blessings

Kristin Joiner, The Connective

Lance Williams, Kaibosh

Lara Cowen, MfE

Laura Hetherington, MPI

Lauren Beattie, Gizzy Kai

Lauren Simpson, Auckland Council

Leanne Young, University of Auckland

Lena Kovac, WasteMINZ

Lesley Ottey, EcoEducate

Liam Prince, The Rubbish Trip

Libby Harrison, NZ Food Safety Science & Research Centre

Linden MacManus, MfE

Lisa Bridson, Nelson Marlborough District Health Board

Lisa Busch, University of Auckland

Lisa Eve, Eunomia Consulting

Lisa Te Morenga, Massey University

Livné Ore, Waiheke Resources Trust

Liz Butcher, MfE

Liz Goodwin, World Resources Institute (UK)

Logan Dingle, Living Earth

Louise Lee, Independent researcher

Luca, Serventi, Lincoln University

Lucy Pierpoint, Tamaki WRAP

Madeline Shelling, University of Auckland

Madelon de Johngh, WasteMINZ

Madi Walter, NZFN

Manpreet Dhami, Manaaki Whenua

Marc Gaugler, Scion

Marco Morgenstern, Plant and Food Research

Margaret Thorsen, University of Otago

Marian McKenzie, Plant and Food Research

Marian McKenzie, Plant and Food Research

Marianne Lukkien, MPI

Mark Barthel, Stop Food Waste Australia

Mark Bell, Countdown

Mark Casey, Foodstuffs

Mark Milke, University of Canterbury

Marshall Bell, The Foodbowl (NZ Food Innovation Network)

Martin Workman MfE

Mary-Ann Carter, MoH

Mat Walton, ESR

Matiu Prebble, University of Canterbury

Matthew Ashworth, ESR

Meghan Cooper, Rotorua Lakes Council

Meghan Hughes, Aotearoa Food Rescue Alliance

Melanie Vautier, MfE

Melissa Hodd, Foodstuffs

Meng Wai Woo, University of Auckland

Michael Backhurst, Auckland Council

Michael Brooks, New Zealand Feed Manufacturers Association

Michael Maahs, Waiheke Resources Trust

Michael Macbeda, Waimate District Council

Michael Hall, University of Canterbury

Michael Quintern, Mynoke

Michaela Coleman, MSD

Michal Garvey, Foodprint

Michelle Blau, Fair Food

Michelle Gibbs, MPI

Mike Beare, Plant and Food Research

Mike Perry, DOC

Milana Blakemore, MPI

Millie Porter, Countdown

Miranda Mirosa, University of Otago

Mohan Dutta, Massey University

Molly Chapman, Fight Food Waste Cooperative Research Centre (Australia)

Monisha Wylie-Kapoor, Auckland Council

Na Luo, Dongbei University of Finance and Economics

Nadine Wakim, Auckland Council

Natalie Exeter, Nourish App

Neil Birrell, University of Auckland

Neill Ballantyne, MSD

Nic Turner, Mainstream Green

Nick Hanson, NZ Pork

Nick Lanham, Central Otago District Council

Nick Loosley, Everybody Eats

Nick Smith, Riddet Institute

Nicky Solomon, Hawke's Bay Business Hub

Nicole Banks, Tauranga City Council

Nigel French, Massey University

Nigel Davenport, Venture Timaru

Nitha Palakshappa, Massey University

Olga Pantos, ESR

Olivia Ogilvie, Opo Bio

Olivia Sutton, Supie

Parul Sood, Auckland Council

Patrick Morel, Massey University

Paul Bennett, Scion

Paul Johnstone, Plant and Food Research

Petelo Esekielu, Auckland Council

Peter Cressey, ESR

Phil Bremer, University of Otago

Phil Grainger, Venerdi

Philippa Hawthorne, MPI

Phillipa Hunt, Satisfy Food Rescue

Qinhua Shen, MPI

Racheal Bryant, Lincoln University

Raewyn Bleakley, Food and Grocery Council

Ray O'Brien, University of Otago

Rea Kenkel, Healthy Families Waitākere

Rebecca Culver, Just Zilch

Rebecca Doonan, MPI

Rebekah Graham, Independent researcher

Regina Wypych, Beef and Lamb

Renwick Dobson, University of Canterbury

Ricardo Bello-Mendoza, University of Canterbury

Richard Love, Massey University

Richard O'Driscoll, NIWA

Rob Tinholt, Watercare

Roderick Boys, MfE

Roger Cook, MPI

Roger Hurst, Plant and Food Research

Rupinder Brar, BD Enviro

Sally Fraser, Waipā District Council

Sam Beaumont, KiwiHarvest

Sam Buckle, MfE

Sam Oakdon, Stop Food Waste Australia

Sara Mustafa, University of Auckland

Sara Smeath, CiRCLR

Sarah Crisford, The Warehouse Group

Sarah Gell, Dunedin City Council

Sarah Grant, Magic Beans

Sarah Knight, University of Auckland

Sarah Pennell, Foodbank (Australia)

Sarah Pritchett, WasteMINZ

Sarah Reader, MPI

Sean Connelly, University of Otago

Serena Curtis, MSD

Sharon McIver, Our Daily Waste

Shaun Lewis, MfE

Shawn Gardner, Enspire

Shawn Shepherd, ReFED (US)

Sheila Skeaff, University of Otago

Sheree Kearney, Whakatane District Council

Sheryl Ching, MoE

Simon Lipscombe, Compass Group

Simon Lockrey, Fight Food Waste Cooperative Research Centre (Australia)

Sonya Cameron, Kore Hiakai Zero Hunger Collective

Sophie Mander, Queenstown Lakes District Council

Sophie Percy, New Zealand Food Network

Spring Humphries, EnviroWaste

Stef Van Meer, Satisfy Food Rescue

Stephanie Hill, MfE

Stephen Trebilco, MBIE

Stewart Collie, AgResearch

Stewart Donaldson, IRD

Subh Ganguly, University of Auckland

Sunshine Yates, Sunshine Yates Consulting

Susanna Barris, MPI

Susie Robertson, Kaibosh

Susie Trinh, Auckland Council

Taima Moeke-Pickering, Laurentian University

Talia Hicks, AgResearch

Tane Leong, MfE

Tava Olsen, University of Melbourne

Te Kawa Robb, Para Kore

Tessa Brothersen, WasteMINZ

Tessa Vincent, Climate Champions (UK)

Thao Le, Auckland University of Technology

Tim Garlick, MSD

Timofey Shalpegin, University of Auckland

Toine Timmermans, Wageningen University & Research (Netherlands)

Tracey McIntosh, MSD

Tracey Pirini, Fair Food

Tric Malcolm, Kore Hiakai Zero Hunger Collective

Trixie Croad, University of Otago

Tyler Northern, MfE

Ulrich Kornmueller, Bioenergy Association

Valerie Bianchi, Waikato Regional Council

Veronica Shale, Zero Food Waste Aotearoa

Vicki Burggraaf, AgResearch

Victoria Egli, University of Auckland

Wallis Greenslade, MfE

Wayne Langford, Meat the Need

Wender Martins, University of Auckland

Wendy Zhou, Perfectly Imperfect

Zoe Mack, Climate Change Commission

Contents

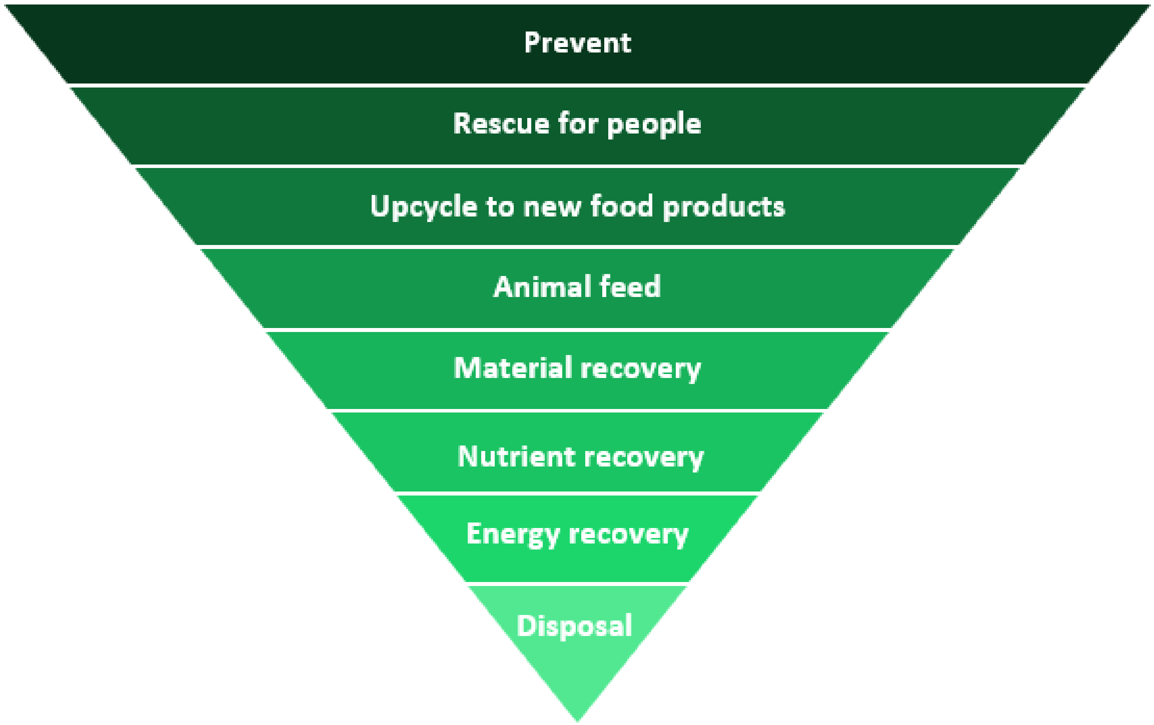
Summary and recommendations

Executive Summary

Introduction

Food loss (which occurs before the food reaches the shelf) and food waste (which occurs afterwards) are detrimental to the environment and have economic consequences for both food producers and consumers. A key challenge in New Zealand's efforts to reduce food loss and waste is that the levers for change – policies, regulations, funds, standards, and the like – sit across different parts of government. The creates a co-ordination problem, not only because there are so many pieces to the food waste puzzle, but also because the pieces are tied to different agencies.

The food waste recovery hierarchy provides guidance in prioritising different approaches to deal with food loss and waste. Solutions near the top of the hierarchy, which keep food directly or indirectly available for eating, are preferred to solutions near the bottom, such as disposal, which are to be avoided. A range of different food recovery hierarchies exist, reflecting a range of priorities and strategies among different countries, researchers, and organisations. While food waste prevention and food rescue are uniformly prioritised across these hierarchies, the tiers covered in this report – upcycling, animal feed, material recovery, nutrient recovery, energy recovery, and disposal – are often varied in their sequencing, grouping, and description. We use the following simple hierarchy:



Our last report covered food rescue. In this, our third report on food waste, the focus is on the ways that food waste that is not fit for direct human consumption can be used as a resource from which to gain value. That value can take many forms: new, commercially viable, food products; traditional and novel animal feeds; nutrients in our soils; and energy that could contribute to our transition away from fossil fuels. Each of these ways to capture value has unique considerations and are location and context dependent, which we explore in detail.

Upcycling

Upcycling is the process of turning food loss and/or food waste into new products. While recognising that this practice has been used in domestic kitchens for centuries, and should be encouraged in modern households, we limit our discussion to upcycling undertaken by businesses, meaning that the end product must be commercially viable. There is reason to believe that New Zealand consumers are open to upcycled products, but appropriate research both in product development and in marketing will be necessary to identify niches for new upcycled foods.

One of the biggest barriers to widespread upcycling is a lack of mechanisms to connect producers of food loss and waste with potential manufacturers of upcycled food products. Support to forge these relationships, as well as to help manufacturers of these products with the costs of innovation, would be useful.

Converting food loss and waste to animal feed

Globally, significant land use and emissions are associated with the production of crops for animal feed, and so replacing some of these with products derived from food loss and waste, such as grape marc, would have positive environmental impacts. In New Zealand, up to a quarter of agricultural animal feed already derives from food loss and waste, but we still grow and import products for feeding animals, creating an opportunity to expand the use of an otherwise wasted resource.

The barriers to incorporating more food loss and waste into animal feeds are largely technical. Agricultural animal feed must support both the productivity and the welfare of the animal, and there is variation in how different sorts of food loss and waste perform in these domains. There are additional biosecurity considerations – and regulations – that limit when meat can be used in animal feed, to avoid inadvertent transmission of disease.

As well as technical barriers, there also logistical challenges. Waste needs to be transported for processing and distribution to where it is needed. Food loss and waste is also more variable than purpose-grown crops, in terms of availability, volume and composition, which makes planning more difficult.

Using food loss and waste in emerging parts of the food system

Food loss and waste can be used in two emerging parts of the food system: cellular agriculture and insect bioconversion. Cellular agriculture aims to synthesise protein products that are functionally identical to natural products like meat and dairy. Scaffolds and growth media are required for these products, and some kinds of food waste have potential in these roles. Insect bioconversion involves feeding food loss and waste to insects and using the insects themselves, or their larvae, as animal feed or to feed people (although the latter faces challenges of social acceptability in Aotearoa). Frass, waste excreted by the larvae, from these processes can also be used in nutrient recovery, discussed below.

Material recovery

By-products from food production can also be used to make non-food products. These include traditional products such as wool and leather and more recent advances, such as extracting collagen from animal by-products for use in cosmetics and beauty products. New Zealand has developing expertise in this field and the potential to grow further.

Nutrient recovery

Food loss and waste hold valuable nutrients, which can be extracted to improve soil health and condition and regenerate the environment. Using food loss and waste in this way has the potential to reduce our reliance on imported fertilisers, providing additional environmental and economic benefits. To do so in a commercial environment requires consistency in supply and specifications of the waste-derived product to at least match those of synthetic fertiliser.

Composting and vermicomposting dominate this space. Both break down organic waste to produce a material that can be applied to soil. With composting, this process is driven by microbial activity, while vermicomposting relies on worms alongside microbes. As well as industrial scale facilities, both composting and vermicomposting can operate at local scale, which provides additional social benefits.

Another way to recover nutrients for soils is to apply digestate from anaerobic digestion processes, which is discussed in the context of energy recovery. This is not yet widespread in Aotearoa, but is likely to grow.

Energy recovery

Despite already generating a high proportion of our electricity from renewable sources, New Zealand faces challenges in dry years when hydro lake levels are low, and we will need to increase our supply of electricity as we transition transport and other key sectors to electricity from other energy sources. Using food loss and waste to generate energy has some potential in this arena.

A range of processes exist for capturing energy from waste, but most are poorly suited to food waste feedstocks. Anaerobic digestion is an exception. In anaerobic digestion facilities, microbes break down waste to produce a gas which can provide heat, used to generate electricity, or replace virgin natural gas.

Conclusion

There is a tension between capturing value in the near term and avoiding food loss and waste in the longer term.

This tension arises from the fact that some ways to capture value require investment in infrastructure, and realising the economic return on that investment will require a secure supply of feedstock in the longer term, running the risk of incentivising wasteful practices. But this tension is resolvable, and our recommendations are designed to ensure we do not lock in less preferred approaches to our food waste challenge.

There are important unknowns and limitations… but we can still make progress now.

There is a lot we don’t know about our food loss and waste in New Zealand, including, crucially, what’s in it and how much we have. This presents a challenge to taking a systematic approach to capturing value, because the specific qualities of the food waste available will determine the purposes for which it is suited. The Ministry for the Environment has commissioned research from the University of Otago which will contribute to filling this gap. What is still missing is a comparative life-cycle analysis of the different options set in our unique local context.

In the meantime, there are countless examples at all scales from multinational corporations to small local startups demonstrating existing opportunities to capture value from our food loss and waste. Strategic support would make a real difference, and our recommendations highlight where some of these opportunities are.

The problem is big enough for multiple solutions at different scales.

There are many instances where different processes can work in a complementary fashion to maximise the value extracted from wasted food. In addition to inter-linking technological processes, we can also combine their products, playing to their relative strengths. Some of these interrelationships are captured in the summary figure below, highlighting opportunities and challenges at every stage of the pathway from waste to valuable product. Importantly, one size does not fit all and any regulatory framework needs to allow for the specific constraints and opportunities of local solutions to food loss and waste.

Recommendations

Recommendations on food waste are being made under five themes. Each report in the series will contain recommendations under these themes. The recommendations relating to this report are summarised below.

Systems problem, systems solutions	C 1: Take a nationally consistent approach to food loss and waste valorisation that is informed by the food recovery hierarchy and lifecycle assessment approach.[a] C 2: Lead by example on food loss and waste valorisation and utilisation of food waste-derived products.
Measure and monitor	C 3: Understand the scale of New Zealand's food loss and waste problem with greater granularity so that valorisation opportunities can be identified.
Prevent food waste at source	*There are no recommendations under this theme. Source prevention of food loss and waste will be covered in a future report.*
Save good food for people	C 4: Foster the growth of New Zealand's upcycled food sector, prioritising sustainability, nutrition, and whole food utilisation.
Capture value from unavoidable food loss and waste	C 5: Work to replace purpose-produced and imported animal feed ingredients with food loss and waste, particularly utilising food system by-products and post-consumer food waste, without compromising feed safety and animal nutrition. C 6: Support material recovery efforts for food loss and waste streams that are inedible and can't readily be prevented at source. C 7: Ensure that processes and pathways are in place to enable nutrients from unprevented food loss and waste to be safely returned to the environment via productive land, parks, and gardens, aligning with the Ministry for the Environment's *Te rautaki para | Waste strategy*. C 8: Explore the potential for solutions to food loss and waste to supplement natural gas supplies. C 9: Explore the merits of banning food loss and waste from landfill. C 10: Halve our total food loss and waste by 2030 (as per SDG 12.3) and set a zero food loss and waste target.

Each recommendation contains detailed sub-recommendations. For each sub-recommendation, we provide an indicative timeframe for implementation.

[a] NB: The recommendations for each report will be assigned a letter code so that they can be distinguished when brought together in the summary report. Recommendations from the present report are prefixed with a 'C' to indicate 'Capture.'

- **Next 12 months** – These recommendations should be considered for immediate implementation, to capture existing momentum and make the most of low-hanging fruit.
- **By 2026** – These recommendations might take a little longer to implement but should be pursued in the near term to keep Aotearoa on track to a future without food waste.
- **By 2030** – The United Nations Sustainable Development Goal (SDG) 12.3 calls for per capita retail and household waste to be halved by 2030, and for food loss to be reduced elsewhere in the food system. These recommendations should be considered for implementation by 2030, in pursuit of SDG 12.3.

The recommendations from all our food waste reports will be brought together in a summary report, where we will also introduce additional recommendations as required to capture opportunities at the interface between workstreams, as well as overall systems solutions.

Theme 1: Systems problem, systems solutions

Combatting food waste requires people throughout the food system and in the waste management sector to work together on actions. Clear direction, food waste reduction targets, and coordination mechanisms will enable and accelerate change across the system.

Capturing value recommendations for theme 1

C 1: Take a nationally consistent approach to food waste valorisation that is informed by the food recovery hierarchy and lifecycle assessment approach.

Next 12 months	By 2026	By 2030
a) Develop and adopt a food recovery hierarchy for New Zealand. **b)** Ensure food loss and waste valorisation policies and investments are consistent with the food recovery hierarchy. **c)** Ensure collaboration between agencies with mandates relating to combatting food waste, supporting a shift towards a circular economy, and the development and utilisation of valorised food loss and waste.	**d)** Support the development of publicly accessible resources to facilitate a lifecycle assessment approach to exploring food loss and waste valorisation options, with a particular focus on emissions.	

Considerations

C1.a We strongly support the Ministry for the Environment's (MfE) drive to reduce food waste in New Zealand. A food recovery hierarchy that is recognised across government and referred to in all government food waste policy and factored into investment decisions would enable faster progress to be made. The recent 'food waste scale' published by the US Environmental Protection Agency is a good example of an updated hierarchy that reflects advances in technology and a variety of pathways. With territorial authorities playing a crucial role in combatting food waste, recommendation C1.a should be generic for all of New Zealand but provide additional guidance on how it can be adapted for regional contexts by local government.

Implementation of C1.b is particularly relevant to food loss and waste valorisation solutions that require large amounts of capital expenditure and/or have minimum food loss and waste input requirements to be viable.

As an example, recommendation C1.c could involve collaboration between MfE and Ministry of Primary Industries (MPI) on food waste-to-animal feed and soil amendment policy, with MfE responsible for waste management and MPI responsible for agriculture and biosecurity. To facilitate this collaboration, there is scope to better define ministerial roles in enacting actions around waste in the Emissions Reductions Plan (Chapter 15).

Recommendation C1.d could draw inspiration from the New South Wales Environment Protection Agency's resources on the emissions impacts of food waste recovery technologies. To build understanding and confidence in the resources, assumptions and key sources should be clearly articulated.

C 2: Lead by example on food waste valorisation and utilisation of food loss and waste-derived products.

Next 12 months	By 2026	By 2030
a) Use government purchasing power (i.e. procurement) at the central and local level to increase the uptake of food waste valorisation products (e.g. compost, upcycled food) to help transform the supply market and lead by example.	**b)** Require all government agencies and public institutions to have systems in place to divert food waste from landfill and look for opportunities to prevent food waste.	
Considerations Recommendation C2.b could, for example, be implemented as part of school lunch programmes.		

Theme 2: Measure and monitor

We need to know more about food loss and waste in Aotearoa. Not just how much food is lost and wasted, but where in the food system that loss and waste occurs, current diversion practices, dominant food waste types, and geographic variation in waste volumes. Good data is crucial to articulating the challenge, galvanising action, designing well-targeted interventions, and monitoring progress.

Capturing value recommendations for theme 2

C 3: Understand the scale of New Zealand's food loss and waste problem with greater granularity so that valorisation opportunities can be identified.

Next 12 months	By 2026	By 2030
a) Gather more granular data on food waste throughout the food supply chain, leveraging the MfE food waste baseline calculation work. See also R2.c from *Food rescue in 2022: Where to from here?*	**b)** Develop food loss and waste questions to include in the 2027 Agricultural Production Census, including primary producer estimates of food waste volumes and how food waste is utilised and/or managed. **c)** Commission independent research to understand food waste volumes and how food waste is utilised and/or managed in the: food and beverage processing; retail sector; and food service sector. **d)** Investigate the best method for measuring changes in household food waste over time and implement. **e)** Support the development of publicly accessible data and resources to facilitate a lifecycle assessment approach to exploring food loss and waste valorisation options, with a particular focus on emissions.	**f)** Gather up-to-date data about food loss and waste volumes and utilisation throughout the food supply chain and use this data to evaluate the success of food loss and waste valorisation interventions. Are they working? See also C3.b–d. **g)** Consider the adoption of *ISO/WD 20001* once finalised, which provides a generic but standardised tool for measuring and reducing food loss and waste across the supply chain.

Considerations

We understand that the MfE food waste baseline calculation is going to be based on existing data, such as industry reports and published papers, as well as interviews and survey responses. Recommendation C3 would be a first step in quantifying the emissions impacts of food loss and waste, as advised by the Climate Change

Commission. Recommendations C3.b–d are intended to increase the available primary data, with which the baseline could be updated. For recommendations C3.b–d, food loss and waste should be differentiated by whether it is surplus food or a by-product, post-consumer food waste, or other food waste type. Handling, storage, transport, and distribution throughout the food supply chain should also be considered.

Recommendation C3.d could be coupled with a household survey that explores engagement with home- and community-based food waste management solutions, self-reported reasons for wasting food, and self-reported food waste awareness.

Recommendation C3.e would include data collected through recommendations C3.b–d as well as other data relevant to life cycle assessment.

Theme 3: Prevent food waste at source

Preventing food loss and waste at the source has scope to deliver the greatest environmental, social, and economic benefits throughout the food system, and everyone has a role to play. A high degree of connectivity means that New Zealanders can contribute to food loss and waste prevention not just at their stage of the food supply chain, but throughout the system.

Capturing value recommendations for theme 3

There are no recommendations under theme 3 from this report. Source prevention of food loss and waste will be covered in the next report.

Theme 4: Save good food for people

Good food is not a waste stream to be managed – it is a resource for nourishing people. Surplus food, imperfect but nutritious produce, and edible by-products are examples of food, not food waste. Resources, systems, and enabling conditions that promote food rescue and upcycling are crucial to ensuring edible food is never treated as waste.

Capturing value recommendations for theme 4

C 4: Foster the growth of New Zealand's upcycled food sector, prioritising sustainability, nutrition, and whole food utilisation.

Next 12 months	By 2026	By 2030
a) Consider targeting support for innovation in the food sector through upcycling via the Food and Beverage Industry Transformation Plan or alternative mechanism. **b)** Identify mechanisms to prioritise nutrition outcomes alongside outcomes in the development of New Zealand's upcycling sector. **c)** Undertake or commission work to identify opportunities for upcycled product development in Aotearoa.	**d)** Work with manufacturers to adopt an upcycling certification scheme so that the term 'upcycled' can be trusted by consumers to indicate a product is combatting food waste and providing environmental benefit.	**e)** Have an established network linking food producers and manufacturers with unused by-products with processors that upcycle these products, replacing use of virgin materials and reflecting upcycling international best practice.

Considerations

Recommendation C4.c could build on Central Otago District Council's exploration of upcycling opportunities for fruit producers in the region and could take methodological inspiration from the Plant and Food Research (PFR)-led project mapping animal feed opportunities as well as employing various specialised consumer research techniques to ensure marketability.

Recommendation C4.d could be pursued through the Fair Trading Act, Food Standards Australia New Zealand food claims regulations, the Upcycled Food Association's certification, and/or sustainability claims work being undertaken by Codex Alimentarius. If an upcycling certification or similar is adopted, future work could explore the utility of expanding it beyond human food products (e.g. to animal feed and materials).

Theme 5: Capture value from unavoidable food loss and waste

There will always be some unavoidable waste in our food system, which must be managed to capture value in alignment with circular economy thinking and the food recovery hierarchy. Diversion to animal feed and workable approaches to material, nutrient, and energy recovery from food waste will ensure there are decent end-of-life options for unavoidable food waste. Landfilling food waste has no place in our waste management future.

Capturing value recommendations for theme 5

C 5: Work to replace purpose-produced and imported animal feed ingredients with food loss and waste, particularly utilising food system by-products and post-consumer food waste, without compromising feed safety and animal nutrition.

Next 12 months	By 2026	By 2030
a) Support existing efforts to develop a picture of the food loss and waste-to-animal feed opportunity in Aotearoa. **b)** As part of a), evaluate the degree of compliance with food waste-to-animal feed regulations, particularly post-consumer food waste feeding practices.	**c)** Clarify the regulatory status of insect bioconversion as a process for converting food waste to animal feed, considering a wide variety of vegetal and meat-containing waste streams. See also C5.d.	**d)** Evaluate processing techniques that can render food waste streams microbiologically safe for animal consumption, looking beyond heat treatment and giving consideration to the risk of prions.

Considerations

Efforts towards C5.a have already begun (e.g. PFR-led project, University of Canterbury research). This work could be built on and expanded, including an exploration of food waste utilisation in cellular agriculture.

Recommendation C5.c could also cover non-food waste streams such as biosolids and manure and could also cover insect bioconversion for human food. This work could draw on the European Food Safety Authority's 2015 risk profile related to production and consumption of insects as food and feed and more recent literature. Recommendation C5.c could take place within a broader programme of work related to recommendation C5.d.

Findings produced from recommendation C5.d could be used to inform a review of the regulations governing animal feed in Aotearoa, such as the *Biosecurity (Ruminant Protein) Regulations 1999* and the *Biosecurity (Meat and Food Waste for Pigs) Regulations 2005*.

C 6: Support material recovery efforts for food waste streams that are inedible and can't readily be prevented at source.

Next 12 months	By 2026	By 2030
a) Support material recovery research and development collaborations between industry and researchers, e.g. the Bioresource Processing Alliance.	**b)** Ensure that any biobased products and packaging produced through material recovery efforts are developed in alignment with guidance from key government stakeholders like MfE, industry stakeholders like New Zealand Composters, and relevant international standards.	
Considerations Recommendations C6.a and C6.b could be mediated through the Bioresource Processing Alliance (BPA) and Sustainable Food and Fibre Futures (SFF Futures). At time of writing, relevant guidance for recommendation C6.b included MfE's position statement on compostable products and the New Zealand Composters' position statement on compostable packaging; relevant documents will change over time. Implementing recommendation C6.b will help facilitate nutrient recovery efforts.		

C 7: Ensure that processes and pathways are in place to enable nutrients from unprevented food loss and waste to be safely returned to the environment via productive land, parks, and gardens, aligning with MfE's *Te rautaki para|Waste strategy*.

Next 12 months	By 2026	By 2030
a) Support existing work to develop and implement guidelines for the beneficial use of organic materials on productive land. This could include: **i.** ensuring that voluntary standards are adopting best practice from overseas before mandating locally; **ii.** supporting regular updates, including future expansion of scope (e.g. to include	**d)** Commission independent research to evaluate the growth/productivity benefits of different food waste-derived soil amendments and biofertilisers. Soil amendments should be compared against one another and against synthetic fertiliser, in the New Zealand context, building on international insights.	**h)** Design an evaluation of diversion and contamination rates from kerbside food waste collection services, and where rollout is well established, implement the evaluation and use insights to inform continuous improvement. **i)** Evaluate key sources of macro- and micro-contaminants in nutrient recovery products and continuously work to reduce their introduction through feedstocks.

insect frass, a wider range of contaminants, applications beyond productive land, te ao Māori insights and considerations); **iii.** supporting the development of industry-led technical guidelines; **iv.** clarifying the relationship between the organic materials guidelines and synthetic fertiliser regulations; **v.** supporting the development of the nutrient recovery workforce, building the people skills required to meet the guidelines; and **vi.** exploring the need for complementary efforts to manage the inputs to nutrient recovery processes (see C7.g). **b)** Embrace social procurement principles and value place-based solutions when developing food waste collection and processing. **c)** Continue to support home-based nutrient recovery (e.g. via home compost bins, worm farms, and bokashi bins).	**e)** Seek independent review of industry-led guidelines for digestate production and application to land. **f)** Review and update compost standard (*NZS 4454:2005*) to reflect different waste streams, with potential to make compost standards/grading mandatory. **g)** Explore a nitrogen (N) cap for non-synthetic sources of N.	Mechanisms for contaminant reduction could include: **i.** education and communication campaigns; **ii.** penalties for introduction of macro-contaminants; **iii.** product regulations or bans (e.g. relating to compostable products, use of plastic in tea bags, herbicides).

Considerations

Recommendation C7.a relates to New Zealand's voluntary compost standard in Aotearoa (*NZS 4454*), the *Organic Products Bill*, and the Hua Parakore verification scheme. Relevant agencies include MfE and MPI, as well as territorial authorities. Contaminants that could be considered under C7.a.ii include microplastics, per- and poly-fluoroalkyl substances (PFAS), and herbicides.

Recommendation C7.b could be linked to wider community resilience, community building, and sustainability education initiatives. It could be implemented through initiatives such as reserving a set proportion of households and/or businesses for community-based providers, reserving a set proportion of food waste for community-based providers, and/or requiring industrial providers to work with community partners. C7.d could include ploughing unharvested food back into soil, or this could be the subject of a separate piece of research. The findings from recommendation C7.e could support future lifecycle assessment work looking at the lifecycle impacts (including emissions) of nutrient recovery solutions, factoring in the impacts of potential synthetic fertiliser displacing. The results could also be used to build end market confidence in soil amendments and provide an evidence base for effective integration into agricultural systems. Aspects of the New Zealand context of relevance to this work include soil types, agricultural systems, and soil amendment (and synthetic fertiliser) application practices, regulations, and guidelines.

C 8: Explore the potential for solutions to unprevented food loss and waste to supplement natural gas supplies.

Next 12 months	By 2026	By 2030
a) Develop a guide for investment in infrastructure, which sets out a position on different technology types and where investment/efforts should be focused.	**b)** Enable energy recovery from food waste to displace virgin natural gas.	
Considerations Recommendation C8.a would consider the viability and implications of all sources of feedstock including food. The guide may need periodic updating as new technologies emerge or existing technologies improve. Successful implementation of recommendation C8.b would require biogas derived from food waste streams would have to be the same price, or cheaper, than virgin natural gas. Industry estimates suggest that food waste derived biogas could displace 1.5% of virgin natural gas, or 0.3% of our total energy consumption.		

C 9: Explore the merits of banning food loss and waste from landfill

Next 12 months	By 2026	By 2030
a) Clearly signal the intention to ban food loss and waste from landfill by 2030.	**b)** Scope options for the implementation of a food waste disposal ban, including considerations to avoid food waste dumping, options for food waste management in the face of unexpected events, the level at which the ban should be enforced (e.g. waste producer and/or waste processor), and the mechanism of enforcement. **c)** Make it easy for food waste 'owners' to find alternatives to disposal. This could include: **i.** Mapping out available valorisation options at a variety of scales (see C3); and **ii.** Support for food waste brokering providers and platforms.	**d)** Evaluate New Zealand's readiness to implement a ban on food loss and waste from landfill.

Considerations

Effective implementation of recommendation C9 relies of the development of feasible alternatives, as covered in this report and *Food rescue in 2022: Where to from here?*, as well as food waste prevention interventions.

MfE has already signalled the intention to ban organics to landfill by 2030 (in the Emissions Reduction Plan). Recommendation C9.a could be taken further; our recommendation is limited to food waste given the project's scope.

The Emissions Reduction Plan signalled an intention to require landfills to have gas capture systems in place by 2026.

Implementing C9.c.i could expand efforts at Manaaki Whenua to survey and map out community-scale composting clubs and social enterprises, or work done on MfE's 2021 Infrastructure Stocktake, to include upcycling, animal feed, and material recovery businesses.

C 10: Halve our total food loss and waste by 2030 (as per SDG 12.3) and set a zero food loss and waste target

Next 12 months	By 2026	By 2030
a) Clearly signal the intention to halve our total food loss and waste (as per SDG 12.3).	**b)** Develop a strategy to achieve halving of food loss and waste (as per SDG 12.3) by 2030. This could include adopting recommendations C1-C9, as well as: **i.** Undertaking regular scans for new opportunities to capture value; **ii.** Engaging with stakeholders across the supply chain and consumers to identify remaining barriers to reducing waste; and **iii.** Considering large scale interventions targeting public attitudes and knowledge around food waste as a potential resource. **c)** Commission or undertake work to establish a realistic timeline for a zero food loss and waste target.	**d)** Evaluate whether New Zealand has halved its total food loss and waste (as per SDG 12.3). **e)** Commit to a zero food loss and waste target.
Considerations Recommendation C10.b could be informed by other countries' strategies, but will need to be suitable for our context.		

1. Capturing value in the context of the food recovery hierarchy

This report is the third in our series addressing food loss and waste (FLW) in Aotearoa New Zealand. It explores opportunities and pathways to capture value from unprevented FLW. This work builds on several resources produced by our office. In our first report on FLW,[1] we introduced and outlined the problem, both globally and locally. In our second report,[2] we highlighted the role of New Zealand's food rescue sector, providing recommendations on how to support this important work. In addition, we created a web resource[3] designed to help individuals and communities engage with, and valorise, household food waste.

1.1 We are not using lost or wasted food to its full potential

Globally, an estimated 40% of food produced each year goes to waste.[4] In New Zealand, hundreds of thousands, or even millions of tonnes, of food are wasted annually[1]. The full extent of food waste across our food system is unknown, but the Ministry for the Environment (MfE) has commissioned a baseline study that will provide the first overall estimate of FLW in New Zealand.[5]

Globally, an estimated 40% of food produced each year goes to waste.

As we've highlighted in our report *Food waste: A global and local problem*, we know that lost or wasted food is only sometimes used to its full potential in Aotearoa.[1] Often it is landfilled,[6] left on trees, vines, or in fields,[7,8] buried in pits,[8] or held in methanogenic stockpiles.[9] Even when efforts are made to capture value from food waste, that value – in environmental, social, and economic terms – is not always maximised.[10] For example, food and beverage businesses that have approached the Bioresource Processing Alliance (BPA) together produce 350,000 tonnes of food by-products each year that could potentially have been processed to new food products or nutraceuticals but is currently spread on land or used as animal feed or fertilisers, if not sent to landfill.[11]

1.2 We are updating our food waste terminology

MfE recently published the New Zealand Government's definitions of FLW to describe food wasted across our food supply chain,[12] aligning with international definitions[13,14] and a helpful step in supporting initiatives to measure FLW, improve household kerbside collections, and support the emissions reduction plan.[15] MfE's overarching definition for wasted food incorporates both food loss and food waste, reflecting where food leaves the supply chain (see figure 1). In earlier work,[1–3,16] we have used the term 'food waste' as a catch-all phrase, which incorporated both wasted and lost foods as defined by MfE. Here, we adopt MfE's new nomenclature[12] for consistency: FLW. Put simply, food loss occurs before the food reaches the shelf; food waste occurs afterwards.

Put simply, food loss occurs before the food reaches the shelf; food waste occurs afterwards.

Figure 1: Food loss and food waste within the food supply chain, as per MfE's definition.[12] MfE defines FLW as: "Imported or domestically produced food and drink, including inedible parts, which leave the food supply chain from the point that crops and livestock are ready for harvest or slaughter onwards to the point of consumption, to be recycled, recovered, or disposed of in Aotearoa."[12] Image credit: MfE.

1.3 Getting more from our food loss and waste: the food recovery hierarchy as a guiding framework…

Food that is currently disposed of or not used to its full potential can be valorised through a wide variety of processes.[17] As described in *Food waste: A global and local problem*, the types of solutions available to combat food waste are often prioritised according to the food recovery hierarchy, a modified version of the standard waste hierarchy that prioritises food waste solutions according to their ability to deliver on environmental, economic, and social outcomes.[17–19] Figure 2 illustrates the hierarchy that we use in this report and section 1.4 discusses other similar hierarchies used globally.

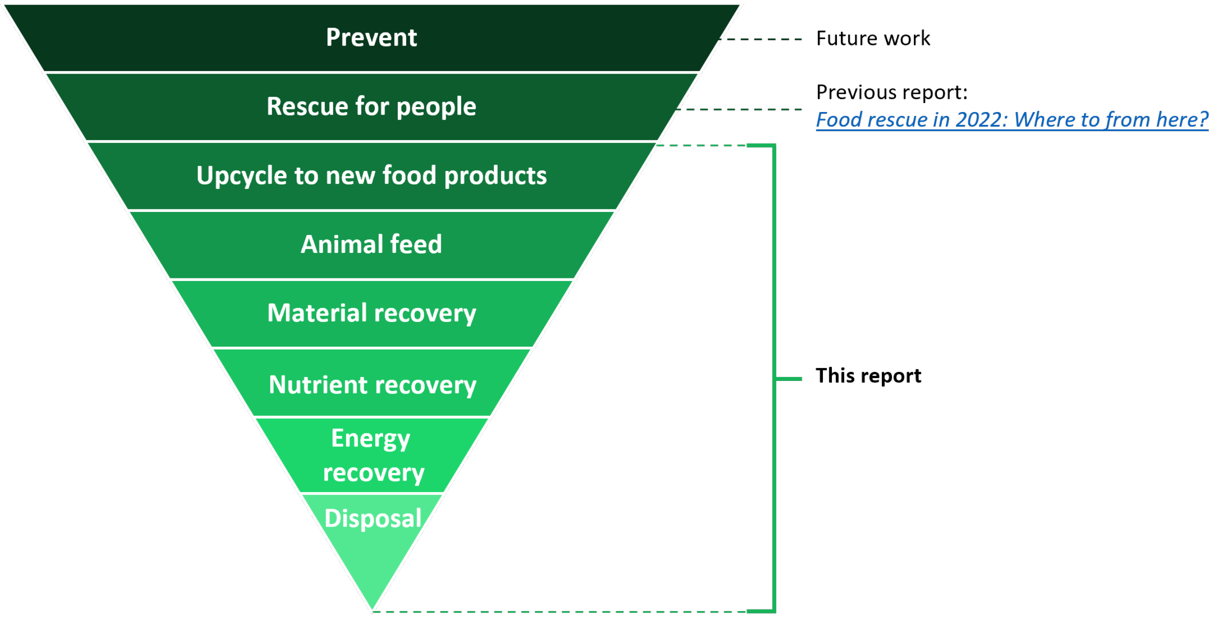


Figure 2: The food recovery hierarchy, modified from Teigiserova et al. and Moshtaghia et al.[17,18] The food recovery hierarchy is a modified version of the waste management hierarchy, which provides a framework for reducing waste by promoting avoidance. Prevention sits at the top of the hierarchy and will be addressed in later work on FLW, and our previous report covered food rescue.

Much of the food that is lost in Aotearoa comprises by-products from food production, processing, and manufacturing, and components of food that cannot readily be eaten[1,6], so while we can aspire to increasing success at source prevention, there will always be some food waste that is not avoided.

Upcycling, animal feed, material recovery, nutrient recovery, and energy recovery offer solutions to capture value from this food waste and are defined below, as is disposal.[17]

- Upcycling (see section 3.1) – Keeping food at risk of going to waste in the human food supply chain by creating new food products from by-products or unmarketable foods such as stale bread, offcuts, incorrectly labelled items, or damaged produce.
- Animal feed (see section 3.2) – Using food at risk of going to waste as animal feed. Some food waste streams are safe, palatable, and digestible to animals with minimal modification, while other streams could be processed through a range of techniques such as heat treating, drying, ensiling, blending, bioconversion, and beyond. These can displace imported sources of animal feed with high environmental impacts, such as palm kernel expeller.
- Material recovery (see section 3.3) – The use of inedible or discarded components of food to produce useful materials, such as fibre-based packaging.
- Nutrient recovery (see section 4.3) – Capturing nutrients from food waste so that they can be used in agricultural systems, gardens, and to regenerate natural environments.
- Energy recovery (see section 4.4) – Capturing the energy held in food waste so that it can be used to generate heat or electricity, or as a fuel or natural gas equivalent.
- Disposal (see section 5) – Throwing food away.

These tiers can be divided into those which process edible food for human consumption (upcycling) and those which treat inedible food (all others).[17] Importantly, this distinction is currently only a theoretical one. While edible food is upcycled (and, like all food processing techniques, is subject food safety regulations[20–22]), edible food waste also ends up in lower tiers of the hierarchy. Ideally, the 'middle' tiers of the hierarchy – from animal feed to energy recovery (see figure 2) – should only capture inedible food waste, including naturally inedible components (e.g. coconut husks or fruit stones), processing waste residues (e.g. pomace or grape marc), and foods that have become inedible due to natural causes or mismanagement (e.g. food not stored at correct temperatures).[17]

According to MfE,[12] any destination where food is not consumed by humans or animals (i.e. material recycling through to disposal, see figure 1) is considered a loss or waste. This framing is designed to prioritise waste reduction first, but acknowledges that recovering material, nutrient, and energy from wasted food can deliver high-value benefits and products.[12]

1.4 …but the hierarchy isn't set in stone

A range of food recovery hierarchies exist,[17–19,23–30] reflecting a range of priorities and strategies among different countries, researchers, and organisations. While food waste prevention and food rescue are uniformly prioritised across these hierarchies, the tiers covered in this report – upcycling, animal feed, material recovery, nutrient recovery, energy recovery, and disposal – are often varied in their sequencing, grouping, and description. The most common divergence among hierarchies is the prioritisation of nutrient and energy recovery. For example, hierarchies adopted by Australia[30] and the EU[24] prioritise nutrient recovery over energy recovery, whereas countries like Canada[29] give equal weighting to these approaches, combining them under the banner of 'recycling'. The US formerly gave priority to energy recovery[23], but recently updated its 'food waste scale' to reflect technology-specific pathways for food waste management that emphasise the importance of nutrient recovery.[31] New Zealand doesn't have a hierarchy specific to food waste, although its generalised waste hierarchy combines composting (nutrient recovery) and anaerobic digestion (AD) (energy and nutrient recovery) under 'recycling'.[27] Given its utility and widespread international use,[30–32] we recommend that New Zealand adopts its own food recovery hierarchy to enable a clear understanding and prioritisation of actions (policy and investment) to reduce food waste, for example, by following a similar approach to the US Environmental Protection Agency's recently published food waste scale.[31] Adopting a hierarchy from elsewhere (e.g. Australia,[30] the UK,[32] or the US[31]) could overlook context-specific factors regarding New Zealand's waste streams, legislative context, end markets, and environmental priorities.

…the tiers covered in this report – upcycling, animal feed, material recovery, nutrient recovery, energy recovery, and disposal – are often varied in their sequencing, grouping, and description.

As shown in figure 2, we have placed nutrient recovery above energy recovery, and on separate tiers.[1,17] This is because many nutrients are valuable, finite resources, some of which we are already depleting, such as phosphorus and potassium, and which are often produced or extracted using environmentally harmful

… nutrients are valuable, finite resources, some of which we are already depleting, such as phosphorus and potassium, and which are often produced or extracted using environmentally harmful processes that generate substantial greenhouse gas emissions.

processes that generate substantial greenhouse gas emissions (see box 1).[17,31] In addition to major nutrients, the carbon (C) in wasted food can be applied to soil to build organic matter, store C, and improve the health of the soils we rely on to produce our food.[31] By comparison, in New Zealand, more than 80% of our electricity is already generated from renewable sources[33] – with a goal to move to 100% by 2030[34] – making the case for prioritising nutrient recovery more urgent than that for energy recovery. However, there remain viable options for energy recovery from FLW in New Zealand (see section 4.4), where biogas has the potential to displace some fossil-derived natural gas.

Box 1: The importance of nutrient recovery

Nitrogen (N), phosphorus (P), and potassium (K) are three crucial nutrients required for plant growth and health. With agricultural systems disrupting natural cycling of these nutrients, they are often depleted from soils, with synthetic fertilisers containing these nutrients (i.e. N, P, K fertilisers) being added back to the land to promote agricultural productivity. However, the way these nutrients are currently sourced is unsustainable in the long term.

- While N is abundant in the atmosphere, getting it into a solid form that can be used as fertiliser involves the energy-intensive Haber-Bosch process, through which hydrogen and N are combined at high temperature and pressure to make ammonia. The hydrogen used in this process typically comes from burning fossil fuels such that every ammonia molecule generated leads to the release of one carbon dioxide (CO_2) molecule (although more sustainable processes are being developed).[35]
- P is mostly derived from mined phosphate rock. We have an estimated 300 years' worth of P from this source remaining. In addition, phosphate rock is geographically concentrated, its mining is geopolitically fraught and has human rights concerns, and prices fluctuate dramatically.[36,37]
- K reserves are estimated to hold enough K for just 100 more years.[38]

Additionally, there is some debate about whether synthetic fertilisers offer the expected benefits to soil health or instead negatively affect the soil microbiome.[39–42] When nutrients are recovered from organic waste streams, including food waste, we can displace some of the synthetic fertiliser used in our agricultural systems, using what we already have. Our Phosphorus Future Network highlighted the importance of nutrient recovery in their 2022 report on P sustainability, stating that "a move towards a circular P economy stands to increase the resilience of … food systems."[37]

As discussed in *Food waste: A global and local problem*, the food recovery hierarchy is a useful guide, but needs to be applied with nuance and awareness of context.[1] For example, while animal feed sits higher in the hierarchy than nutrient recovery, if food waste is produced in a region with minimal animal husbandry but large amounts of land in crop production, it may be more practical, efficient, and useful to capture nutrients from food waste for use as compost than to convert it to animal feed and transport it elsewhere in the country.

> … the food recovery hierarchy is a useful guide, but needs to be applied with nuance and awareness of context.

Some food waste processing solutions sit in multiple tiers of the food recovery hierarchy.[17] For example, AD could be described as a form of energy recovery, a form of nutrient recovery (if the digestate is used as a soil amendment), or both (see section 4.4, Anaerobic digestion). In another example, some landfill operators with high levels of methane capture and utilisation frame their activities as energy recovery rather than disposal, and incineration could be described as disposal or energy recovery depending on whether the amount of heat energy produced is greater than or less than the energy inputs required to run the incinerator. Similarly, insect-based bioconversion produces both animal feed and frass, the latter of which has potential applications as a soil amendment (i.e. nutrient recovery). This report does not seek to fix a specific process to a given tier of the food recovery hierarchy – processes can sit across multiple tiers at once or move between tiers depending on how the process is carried out and how the product is used in a local context.

It's also worth noting that food waste valorisation solutions are often not mutually exclusive, with multiple processes capable of working in tandem to capture as much value as possible from food waste streams (see section 6.3).

1.5 Unpreventable food waste can be reimagined as a resource…

The food waste processing options covered in this report can help food waste shift from being seen as a waste stream to be managed to a resource from which value can be captured. Auckland Council, through consultation with mana whenua, landed on the term 'rukenga kai' to describe the potential held in food waste reimagined as a resource, where kai means food and ruke(nga) means to cast forth or cast onward.[43]

In 2021, the Infrastructure Commission found that only 35% of New Zealand's waste is recovered (across all types, not just food waste), one of the worst recovery rates in the Organisation for Economic Co-operation and Development (OECD).[44] The commission suggest this poor recovery rate is partially driven by the ineffective distribution of research recovery assets, making resource recovery inaccessible and not cost effective to many parts of the country.[44] Researchers from both academia and advocacy organisations have suggested Aotearoa is currently at a critical juncture where food waste is being reframed as a resource and investment decisions are increasingly being made to capture its value.[45,46]

> In 2021, the Infrastructure Commission found that only 35% of New Zealand's waste is recovered (across all types, not just food waste), one of the worst recovery rates in the OECD.

This historic underinvestment in food waste valorisation (and resource recovery generally)[44,47] is beginning to be addressed by current policy programmes such as *Te rautaki para | Waste strategy*[27] released by the MfE in early 2023, and has been highlighted as a key component of the *Emissions Reduction Plan*,[15] as well as being central to the Waste Minimisation Fund's (WMF) current investment signals and the Fund's strategic intention (see figure 3).[48]

1.6 …but this reframe shouldn't undercut the food recovery hierarchy

Critics caution against overinvestment in value capture solutions, highlighting that prevention is the key action in the food recovery hierarchy so should arguably receive the most resourcing,[49] and noting the risk that overinvestment in value capture infrastructure may undermine prevention efforts by serving as a distraction or even incentivising wastefulness.[47,50,51]

When describing resource recovery infrastructure generally, the Infrastructure Commission noted that waste infrastructure is relatively more rigid and long-lived than the factors dictating waste production.[44] Available volumes of food waste will change, such that current volumes of food waste should not be assumed to reflect future volumes of food waste. Indicative analysis shows potential infrastructure funding needs of approximately $2.1 to $2.6 billion and other enabling service funding needs of approximately $0.9 billion over the next 10 years.[52]

> … current volumes of food waste shouldn't be assumed to reflect future volumes of food waste.

Policy initiatives in other jurisdictions demonstrate possible options for preventing waste infrastructure lock-in. For example, the Queensland Government has published an *Energy from Waste Guideline*, which requires energy-from-waste (EfW) processors to think about how reductions in waste volumes and changing waste composition will affect their processes and products.[53] The Guideline includes a decision tree for EfW processors to ensure they are not processing waste which could be reused or recycled, and specify that EfW facilities "should not undermine future options or innovations in waste avoidance, reuse, and recycling."

> Policy initiatives in other jurisdictions demonstrate possible options for preventing waste infrastructure lock-in.

One of the WMF's strategic aims is to "shift attitudes and behaviours higher up the waste hierarchy" and another is to "accelerate system-level change,"[48] (see figure 3) a signal that MfE will strive to mitigate the risk of overinvestment in solutions that do not capture value from food waste at its highest possible tier in the food recovery hierarchy. Other jurisdictions go further, with specific food recovery hierarchies included in legislation or policy documents.[23,54] MfE has developed a waste hierarchy that is not specific to food, but signals that value-capture solutions like composting and AD are considered waste destinations that should not take precedent over prevention or repurposing of waste.[27]

Figure 3: The four high-level objectives of the Waste Minimisation Fund. Image credit: MfE[48]

1.7 Embracing the food recovery hierarchy can help the transition to a circular economy

As we've explored in our report *Food waste: A global and local problem*,[1] the food recovery hierarchy can be used as a tool for enabling circular thinking around food waste by providing and prioritising pathways for different types of food waste (e.g. edible or inedible) that enable re-use and value capture from food-derived waste streams. Transitioning away from linear systems which 'take, make, use, and waste' resources is a primary objective of a circular economy or 'circular society',[55,56] and has particular relevance to our food systems.[57] In the context of this report, capturing value from FLW reflects the circular principles of keeping products and materials in use, and with several pathways providing the chance to regenerate natural systems.[58] Addressing waste generation and management is a fundamental part of creating more circular food systems.[59]

In Aotearoa, circular thinking has deep resonance with a te ao Māori worldview, which links people and the environment through whakapapa relationships and fosters holistic, intergenerational kaitiakitanga of te taiao (the natural world). Reflecting these roots, a collaborative effort led by Māori soil scientist Teina Boasa-Dean and Project Moonshot[60] provides a re-imagined version of the doughnut economic model,[61] which places the environment at the centre and social elements along the outer ring to emphasise society's ecological foundations. Putting theory into practice, Para Kore, a Māori not-for-profit organisation, provides an example of moving towards the goal of zero waste by developing systemic solutions, advancing mana motuhake (self-determination), and strengthening whakapapa connections to Papatūānuku and Ranginui.[62]

2. New Zealand's food waste streams, the current state of value capture, and future ambitions

2.1 New Zealand's FLW takes many forms and is distributed unevenly across the country

In our first report overviewing the food waste problem,[1] we collated data sources quantifying FLW along various stages of Aotearoa's food supply chain. This work highlighted that data on New Zealand's FLW is scarce, with particularly low visibility of food waste volumes at the national levels during production, processing, manufacturing, and distribution.

> …data on New Zealand's FLW is scarce, with particularly low visibility of food waste volumes at the national levels during production, processing, manufacturing, and distribution.

In terms of the size of the problem, several studies provide an indication of the scale of FLW in New Zealand, but often without yielding specifics on the types of food streams wasted, their frequency, or their end destinations:

- A recent infrastructure stocktake[63] estimates that New Zealand produced an estimated 4 million tonnes of organic waste in 2021, the percentage of which is FLW is unknown.[b] Of this waste, 2.2 million tonnes were recovered, either via composting or rendering, while 1.8 million tonnes were disposed of to landfills or on farms.[63] Importantly, this estimate does not include food lost and/or recovered on farms.
- A mixed-methods study in 2020 estimated that 60,500 tonnes of food waste goes unsold at New Zealand's three main supermarkets.[64]
- A 2018 audit suggests that New Zealand households produce 300,000 tonnes of food waste per year, over half of which is avoidable.[6] If patterns of food waste in Aotearoa reflect those seen in Australia[30] and the US,[65] it is likely that consumer-generated waste accounts for some of the largest amounts of food wasted along our food supply chain.

The scattered and in-confidence nature of FLW reporting means we have little evidence for where our biggest problems lie along our supply chain. Importantly, these data gaps have implications for how we might go about capturing value from our FLW. The ways we can capture value are not homogeneous, and not all types of FLW are equally well suited to all these processes. Whether we are talking about creating feed for animals or feedstock for compost, the specific composition of the food-derived waste streams matters. This means that to fully understand the scope to use these processes in dealing with our FLW, we need to understand the composition and availability of this waste. This is a real constraint in evaluating the potential of different processes to address our FLW problem.

> MfE has commissioned a baseline study that will estimate how much food New Zealand wastes, and how much is lost during production, which will help us better understand the scale of the problem.

MfE has commissioned a baseline study that will estimate how much food New Zealand wastes, and how much is lost during production, which will help us better understand the scale of the problem. This work is ongoing

[b] The percentage of food waste may be known but cannot be shared due commercial in confidence data sharing practices.

and being undertaken by Otago University's Food Innovation research group.[66] Additionally, the International Standards Organisation is in the early stages of developing a new standard, ISO/WD 20001, to help organisations reduce FLW by providing a common framework for measurement and reporting.[67,68] Measuring FLW in a standardised manner is fundamental to accurately comparing waste streams across the food supply chain, monitoring changes over time, and determining the impact of various interventions.

Much like our data on food lost and wasted along our supply chain, we know little about the scale, make-up, and efficacy of FLW recovery in Aotearoa. In terms of volume, the current state of value capture from FLW is likely dominated by composters and renderers of animal waste,[63] although a range of other approaches derive useful products from food-derived waste streams in New Zealand, including conversion to animal feed (see section 3.2), upcycling (see section 3.1), material recovery (see section 3.3), nutrient recovery (see section 4.3), and energy recovery (see section 4.4). Figure 4 shows data on organic waste recovery in New Zealand from the 2021 stocktake prepared for MfE.[63] This dataset covers a range of organic materials,[c] including various food waste streams, but data was provided commercial in confidence and has been aggregated, limiting its usefulness in understanding our food waste problem. A lack of data, or the lack of its availability, remains a persistent problem in work on FLW, and undermines our ability to tackle these waste streams.

A lack of data, or the lack of its availability, remains a persistent problem in work on FLW, and undermines our ability to tackle these waste streams.

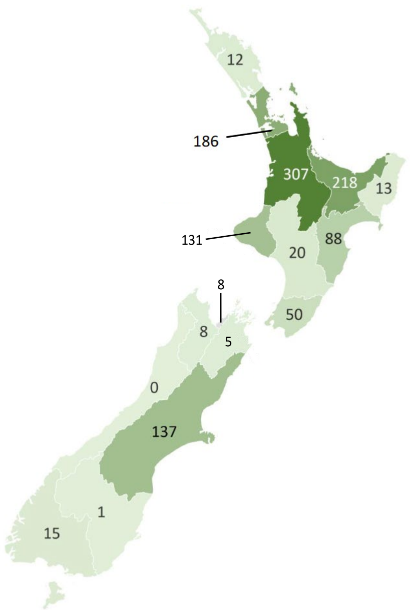


Figure 4: Quantities of organic waste (x1,000 tonnes) recovered, primarily by composters, by region in New Zealand. Data not limited to food waste. The data is not adjusted for population size or economic activity. Figure modified from the 2021 *Waste and resource recovery: Infrastructure and services stocktake*.[63]

---

[c] Categories of organic waste collected in the stocktake included: household food waste, household garden waste, other household organics, commercial food waste, commercial sludges, ICI garden waste, wood and timber, animal manures, animal by-products, agricultural by-products, compostable plastics, WWTP sludge, and other organics.

2.2 There are many shared challenges and opportunities in the value capture landscape

Implementing processes to extract value from food waste at scale presents several challenges. At a high level, two of the most important are sanitation considerations when recovering food for human use (i.e. food safety considerations) and the energy requirements to gather heavy, wet organic waste. Figure 5 shows where in the process such challenges are likely to arise. The figure distinguishes between opportunities (which include 'good' challenges such as a lack of feedstock due to effective FLW prevention efforts) and structural barriers, where technology, infrastructure, or some other component of the system does not support implementing or scaling up recovery technologies. We make this distinction with reference to the food waste hierarchy but note that the individual challenges we identify are not independent and potentially feed into each other. We explore these challenges, and opportunities to address them, in the remainder of this section.

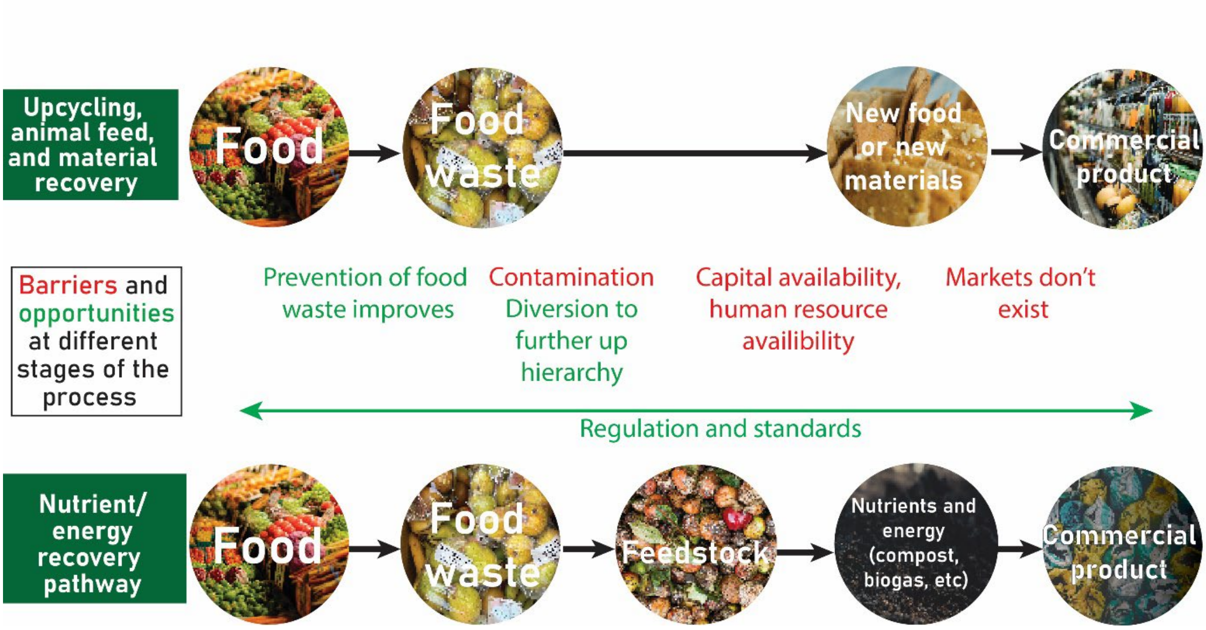


Figure 5: Opportunities and challenges at various stages of valorisation.

System problems, capital availability, and off ramps

The need for FLW as an input to create a commercial product through a process which can require significant investment could disincentivise policy makers and other stakeholders from reducing FLW. Alternatively, investors might conclude that given a future transition to better preventing our FLW, the return is unlikely to be sufficient to justify financing recovery processes in the interim. The challenge, then, is to simultaneously promote processes like nutrient and energy recovery in the interim, and prevention and food-system focussed interventions in the longer term, without either effort undermining the other.

Throughout the report we make some observations which may support addressing this challenge. Firstly, FLW is a problem that is big enough for multiple solutions (see section 6). Secondly, changes in technology and available feedstock over time may address this issue. Creative partnerships across the sector will be key. The private sector invests primarily on the basis of expected monetary returns and governments can act to address market failures including by providing public goods. Direct investment by government or provision of subsidies may enable interim solutions like nutrient and energy recovery to operate without being a barrier to solutions higher up the hierarchy.

> …FLW is a problem that is big enough for multiple solutions.

In addition to economic considerations, barriers to the uptake of biological treatment plants in new regions include the lack of expertise to run and regulate plants, the lack of exposure of municipal decision makers to such plants, and the uncertainties in establishing markets for end products like compost. A gradual development of processing capacity and concomitant end markets, as undertaken in California for AD and composting, could mitigate over-capitalisation risks.[69]

Markets, contamination, and regulation

The success of most of the value capture approaches we explore in this report depends on being able to produce a product that is commercially viable. Commercial viability requires, among other things, a high-quality product. For products derived from food waste, one challenge to achieving this consistently is contamination. For upcycled food products the issues are around maintaining food safety, efficiently; systems will need to ensure that by-products that will go into upcycled food remain separate from by-products that are unsafe to eat. Thorough discussions of contamination in organic waste including food waste in the context of nutrient and energy recovery have been produced by the International Solid Waste Association[70] and the US Environmental Protection Agency (EPA);[71–73] we present only a summary of the most salient issues.

Contaminants can be physical, chemical, or biological, the latter being a particular challenge because they can occur naturally in the waste source.[70] Chemical contaminants in the form of per- and polyfluoroalkyl substances (PFAS) tend to be higher for composts made out of kitchen waste than for composts made from garden waste or other biomass.[71] Although global research is still ongoing about the plant and human health implications for using composts containing PFAS, the plausibility of adverse outcomes in these domains limits the marketability of the end product.[71]

Plastic contamination in food waste feedstocks come both from plastic packaging and similar products, and from microplastics that are present in food and therefore food waste.[72] Again, plastic contamination diminishes the value of the feedstock or finished product, and this can sometimes prevent food waste being processed as it is rejected by the facility.[72] An additional challenge with plastic contamination is that some techniques to remove visible large pieces of plastic result in the creation of microplastic contamination.[72]

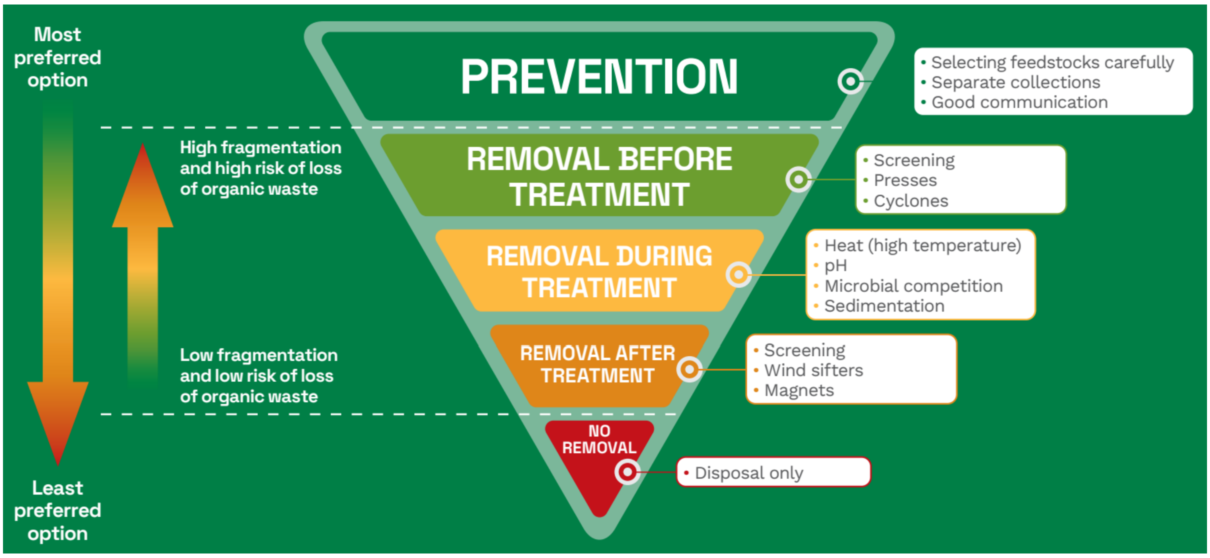


Figure 6: Contaminant management hierarchy. Image credit: International Solid Waste Association.[70]

Figure 6 considers options for dealing with contamination, taking an approach analogous to the food recovery hierarchy we have used throughout the report. Unlike the food recovery hierarchy, the contaminant hierarchy introduces a trade-off: while actions further up the hierarchy are more effective and preferred, they are also likely to result in less waste making it into processing.[70,72] Additionally, different approaches are suitable for different waste streams – biological contaminants can be relatively easily removed during treatment, while some chemical contaminants are more difficult to remove.[70] Prevention will rely on behaviour of consumers and other producers of food waste to be effective, while solutions further down the hierarchy can be undertaken wholly by processors of waste.

One approach to provide assurance to consumers of the end products, and thereby strengthen the market for these products, is to require standards are met. The present regulatory frameworks for nutrient recovery products are voluntary and poorly connected (annex 10 describes use and regulation of digestate and compost), although a more comprehensive approach is being developed for the application of organic waste to land (see box 2).

Box 2: Safely and successfully returning nutrients to soils

Be it compost, digestate, frass, vermicast, biochar, or unprocessed food waste – or indeed other organic materials beyond the scope of this work such as biosolids or animal manure – we need to ensure that what we apply to our productive lands is safe and effective. This means that processed organic materials do not introduce physical, chemical, or harmful microbial contaminants to our environment which threaten human, animal, plant, or environmental health. This includes ensuring we do not overload soils with excess nutrients or add too much organic matter to soils to the point they become anoxic. As we discuss in section 4.3, getting this right can have significant benefits for our soils, and in turn our food systems.

Many countries have given thought to how we use organic materials derived from organic waste streams. For example, numerous countries have standards or legislation that regulate the use of fertilisers, such as compost or digestate, derived from organic materials (see annex 10). In Aotearoa, work is ongoing to produce a guide for the beneficial use of organic materials on productive land.[74] Four sector bodies (Water Care, WasteMINZ, Centre for

Integrated Biowaste, New Zealand Land Treatment Collective) have been working on a guide to assist producers, applicators, and consent authorities to gain the benefits of applying good quality organic material to land to increase soil fertility and productivity. As New Zealand gears up its food waste collections,[27] finalising this guide[d] and putting it into practice becomes a priority.

In summary, the draft guide[74] suggests a standardised set of approaches for the application of organic materials to produce land, aiming to inform district and regional plans and the resource consent process. The guide proposes that organic materials be graded based on their pathogen and contaminant levels to manage and mitigate risks, outlining process methodologies for product standards. It will require controls over the sources of both raw and processed materials. Risk management protocols span human health, water quality, soil fertility, air quality, habitats and biodiversity, trade and international practices, and the preservation of culturally significant areas. The guide also outlines process methodologies for an agreed standard of final products that can be used.

2.3 Despite the challenges, there are examples of good practice and change is afoot

Fortunately, we do not need to reinvent the wheel in building systems to improve our food waste situation. There are examples from around the world and here at home of systems – at all levels, from national to local to single enterprises – which facilitate some of the techniques available to capture value from food waste. Figure 7 highlights some of these examples.

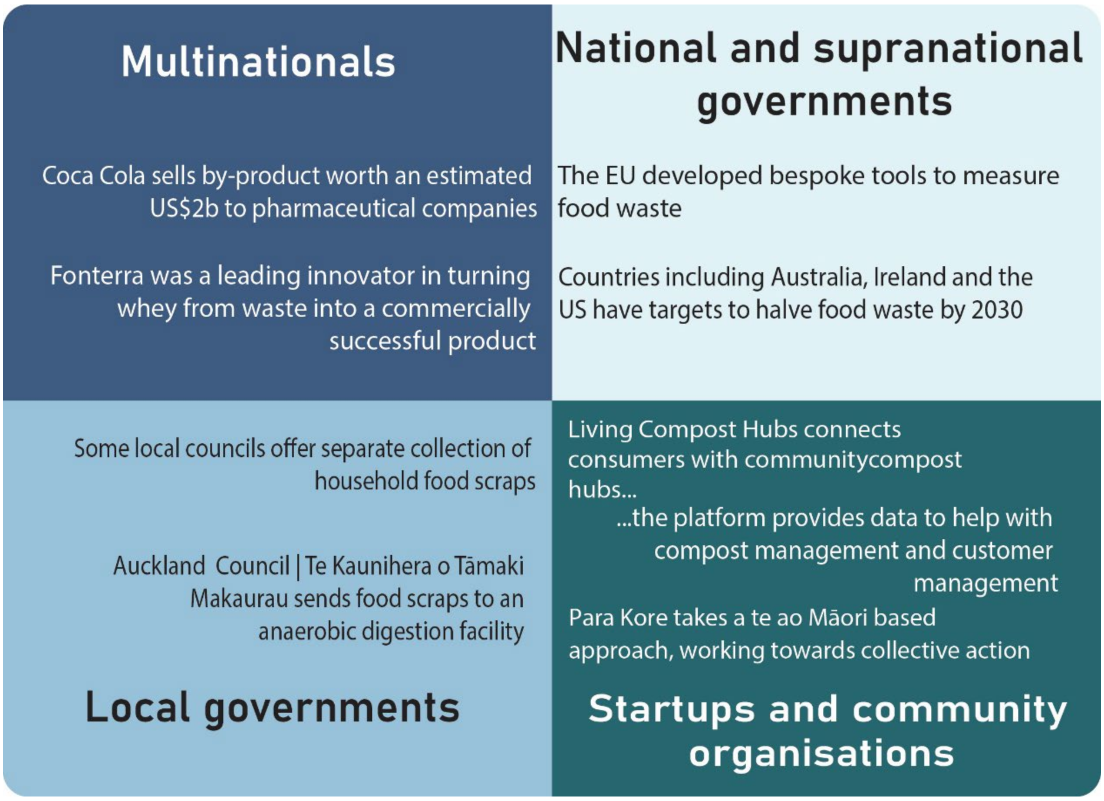


Figure 7: Examples of good practice from multinational corporations, national and supranational governments, local governments, and a Wellington startup. Upper left panel: Coca Cola's processing of coca leaves to make its eponymous soft drink results in about two tonnes of cocaine as by-product each year; one estimate puts its

[d] Which has remained in draft form since 2017.

value at US$2 billion.[75] Fonterra innovated in the use of their by-products from cheese production.[76] Lower left panel: see case study 15 on Ecogas. Lower right panel: one community hub using Living Compost Hubs is Kaicycle; see case study 12).

Figure 7 shows examples of good practice in capturing value at scales ranging from global to local, including both the public and private sector. In the case of the private sector, capturing value is driven by economics – turning by-products into revenue streams has obvious benefits for the bottom line. While it is true that in the current era some consumers include a company's environmental practices in their purchasing decisions, and thereby provide a commercial incentive for companies to behave in environmentally responsible ways, it is unlikely most producers will pursue innovation in this space if they do not anticipate it being profitable. Governments could consider exploring what is necessary to incentivise innovation.

Large and small organisations have distinct advantages in this space. As large organisations Coca Cola and Fonterra have resources to devote to innovation and established brands to strengthen their relationships with potential consumers, including business consumers. Small and medium enterprises (SMEs) may need support to pursue similar paths, but may have other advantages at the hyper local scale: scalability. Initially built with seed funding, the Living Compost Hubs can succeed even starting at a small scale. Growth in the number of consumers and hubs can happen flexibly without jeopardising the effectiveness of the model. Local scale actions offer unique benefits. Compost production facilitated by the Living Compost Hubs platform happens in the communities in which the inputs are derived (see case study 13). These communities benefit directly from the resulting compost being donated to local food-growing projects, and from jobs created to ensure a high-quality composting process. Aotearoa Composters Network[77] is another example of compost production operating at local scale.

Sometimes though, operating at scale is necessary. Auckland Council's involvement provides some certainty for the operators of the AD facility where the food scraps are processed, who benefit from a long-term contract,[78] and allows all stakeholders to benefit from economies of scale (see case study 15).[e] For individual households, Council involvement makes minimising their food waste easier than many at-home alternatives. For example, the appropriate bins are provided by the Council and are collected at the same time as other household refuse. Moreover, food scraps only need to be separated from other household waste; there is no need for further separation, for example, of meat and plant products.

At the national scale, there are a variety of approaches possible (see case study 1). In the EU, specific targets for food waste reduction are expected to be set by legislation, while in Australia, a new governance body was created[79] to lead in this area. Despite considerable variation in approach, the national/supra national examples have some commonalities: a strategy to reduce food waste; measurable and timebound targets for reducing food waste; and collecting/maintaining high quality data on food waste. The philanthropic sector has also identified actions it can support at national and global levels.[80]

…the national/supra national examples have some commonalities: a strategy to reduce food waste; measurable and timebound targets for reducing food waste; and collecting/maintaining high quality data on food waste.

[e] Although the Ecogas facility is further than existing facilities, our understanding is that the transport of the waste uses backhaul, meaning the trucks would otherwise be making the same journey empty, and so the distance does not have much effect on emissions.

An important part of capturing value will be consumer behaviour. Local and national governments and non-profits like Living Compost Hubs[81] are providing infrastructure to make it easy for consumers to participate in value capture pathways. Other actors are working to increase consumer knowledge and influence attitudes around waste. Para Kore,[62] a Māori non-profit, provides wānanga on a range of waste related topics including several that embody valorisation.

Finally, the examples highlighted demonstrate that good practice can come from outside the obvious stakeholders in the food and governance sectors. Living Compost Hubs acts as an exchange or connection service. A group or community organisation seeking to get started in composting will have support in both the composting process and in connecting with input sources, lowering barriers to entry. As we discuss in section 3 with regard to upcycling and animal feed, a mechanism for connecting producers of food waste with potential users of that product is crucial. Actors outside the sectors could potentially be part of providing this enabling technology, as Living Compost Hubs has for compost.

MfE's updated waste strategy is a reflection of international efforts to combat FLW.[24,30,31] Box 3 looks in detail at MfE's proposed approach to household food scrap collection. Encouragingly, among the examples of good practice we have highlighted, there are New Zealand models happening at multiple scales, from multinational corporations to small local start-ups. The multinationals have already transitioned to view their waste as a resource rather than a problem, and there is scope to encourage smaller players to similarly capture value from waste, using seed funding and other mechanisms of support.

Case study 1: Austria's decentralised approach to household food waste

Separate household food waste collection in Austria began in 1986 in Vienna and subsequently spread throughout the country.[46] The Biowaste Ordinance was enacted in 1992, making separate biowaste collection mandatory at all stages of the food supply chain, including at the household level, unless biowaste is recovered by the household (e.g. by home composting) or generator.[82]

Source-separated household food waste is predominantly processed by a decentralised network of at least 400 composters (roughly one per 20,000 people), with an average processing capacity of 3,000 tonnes per composter per year.[83] Austria's composters are mostly farmers, who process food waste on-farm and use much of the compost to improve soil fertility. Decentralised processing may be coupled with centralised collection in larger cities such as Graz, where collection and pre-processing is centralised before organic waste is distributed to 18 local farms for composting.[46]

Austria has composting manager training schemes, strict rules, and guidelines for making and managing compost, and a compost testing regime to ensure quality. Food waste is collected separately from green waste, which may be collected in separate bins or at drop-off points.[46] Contamination levels are very low, facilitated by education for households[46] and likely further supported by the visible connection households can make between their utilisation of food waste bins and the compost that results,[84] given composting occurs predominantly on local farms.

Box 3: The government's approach to diverting food scraps from landfills

MfE has designed a strategy for implementing kerbside food scrap collection across the country. Subject to approval from the incoming Government, this would see food scraps collections available to urban households nationwide, with the aim of diverting some 80,000 tonnes of food waste from landfill annually by 2035.[85] Specifically:

- Household food scraps will be collected from the kerbside in all urban areas (towns with >1,000 residents).
- Territorial authorities (TAs) would collect food scraps at a minimum, with collection of green waste left to the TAs discretion. MfE has previously noted that the joint collection of food and garden waste (also called FOGO) limits downstream processing options and reduces food waste diversion rates.[86]
- For TAs within 150 km of an existing commercial facility for food waste process with sufficient capacity (see figure 8), kerbside collections would be rolled out by 2027.[85]
- For TAs which require new infrastructure (see figure 8), kerbside collections would be rolled out by 2030.[85]
- TAs would have discretion over the organics processing technology they adopt.[87]

The rollout of kerbside waste collection faces several challenges but also provides opportunities. For starters, MfE lists just six organics processing facilities which currently have sufficient capacity to handle food waste from surrounding urban centres (see figure 8). However, financial support is available through the Waste Minimisation Fund (WMF) to upgrade existing transfer stations,[85] with several additional facilities listed as potential candidates to support the rollout.[16,86] WMF funding has also been specifically made available for organic (including food) waste processing and recovery and includes packages to support councils to rollout food waste collections. Just twelve TAs in New Zealand actively collected food waste prior to the release of the new waste strategy,[16,27] meaning a further 55 may need support in the coming years. MfE is also making available research and resources to support councils to introduce new services.

There are implementation hurdles to overcome. For example, multi-unit dwellings will require unique solutions to avoid a pile-up of bins and unwanted smells in settings where space is at a premium.[88,89] Additionally, TAs will have to give consideration to existing collection systems, such as those organised by communities or social enterprises (see section 4.3, Providing social benefits for communities), and their role in a wider rollout of food scraps collections. This presents an opportunity to engage with community expertise, understand context-specific needs, and build up or scale out infrastructure close by to keep resource and waste flows to smaller, more localised scales.[90–93] The collection of food scraps also requires consideration of end-products and their applications, including opportunities to replenish soils with products like compost, vermicast, and insect frass (see section 4.3) and recover energy with biogas production (see section 4.4).

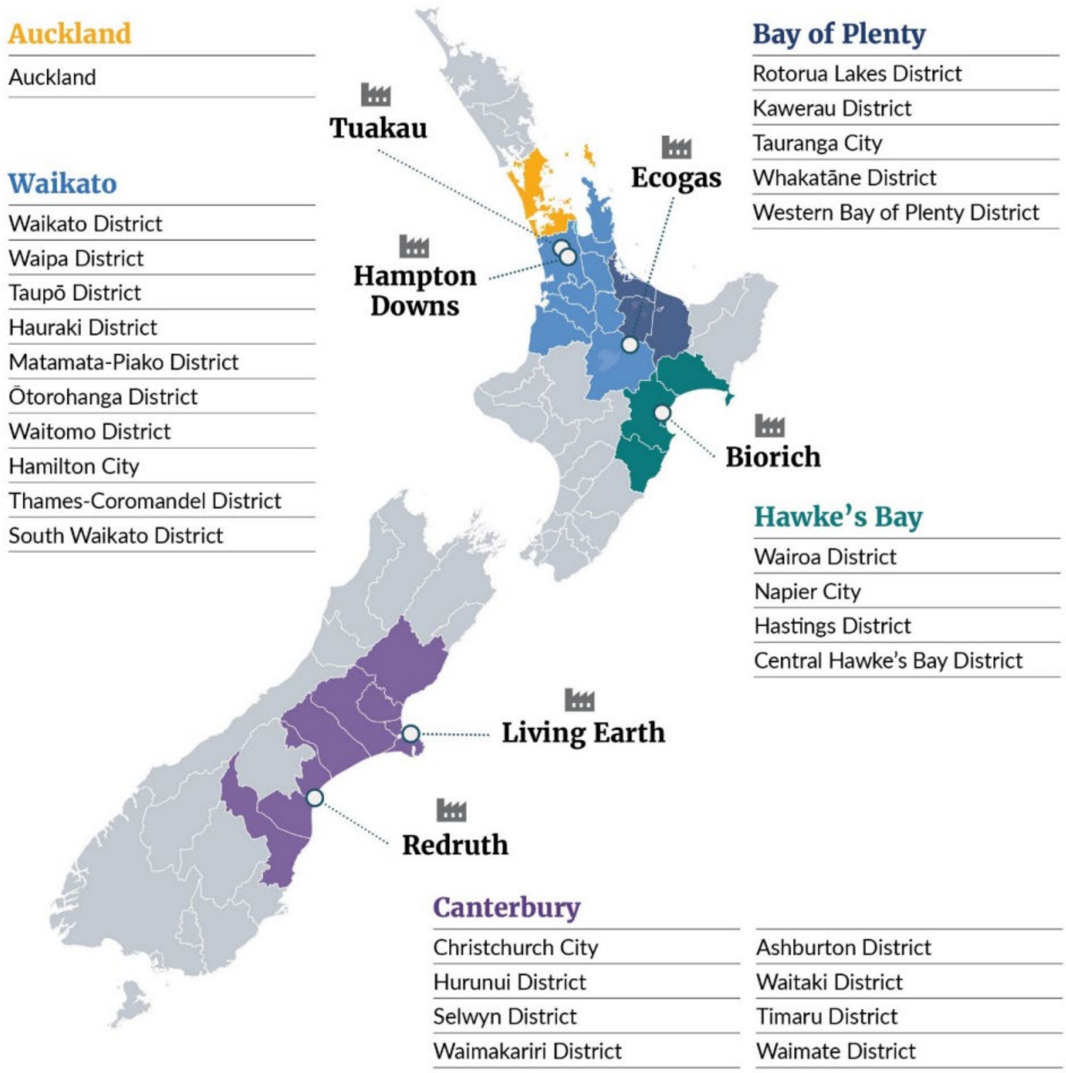


Figure 8: Map of territorial authorities with main centres with 150 km of an organics processing facility with sufficient capacity (grey factory symbols), as determined by MfE in March 2023. [85]

2.4 The levers for change are spread across government, and all need to be considered together

A key challenge facing New Zealand's efforts to reduce FLW is that the levers for change – policies, regulations, funds, standards, investment, and the like (see table 1) – sit across different parts of government. This presents a co-ordination challenge, not only because there are so many pieces to the food waste puzzle, but also because the pieces are tied to different agencies. For example, MfE holds pieces relevant to waste, Ministry of Primary Industries (MPI) oversees food production and food safety, Ministry of Business, Innovation and Employment (MBIE) leads strategic work on the circular economy, and territorial authorities engage with the day-to-day operations of managing food waste within their individual districts. Clearly, all these perspectives are needed to tackle food loss and waste comprehensively, including efforts to capture value from food waste streams. While there is a Cross Agency Food Systems Group (see table 1) to facilitate a coordinated approach within central government, a stronger authorising environment which empowers members of the group to act is likely needed to enact change. Similarly, the TA Forum provides an opportunity for territorial authorities to collaborate and coordinate their FLW responses but needs a closer connection with central government efforts. The emissions reduction plan,[15] and the actions in its circular bioeconomy chapter in particular, shows promise as a unifying tool in addressing this multifaceted challenge, but requires a clear delineation of ministerial roles to enable action.

> There is a Cross Agency Food Systems Group … to facilitate a coordinated approach within central government, [but] a stronger authorising environment is likely needed to enact change.

Table 1, below, summarises some of the policy levers across government.

Table 1: Government levers to capture value from food waste.

	Upcycling	Animal feed	Material recovery	Nutrient recovery	Energy recovery	Disposal
National	Food Act 2014 (MPI) Animal Products Act 1999 (MPI) Wine Act 2003 (MPI) Fair Trading Act 1986 (MBIE) Taxation (Research and Development Tax Credits) Act 2019 (IRD) *Bioresource Processing Alliance (MBIE)* *Eating and Activity Guidelines (MoH)* *Fit for a Better World (MPI)* *Food and beverage Industry Transformation Plan (MPI)**** *Advanced Manufacturing Industry Transformation Plan (MBIE)*	Agricultural Compounds and Veterinary Medicines Act 1997 (MPI) Animal Products Act 1999 (MPI) Animal Welfare Act 1999 (MPI) Biosecurity Act 1993 (MPI) →Biosecurity Regulations (Meat and Food Waste for Pigs) 2005 (MPI) →Biosecurity Regulations (Ruminant Protein) 1999 (MPI) *Bioresource Processing Alliance (MBIE)* *Fit for a Better World (MPI)*	*Bioresource Processing Alliance (MBIE)* *Fit for a Better World (MPI)* *Advanced Manufacturing Industry Transformation Plan (MBIE)* *Position statement on compostable products (MfE)* *Emissions Reduction Plan: Waste (MfE)* *Sustainable Food and Fibre Futures (MPI)* *Waste Minimisation Fund (MfE)* *Transforming Recycling (MfE)**** *National Waste Strategy (MfE)*	Organic Products and Production Bill (MPI)*** Resource Management Act 1991 (MfE)** Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (MfE)** Resource Management (National Environmental Standards for Freshwater) Regulations 2020 (MfE)** *Fit for a Better World (MPI)* *Guidelines for beneficial use of organic materials on productive land (sector led, in*	Engine Fuel Specifications Regulations 2011 (MBIE) Resource Management Act 1991 (MfE)** Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (MfE)** *A waste to energy guide for New Zealand (MfE)* *Emissions Reduction Plan: Waste (MfE)* *Bioenergy and biofuels workstreams (MBIE)***** *Waste Minimisation Fund (MfE)* *National Waste Strategy (MfE)*	Climate Change Response Act 2002 (MfE) Climate Change Response (Zero Carbon) Amendment Act 2019 (MfE) Food Act 2014 (MPI) Animal Products Act 1999 (MPI) Wine Act 2003 (MPI) Litter Act 1979 (MfE)* Resource Management Act 1991 (MfE)** Waste Minimisation Act 2008 (MfE)* *Emissions Reduction Plan: Waste (MfE)* *Transforming Recycling (MfE)**** *National Waste Strategy (MfE)*

	Upcycling	Animal feed	Material recovery	Nutrient recovery	Energy recovery	Disposal
	Food Secure Communities (MSD) *Made with Care (NZTE)* *Sustainable Food and Fibre Futures (MPI)* *Waste Minimisation Fund (MfE)* *National Waste Strategy (MfE)*	*Sustainable Food and Fibre Futures (MPI)* *Waste Minimisation Fund (MfE)* *National Waste Strategy (MfE)*		*partnership with MoH, MfE, MPI)**** *NZS 4454:2005 (Composts, soil conditions and mulches)* *Predator Free 2050 (DOC)* *Emissions Reduction Plan: Waste (MfE)* *Sustainable Food and Fibre Futures (MPI)* *Transforming Recycling (MfE)**** *Regenerative agriculture workstream (MPI)* *Waste Minimisation Fund (MfE)* *National Waste Strategy (MfE)*		
International	Sanitary and Phytosanitary Agreement Australia New Zealand Food Standards Code *Codex Alimentarius*	Sanitary and Phytosanitary Agreement *SDG 12.3*	Sanitary and Phytosanitary Agreement	Sanitary and Phytosanitary Agreement		Paris Agreement *Global Methane Pledge* *SDG 12.3*

	Upcycling	Animal feed	Material recovery	Nutrient recovery	Energy recovery	Disposal
	SDG 12.3					
Emerging coordination mechanisms	Cross-agency food systems group (multiple agencies, incl. MPI, MfE, MSD, MoH, MBIE, MoE, TPK, MPP, DOC, Kainga Ora), esp. food loss and surplus subgroup Emissions Reduction Plan: Circular economy and bioeconomy (MBIE) Sustainable food systems project (MPI, MfE, MSD, MoH)					

*New waste management legislation is in development, which will replace the Litter Act 1979 and Waste Minimisation Act 2008.

**New resource management legislation is in development, which will replace the Resource Management Act 1991.

***In progress. Not yet finalised and/or implemented.

****This formerly included work led by MBIE on the Sustainable Biofuels Obligation Bill, which is no longer progressing. The nature of future bioenergy and biofuels workstreams is unclear.

Plain text: laws, regulations, mandatory standards, binding agreements.

Italics: plans, policies, funds, guidelines, and voluntary standards.

(Parentheses): administering or lead agency.

Only central government actors and levers are shown, as well as international levers; however, central government levers are often partially or largely implemented at the local level.

DOC	Department of Conservation
IRD	Inland Revenue Department
MoE	Ministry of Education
MoH	Ministry of Health
MSD	Ministry of Social Development
NZTE	New Zealand Trade and Enterprise
TPK	Te Puni Kōkiri

3. Using wasted food to make new food products, animal feed, and materials

In this section we explore upcycling, animal feed, and material recovery (see figure 9). This grouping is somewhat arbitrary; material recovery could also have been at home in section 4 which covers nutrient and energy recovery. Upcycling and using food waste for agricultural animal feed go into feeding people, while material recovery does not. However, material recovery has an important commonality with upcycling and animal feed in that the FLW used must be of a certain type and quality. This contrasts with nutrient and energy recovery where food waste is treated as largely homogeneous.

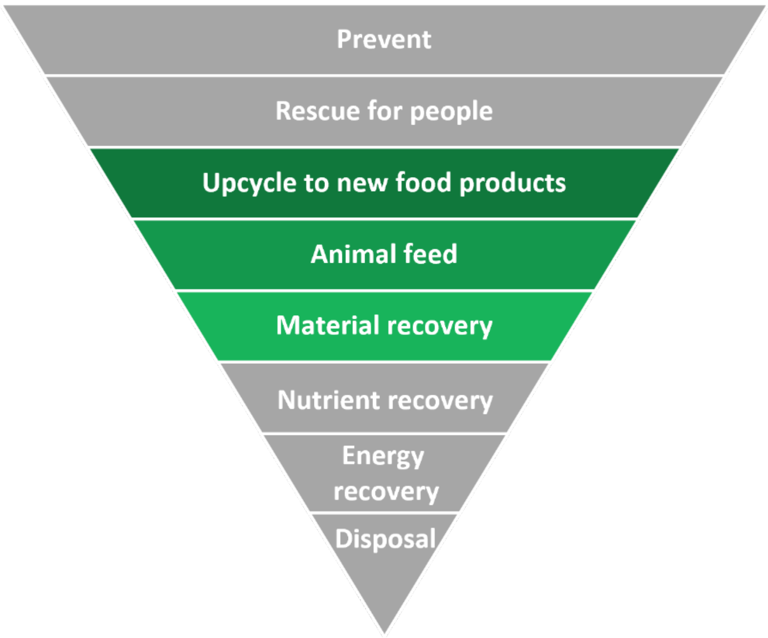


Figure 9: The relative positions of upcycling, conversion to animal feed, and material recovery in the food recovery hierarchy.

3.1 Upcycling gives food a second life

Upcycling is a new term for the age-old practice of creating new food products from by-products or unmarketable foods such as stale bread, offcuts from meat or produce processing, damaged or imperfect produce, and even mislabelled products.[18,85–87] Upcycling can be as simple as making jam, juice, or fruit leathers from imperfect fruit, or more complex and dependent on innovative technologies such as Pulsed Electric Fields (PEF, see case study 2). A formal definition offered by the US-based Upcycled Food Association requires products "use ingredients that otherwise would not have gone to human consumption, are produced using verifiable food chains, and have a positive impact on the environment" to be considered upcycled.[86]

Upcycling has long been undertaken in the home. For example, using stale bread to make bread and butter pudding, using vegetable offcuts and bones to make stock, and making preserves from imperfect produce are common forms of upcycling. This section is focused on upcycling of business FLW. Producing animal feed and new materials from FLW streams can also be described as upcycling, but the term is commonly reserved for the

> This section is focused on upcycling of business FLW.

production of food for human consumption,[18,85,86] which is how we use it in this report (see section 3.2 for content on animal feed).

Figure 10 (left to right): A platter of upcycled food products at a food waste panel event hosted by Otago University in July 2022; Ginger beer made from upcycled bread at the same event. Image credit: University of Otago Food Waste Innovation Research.

The upcycled food industry had an estimated market value of US$55.1 billion globally in 2023, up from US$46.7 billion globally in 2019.[88,89] In Aotearoa, an increasing number of companies are bringing upcycled products to market, with examples including Citizen Collective,[90] Dunedin Craft Distillers,[91] Burger Fuel,[92] Upcycled Grain Project,[93] Rescued Kitchen (see case study 18 in, *Food rescue in 2022: Where to from here?*)[1], Kinda,[94] Six Barrel Soda,[95] The Development Kitchen,[96] and Little Beauties.[97] Supermarkets are also upcycling, for example, by using surplus/day old baguettes to make garlic bread, or leftover hot chicken as a pizza topping. Figure 10 shows examples of upcycled food products.

Case study 2: Pulsed Electric Field technology for the potato and wine industries

In the food industry, PEF technology involves the application of high voltage short electric pulses to a food product during processing (see figure 11). The application of electric pulses to a fruit or vegetable increases the permeability of its cellular membranes and disrupts the cells' storage vessels, known as vacuoles. This can soften the fruit or vegetable and facilitate the release of cellular compounds.[98,99]

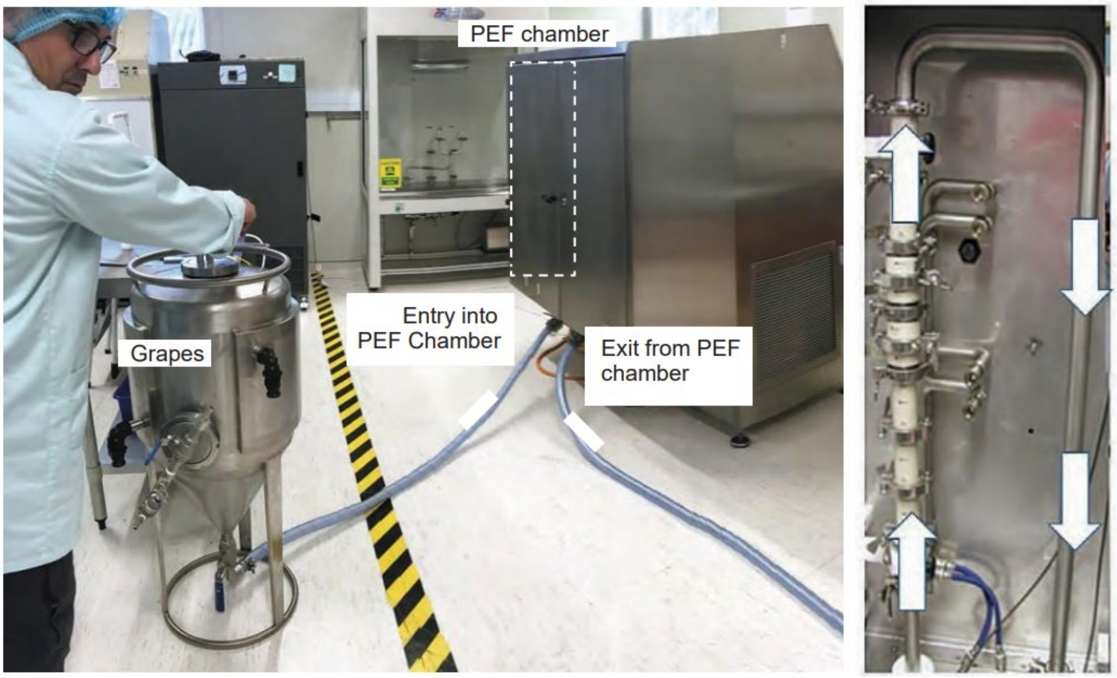


Figure 11 (left to right): Pilot scale Sauvignon Blanc PEF wine trial at the Department of Food Science, University of Otago; inside the PEF chamber cabinet. Abbreviation: PEF = Pulsed Electric Field. Image credit: Department of Food Science, University of Otago.[98]

A leading application of this technology exists in the potato industry, as demonstrated through MBIE-funded research undertaken by the Universities of Auckland and Otago as part of the Food Industry Enabling Technologies (FIET) programme.[100] Initial research explored the use of PEF to improve the efficiency of potato processing and prevent waste, while more recent research has demonstrated that PEF can also be used to restore the quality of late-harvested and psyllid-infected potatoes that otherwise would have gone to waste.

The initial research, undertaken in collaboration with Potatoes New Zealand, demonstrated that PEF treatment can soften potatoes ahead of processing into potato fries or chips, negating the need for parboiling before cutting, which is energy-, water-, and time-intensive. PEF-treated potatoes not only break less frequently during processing, but also cook more evenly, absorb less oil, and brown more uniformly when fried, increasing quality and yield and decreasing waste.[99–102]

In 2020, McCain Foods invested $1.85 million in PEF technology, replacing coal used in the pre-heating process of chip production and thereby reducing its C emissions by 3,900 tonnes/year. McCain now uses 82% less freshwater and saves an estimated $1 million/year. $250,000 in funding from the Energy Efficiency and Conservation Agency's Technology Demonstration Fund supported this investment.[103]

PEF has more recently been demonstrated to have the ability to restore the quality of late-harvested potatoes. If harvest is delayed (e.g. as was experienced in 2020 due to COVID-19 disruptions), potatoes and the resulting chips or fries tend to have an undesirable brown colour due to an excess of sugars and other compounds involved in the Maillard reaction responsible for browning. PEF treatment leads to the release of these compounds, thereby preventing intensive browning during frying.[104] The same principles also apply for Psyllid-infested potatoes, creating a pathway towards marketability for pest-damaged potatoes.[105] Having already invested in PEF technology,[103] McCain could use this same technology to upcycle imperfect potatoes, keeping them in the human food system.

PEF can also be applied to grapes used in wine making, a process that has been applied at pilot scale for red and white wines in Aotearoa (see figure 11).[98,106,107]

Is it really upcycling if the food was already good to eat?

Produce that doesn't meet cosmetic standards is generally safe and suitable to eat, so could remain in the human food supply chain without processing and the associated resource use, emissions, and potential reduction in nutritional value.[18,85,87,108] Aschemann-Witzel and colleagues highlight this challenge and suggest that there are two broad types of upcycling, depicted in figure 12 below.

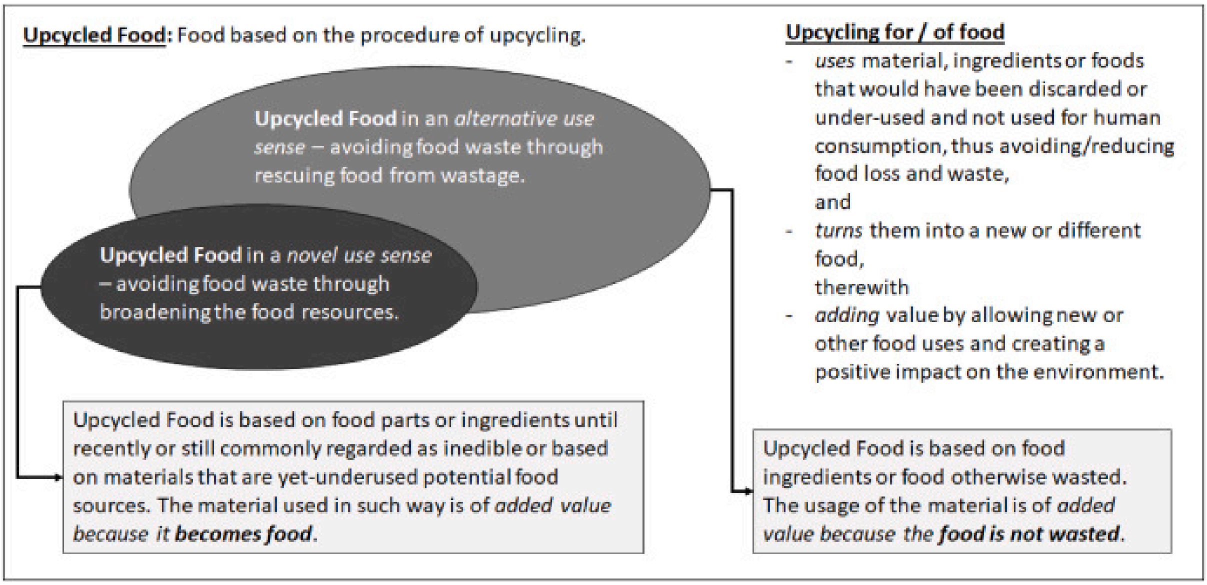


Figure 12: Two broad types of upcycling: alternative use upcycling, which prevents the waste of food that is theoretically good to eat but currently wasted (e.g. surplus bread, imperfect produce) and novel use upcycling, which prevents the waste of food parts or ingredients which are commonly regarded as inedible or not widely eaten. Image credit: Ashemann-Witzell and colleagues.[85]

Upcycling in Aotearoa should continue to be encouraged in the direction of by-product valorisation and whole product utilisation (i.e. 'novel use' upcycling, see figure 12) through the allocation of research and development funding – e.g. from the BPA,[109] WMF,[48] and Sustainable Food and Fibre Futures (SFF Futures) Fund[110] – towards upcycling projects that utilise genuinely unavoidable food waste streams. This approach is taken by Australia's Fight Food Waste Collaborative Research Centre, which focuses its upcycling efforts on genuinely unavoidable food waste[111] and by Rescued Kitchen (see *Food Rescue in 2022: Where to from here?*).

> Upcycling in Aotearoa should continue to be encouraged in the direction of by-product valorisation and whole product utilisation…

At what point does an upcycled product become just another product?

A long-standing and unresolved definitional challenge is determining at what point a product goes from being an intervention that makes a meaningful difference to food loss and waste to becoming a standard food product.[112] For example, hotdogs, whey protein, and Marmite at one time were innovative upcycled products, utilising meat scraps, dairy by-products, and spent brewers' yeast respectively, where these by-products otherwise would have gone to waste.[85,86,113] However, these products now have established markets and supply chains, and are considered business as usual for the industry they represent. One author suggests that "the dream scenario for any upcycled product must be to be considered a mainstream product, because this means that it has become widely recognised and achieved widespread use," but also highlights the definitional ambiguities this produces.[112]

> …hotdogs, whey protein, and Marmite at one time were innovative upcycled products, utilising meat scraps, dairy by-products, and spent brewers' yeast respectively, where these by-products otherwise would have gone to waste. However, these products now have established markets and supply chains, and are considered business as usual for the industries they represent.

Upcycling can deliver social, economic, and environmental benefits

Upcycling can offer societal benefits in the form of increased food security and reducing the environmental footprint of food production, while also being profitable to the individual businesses involved, and offering a niche for new business ventures.[114] Upcycling can contribute to food security by utilising food that is already produced, thereby making more food available without necessitating the production of new food.[21] For example, large quantities of mango peels from mango processing can be used as semolina for pasta[115], while tomato processing waste can be used for carotenoids production, a colorant that extends the shelf-life of food.[17,116] There are also opportunities for greater synergies between the upcycling and food rescue communities, as described in section 5.7 and case study 19 in *Food rescue in 2022: Where to from here?* For businesses, utilisation of food at risk of going to waste reduces waste disposal and management costs while also having the potential to create a new revenue stream.[10,112,117]

Upcycling can reduce the environmental footprint associated with food production and waste management.[18] Not all forms of upcycling have the same degree of environmental benefit, varying depending on what is being upcycled (e.g. by-products or surplus, see figure 12), the processes involved[118] (including the energy sources used in these processes), the destination to which the upcycled food otherwise would have gone (e.g. landfill, compost, animal feed, etc.), and the virgin ingredients being replaced (see annex 2).

> … upcycled foods, when marketed as such, bring a sustainability message to consumers. Therefore, visibly upcycled products has scope to play a role in heightening food waste and sustainability awareness…

In addition, upcycled foods, when marketed as such, bring a sustainability message to consumers. Therefore, visibly upcycled products have scope to play a role in heightening food waste and sustainability awareness,[111,118,119] although we aren't aware of any studies that have sought to measure this effect.

Meaningful certification can guard against greenwashing

With upcycling gaining in prominence and popularity[117,120] and sustainability claims positively impacting consumer willingness to pay for products,[117] there is a risk that 'upcycling' and related terms will be misused in product promotion, exacerbated by the definitional challenges of identifying what constitutes an upcycled product.

> With upcycling gaining in prominence and popularity and sustainability claims positively impacting consumer willingness to pay for products, there is a risk that 'upcycling' and related terms will be misused in product promotion…

We are not aware of any country that directly regulates the term 'upcycling' or related terms through legislation. However, third party certification can be applied, with certified products being allowed to display a protected mark.[121] This approach is used for fair trade products, with Fairtrade International verifying whether products meet criteria identified as being required to claim that they are fair trade before allowing them to display a widely recognised mark that serves as a decision making shortcut for conscious consumers[122]

Such a third party certification scheme for upcycled foods was launched in 2021, initially in the US and now throughout North America.[123] The Upcycled Food Association in the US has produced a standard that describes the criteria food products and ingredients must meet before being permitted to bear the 'Upcycled Certified' mark, which is a protected trademark (see figure 13).[21] For companies that opt not to advertise the upcycled angle of their story to consumers, a certification system can help provide verification of their environmental impact when applying for funding or vying for contracts where sustainability is an assessment criteria. Further details on the certification and other relevant consumer protection issues are in annex 3.

> For companies that opt not to advertise the upcycled angle of their story to consumers, a certification system can help provide verification of their environmental impact when applying for funding or vying for contracts where sustainability is an assessment criterion.

INGREDIENTS & PRODUCTS

Vertical | **Horizontal**

UP CYCLED CERTIFIED ™

Certified Upcycled Ingredients (UIs) and Product Containing Upcycled Ingredients (PUIs) may use either Mark format.

MINIMAL CONTENT

UP CYCLED CERTIFIED MINIMAL CONTENT ™

Minimal content products shall only use this one format.

Figure 13: Upcycled Certified marks for ingredients and products (left) and minimal content products (right). Image credit: Upcycled Food Association.[123]

Chief among the technical requirements in the standard is the ability to demonstrate that the upcycled inputs genuinely would have otherwise not gone to human consumption, with supply chain traceability being key to this. Applicants for certification are also required to assess their own food loss and waste during the production of the upcycled ingredient or food product. Tonnage of food diverted must also be robustly demonstrated. Compliance with the requirements of the standard is monitored annually by a certifying body, Where Food Comes From.[21,124]

Chief among the technical requirements in the standard is the ability to demonstrate that the upcycled inputs genuinely would have otherwise not gone to human consumption, with supply chain traceability being key to this.

The Upcycled Food Association's certification is currently only available in the US and Canada, but Australia's Fight Food Waste Cooperative Research Centre is exploring internationalising certification, which will help to bring credibility and visibility to the sector globally and allow brands to describe the complex concept of upcycling consistently to the consumer, as well as being advantageous for multinational upcycling companies.[111,125]

As well as the certification work already underway, the Codex Alimentarius Committee on Food Labelling (CCFL) is exploring whether there is value or need for new work on sustainability claims on food within its mandate. A discussion paper, drafted by Aotearoa and the EU, is seeking agreement for CCFL to commence new work on sustainability-related labelling.[126] This work may be of relevance to 'upcycled' claims.

Nutrition and food safety should be factored into upcycling efforts

While upcycling can make a substantial contribution to food waste reduction targets, it is preferable to ensure that pursuit of this goal doesn't undermine nutrition objectives. Upcycled foods are often highly processed, discretionary foods, but measures can be taken to drive the development of the upcycled food sector towards more nutritious products.[18,87] Not only does focusing on nutrition contribute to better population health outcomes, but it also has the potential to increase consumers' purchase intentions and willingness to pay for upcycled foods.[117,127,128] Four key measures for upcycled food manufacturers to consider to promote the development of more nutritious upcycled products are listed below and summarised in figure 14.[87]

While upcycling can make a substantial contribution to food waste reduction targets, it is preferable to ensure that pursuit of this goal doesn't undermine nutrition objectives.

- Consider the nutritional profile of the source material, prioritising the upcycling of wholegrains, nuts and seeds, legumes, and fruits and vegetables.
- Focus on producing staple foods (rather than discretionary foods) with high wholegrain, nut, seed, legume, fruit, and/or vegetable content.
- Where feasible, avoid making ultra-processed foods, which are often nutritionally unbalanced. Products that keep processing to a minimum are generally more likely to support good nutritional outcomes.[87]
- Where ultra-processed upcycled foods are produced (which may be hard to avoid where significant processing is needed to make the feedstock safe and suitable for human consumption), focus on improving the nutrient profile of the food category.[87]

Potential levers to drive upcycling in a nutrition-focused direction include adding nutrition guidelines to future iterations of the 'Upcycled Certified' standard[21,87] (see section 4.1) and factoring nutrition into government funding decisions intended to promote upcycling.

Figure 14: Summary of measures upcycled food manufacturers could take to produce more nutritious products, ensuring that food waste diversion efforts don't undermine nutrition objectives. NOVA is a food classification system that characterises the extent of food processing on a scale of 1 (unprocessed or minimally processed) to 4 (ultra-processed). Image credit: Thorsen and colleagues.[87]

The role of food safety is critical to the success of upcycled foods. While the ingredient sources of upcycled foods can contain food surplus, by-products, and waste from food preparation, they must comply with food safety legislation to be eligible for market release.[18,129–131] Simply put, if upcycled foods don't meet safety criteria, they will not reach consumers. Aligned with certification efforts, including a verifiable and auditable supply chain as part of the upcycling approach can contribute to food safety efforts and help with consumer acceptance of upcycled products.[18]

New Zealand consumers are open to upcycled food

> New food products must be attractive to consumers.

New food products must be attractive to consumers. Many of the barriers to establishing a circular economy are social, including consumers' perceptions of, and willingness to eat, upcycled food products.[132] New Zealanders' awareness of upcycled food is low, but when they are introduced to this category they say they are willing to try and buy upcycled foods. In a 2021 survey-based study involving 1,001 frequent Foodstuffs customers, more than 80% said they would be willing to try or buy upcycled products, compared with 6% who said they would not try or buy upcycled products.[117] In the same survey, 73% reported upcycled products to be as attractive or more attractive than conventional food products. Factors such as price, taste, quality, or labelling increased upcycled food's attractiveness for between 42% and 56% of respondents who found upcycled products as or less attractive (65%).[117] While this study acknowledges that the findings do not come from a representative sample of the New Zealand population, they are indicative of some level of openness to upcycled food amongst New Zealand consumers.

> New Zealanders' awareness of upcycled food is low…

International research suggests consumers' positive views of upcycled food are related to ethics and the environment.[133,134] Previous research also suggests ways to further improve consumers' openness to upcycled food. Consistent with the survey findings above, price is a point of sensitivity, with consumers willing to pay[f] less for upcycled food.[135] Clear messaging about the sustainability, social, and environmental benefits of upcycling could increase some consumers' willingness to buy upcycled foods and the price they are willing to pay.[127,132,135,136] Framing is also important: consumers are more likely to find upcycled products appealing if upcycling is framed as the utilisation of food that would otherwise have been wasted, rather than the utilisation of food waste. The 'otherwise wasted' framing situates upcycled products as capturing value from a resource, compared to the 'food waste' framing which portrays upcycled products as utilising valueless and potentially repellent waste material.[18,112,137] See figure 15 for upcycled food in a supermarket.

The 'otherwise wasted' framing situates upcycled products as capturing value from a resource, compared to the 'food waste' framing which portrays upcycled products as utilising valueless and potentially repellent waste material.

Figure 15: Customers try Rescued Kitchen's products in the bakery section of Countdown's Ponsonby store. Six Rescued Kitchen products are stocked in four Countdown stores in Auckland, where they are positioned alongside conventional products. Rescued Kitchen also sells products online and caters for events and venues. Rescued Kitchen's products are made using bread rescued from Countdown's own bakeries as well as other rescued ingredients such as surplus lemons, and contain no virgin flour. Image credit: Rescued Kitchen.

Market research in the food space is highly specialised. See annex 5 for detailed examples, which may be of use for producers of upcycled products.

Collaboration and investment are necessary for successful innovation in this space

Infrastructure gaps, lack of scale, volume variability, food safety, and internal resource to drive upcycling projects have all been identified as barriers to upcycling facing owners of food by-products.[10] Many of these barriers can be overcome by pooling resources and combining efforts:[112,138] case study 3 shows the potential of combining by-products and sharing

[f] Many studies use 'willingness to pay' as a proxy for demand for a product; ability to pay is not captured.

infrastructure,[138,139] and case study 4 demonstrates linking by-product owners with prospective upcyclers.[140,141] In addition, there are easy wins to be had by supermarkets turning ageing fresh produce into takeaways or ready meals on-site.

Case study 3: Collaborating to identify opportunities for the Central Otago fruit industry

With funding support from industry and central government (via SFF Futures and the BPA), Central Otago District Council has undertaken collaborative research to understand fruit loss in the region and explore value capture opportunities for its growers and processors.[142]

The output from the first phase of the project estimated the volume of major fruits in the region that are lost or wasted each year, covering apples, apricots, cherries, nectarines, and peaches.[8] While 85% of fruit leaves orchards for human consumption, 15% (approximately 6,000 tonnes) doesn't, with about 4,000 tonnes not harvested and 2,000 tonnes of harvested fruit going unsold. Labour availability and market factors including demand and cosmetic standards were identified as key drivers of loss and waste.[8]

The second phase of the project, which involved three separate workstreams, explored opportunities to add value to underutilised fruit, focusing on upcycling for human consumption.[142] Key findings from each workstream are summarised below.

Workstream 1: Current processing capacity and constraints in the district,[138] led by the University of Otago

Many growers in the region agreed that picking, processing, and storage equipment and resources could be used more efficiently throughout the region if shared, although turning competitors into collaborators would require a change of mindset. Equipment sharing is particularly feasible when different growers or producers need pieces of equipment at different times throughout the year due to product seasonality. This workstream recommended that Central Otago District Council establish a collaborative food hub that can be used by growers and processors in the region, including a central coolstore, a sales and marketing support resource, and an online database for equipment and storage capacity collaboration.

Workstream 2: Fruit health benefits and properties,[143] and product development trends,[144] led by Plant and Food Research

The fruits covered in the Central Otago District Council project contain several nutrients about which health claims could potentially be made for any upcycled food products that valorise these fruits (see figure 16). Phytochemicals in these fruits also have potential health benefits, but validation via clinical trials would be needed.[143]

Fruit-based bakery products (e.g. fruit pies), jams, and jellies in particular offer promise as market pathways for fruit that is currently lost or wasted in the region. Upcycled fruit products vary in the concentration of fruit they contain, with products that contain a high concentration of fruit having a bigger impact on combatting food waste volumes than those where fruit or fruit extracts are a minor component.[144]

Workstream 3: Local and global demand trends,[139] led by Appetite for Change

While New Zealand fruit in unprocessed form benefits from provenance marketing, market research found that this doesn't hold true for processed food products. Emphasising substantiated health-related benefits could be a more impactful marketing strategy. Product- and market-specific research will be crucial for the success of any new products that utilise the region's fruit lost and wasted fruit. Collaboration between growers could de-risk new ventures.[139]

The third phase of the project is currently underway and involves promoting the research findings and engaging with potential investors to explore collaboration and next steps.[142]

Case study 4: Connecting by-product owners with upcyclers

Making upcycled products is a whole new arm of a business, requiring investment, time, marketing, and management. For producers and food processors and manufacturers who have by-products but don't want to introduce an upcycled product to their business, an efficient way to connect them and their food resources with upcyclers is needed.[112]

Tesco, a British multinational grocery retailer, launched an online marketplace last year that works to meet this need for its suppliers.[141] The online marketplace enables businesses with surplus food and by-products to let other food and beverage companies know what they have available for donation or purchase, with Tesco's Quality Director, Sarah Bradbury noting that "excess stock or waste for one supplier could be a valuable commodity to another. By linking different farmers, producers and manufacturers together, our suppliers can find new ways to trim their bills, reduce waste, and keep delivering great value for our customers."[141]

Start-up business CiRCLR is working to provide a similar service for food and beverage businesses in Aotearoa.[140] CiRCLR allows businesses to measure, trade, track and report on food waste and food loss, connecting value-added opportunities across industries to minimise waste. As well as matching surplus and by-product owners with prospective upcyclers, CiRCLR's platform provides scope 3 emissions reports, impact assessments and life-cycle analysis for traded waste. The platform's inclusion of food waste measurement and verification tools could enable businesses to use it to gather the information necessary to have their products certified as upcycled (see section 3.1).

For connections between upcyclers and by-product owners to work, logistical challenges need to be overcome too, not just the initial connection. New supply chains need to be established and the by-product needs to be handled in compliance with food safety standards (rather than as a waste stream) to ensure it can legally and safely be used by upcyclers.[112]

Upcycled food development is often more constrained than the development of conventional food products because the focus is on utilising food at risk of going to waste rather than a full range of potential ingredients.[21] To be successful within these constraints, the properties of food by-products need to be understood so that the full range of upcycling opportunities can be explored (see case study 5). Additionally, businesses working in this space may benefit from initiatives focused on commercialisation, making innovations practical at scale and in context.[112] The New Zealand Food Innovation Network (NZFIN, see case study 6),[145] BPA,[109] and Sustainable is Attainable in Hawke's Bay and Timaru[146,147] are all initiatives that focus on commercial solutions for food at risk of going to waste, and have strong connections with researchers and industry. Finally, help navigating regulatory challenges unique to upcycling – like labelling requirements when working with potentially variable ingredients – would help upcycling innovations

...businesses working in this space may benefit from initiatives focused on commercialisation, making innovations practical at scale and in context.

The healthiest way to eat fruit and vegetables is with minimal processing...

progress from the lab and pilot scale to the commercial scale.[148] This is consistent with the reflections of participants at an event hosted by FoodBowl early in 2023 (see annex 4).

Case study 5: Digging deeper to find value in fruit and vegetable residues

The healthiest way to eat fruit and vegetables is with minimal processing,[108] but where this is not possible there may be opportunities for fruit and vegetable extracts to be a good source of nutrients and bioactive compounds, including from by-products and inedible components of produce (e.g. grape seeds).[149] Nutraceuticals have for many years been flagged as a food category with particular growth potential.[150,151] To realise this promise, it will be important to demonstrate the stability, efficacy, bioavailability, and health benefits of any extracted nutrients,[108,143,152] and ensure that related product claims are stringently regulated and regulations are enforced.[143,153] In addition, from a food waste perspective, nutrient and bioactive extraction from food at risk of going to waste will produce food waste streams of its own, which need to be managed.

A 2018 study by Sustainability Systems, commissioned by NZTE, identified opportunities to add value to by-products from the food and beverage industry.[10] The study found particularly significant opportunities for valorisation of fruit and vegetable residues, summarised below, and assessed that recognising these properties could enable residue owners to explore innovative valorisation opportunities for residues that are currently either costs to business or low-value earners.[10]

- Potatoes – Good source of K and vitamin C. Peels are rich in dietary fibre. Processed potatoes (from potato chip manufacture) are high in starch. Glycoalkaloids from green potatoes have anti-cancer properties when extracted.[10,154]
- Carrots – Good source of β-carotene, a precursor to vitamin A, which plays a role in normal vision, immune health, reproduction, and growth and development. Carrot pomace is high in dietary fibre.[10]
- Onions – Onion skins are a source of dietary fibre and polyphenols, a diverse group of compounds with antioxidant properties.[10,155]
- Tomatoes – Pomace from sun-dried tomato manufacturing is a good source of lycopene, which can be used as a food colouring agent and has antioxidant properties.[10]
- Strawberries – Flavouring and fragrance compounds can be used in foods, beverages, confectionary, perfumes, and cosmetics.[10]
- Beetroot skins – Contain betalains, which have bioactive properties such as antioxidant, anti-inflammatory, and immunomodulatory effects.[156] Beetroot also contains pectic oligosaccharides which can protect against toxins from *E.coli* and have anti-cancer, antimicrobial, and prebiotic properties.[10,157]
- Sweetcorn cobs and husks – Contain xylo-oligosaccharides, which have pre-biotic properties.[10,158]
- Squash – Squash flesh is a good source of vitamin A precursors. Buttercup squash contains folate which protects against neural tube defects in infants when consumed during pregnancy,[159] dietary fibre, vitamin E (an antioxidant), niacin (a B vitamin with many roles in the body), and K. Seeds and pumpkin shells are a source of antioxidants.[10]
- Apples (small fruitlets) and pomace – Apple peels and pomace contain a wide range of bioactive compounds. Pomaces are also a source of pectic oligosaccharides.[10,157]

- Capsicum and leaf – Capsicums contain vitamin A and its precursors, vitamin C, and proteins and fats. The leaves contain glycoalkaloid toxins but can be rendered safe to eat after boiling or cooking, or the glycoalkaloids can be extracted and explored for their anti-cancer properties.[10,154]

A study undertaken for Central Otago District Council by PFR as part of a wider project on food loss and waste explored the health potential of commonly wasted or process-grade fruit products in the region – apples, apricots, cherries, nectarines, and peaches.[143] Based on Food Standards Australia New Zealand (FSANZ) regulations, it found that several pre-approved health claims could be made on fruit products based on claimable nutrients (see figure 16), although noted that care must be taken to avoid misleading consumers and ensure compliance with the rules governing health claims. While phytochemicals in fruit may also deliver health benefits, any associated health claims need to be substantiated with clinical trials so would require considerable investment[143] – MPI has recently found a New Zealand juice maker to be in breach of the Australia New Zealand Food Standards Code by using unsubstantiated health claims in its packaging and promotional material.[160]

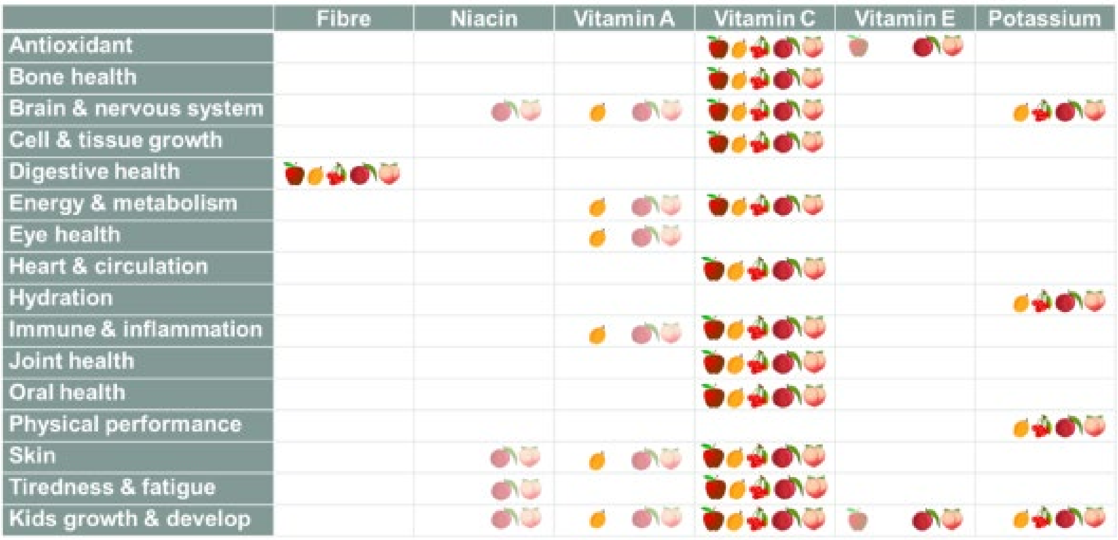


Figure 16: Table showing pre-approved health claims that could be made based on the nutrient content of apples, apricots, cherries, nectarines, and peaches or products containing these fruits. Light shading indicates where claims may depend on the specific variety of fruit. Image credit: Lister, as part of a Plant and Food Research report prepared for Central Otago District Council, Summerfruit New Zealand, LILO Desserts, and the BPA.[143]

Case study 6: New Zealand Food Innovation Network (NZFIN)

NZFIN is a national network of complementary facilities and expertise designed to support the growth and development of New Zealand food and beverage business of all sizes. Located in six locations, NZFIN enables food and beverage businesses to innovate, lab test, and commercially scale up products to take to market, both domestically and internationally. Its services are independent and commercially confidential, and its facilities are export-accredited.[145] NZFIN has close relationships with the wider food innovation ecosystem, including with Callaghan Innovation, NZTE, MPI, MBIE, Crown Research Institutes, universities, consultants, incubators, and industry.[161]

The network was founded in 2009 and currently receives $4.5 million in government funding per year.[161,162] Businesses developing products with the network are required to invest too, ensuring their commitment to the success of their projects. With the open access production facilities having worked with over 200 clients on 620 projects in the last year alone, NZFIN has enabled companies to generate hundreds of millions of dollars in revenue during its lifetime.[162] Helping businesses find valuable uses for by-products and food at risk of going to waste is a growing part of NZFIN's work.

The hub approach enables food and beverage businesses across the country to access the network's expertise. Each node in the network offers different services, tailored to the needs and capabilities of the region in which they are located.

- FoodBowl – FoodBowl is a pilot scale food processing facility with seven hireable food-grade processing suites which can be configured according to clients' needs (see figure 17). It is strategically positioned in Auckland, home to the country's largest cluster of food manufacturers. It has over 300 pieces of equipment, including equipment suitable for extrusion, pasteurisation, ultra-high temperature (UHT) processing, high pressure processing (HPP), retorting, bottling, packing, hot and cold filling, separation, concentration, drying, powder and liquid blending, fermentation, ice cream production, extraction, and size reduction. Acknowledging that the commercial success of a new food product depends on factors beyond the product itself, such as business and marketing strategies, FoodBowl also runs a comprehensive business workshop (including a dedicated upcycling business kōrero hosted in January 2023, see annex 4) and links clients with incubators and accelerators.[161,163]


Figure 17 (left to right): CO_2 super critical extraction technology for extracting high value naturally occurring bioactives; FoodBowl Chief Executive, Grant Verry, shows the team a high pressure processing system, which can be used to non-thermally preserve food, extending shelf-life and preventing waste while maintaining the sensory and nutritional properties of the food product.

- FoodWaikato – FoodWaikato offers a New Zealand Food Safety export-certified spray dryer which manufactures sheep, goat and cow milk into milk powders and converts milk powders into ingredients for nutritional formulas. Clients can also access business support and development services at FoodWaikato, including advice, networking, and access to funding opportunities.[161,164]
- Hawke's Bay – To ensure national coverage, NZFIN has a satellite office based at the Hawke's Bay Business Hub. The office offers business development support to food and beverage businesses on the East Coast and lower North Island and can connect them with other nodes in NZFIN depending on their product development needs.[161,165]

- FoodPilot – Based at Massey University in Palmerston North, FoodPilot offers a wide range of research and development services for food and beverage development. FoodPilot is home to expertise in workshops and ideation, product and process development and innovation, food safety, shelf life determination, and consumer and sensory evaluation (see annex 5).[161,166,167]
- FoodSouth – Based at Lincoln University in Canterbury, FoodSouth specialises in helping businesses achieve growth and export by enabling them to develop prototypes for market validation, trial new equipment, scale up trial work, conduct process development and improvement, and validate quality systems. FoodSouth has three food safe processing spaces and a mobile product development kitchen. Applications include bakery products, snack foods, sauces, powders, beverages, and meat products.[161,168]
- FoodSouth Otago – FoodSouth Otago, located at the University of Otago, is a pilot scale food grade product development facility offering multidisciplinary research expertise and capabilities for food product development using conventional and novel technologies. FoodSouth Otago also offers a sensory panel to support product development.[169]

NZFIN has supported the development of multiple products which utilise food at risk of going to waste. For example, the Apple Press is a Hawke's Bay business which uses imperfect apples from the region to produce a high quality apple juice product.[170] Before investing in a Hawke's Bay-based facility, the company tested and refined its processes and formulations at FoodBowl.[161,171] Sanford is another upcycling success story. The seafood company worked with FoodBowl for four years, trialling a range of products which enabled the company to extract nutritional value from parts of seafood that would otherwise go to waste.[172] It now has its own extraction facility in Blenheim.[161,172]

The Queensland Department of Agriculture and Fisheries in Australia has a pilot plant offering similar services to those provided by NZFIN, which the team visited in 2022 (see figure 18).[173] As with NZFIN, the Queensland pilot plant focuses on bridging the gap between research and commercialisation, provides businesses with access to a wide range of food processing technologies, recognises the importance of fostering both product development and business development, and provides a range of supporting services, including sensory testing (see annex 5).

Figure 18: The Queensland Department of Agriculture and Fisheries in Australia pilot plant and some of the team.

The food and beverage sector draft Industry Transformational Plan highlighted the need to support commercialisation and scale-up of innovative foods beyond the lab bench or pilot plant.[162] The draft plan recommended an increase in support to access to capital for food innovation (beyond existing options which best serve businesses at the early stages of development but are less available for young businesses seeking to achieve scale and become commercially viable), growth of NZFIN, and the establishment of three open access scale up facilities to support early-stage businesses to move through their growth phase.[162]

3.2 Converting food waste to animal feed can reduce the need to grow and import feeds

Food waste utilisation represents an opportunity to reduce the impacts of global feed systems

The contribution to emissions and environmental harm from the production of feed for animal-based agriculture and aquaculture is under recognised,[174–182] particularly for non-pastural animals like chickens, pigs, and farmed fish.[181] Increased utilisation of food system by-products and waste as animal feed would lessen the environmental (including climate) impact of animal feed production.[g] In addition, about 15% of animal feed ingredients could be directly eaten by people so are considered ‘food-competing feedstuffs’ (see figure 19).[182] Replacing food-competing feedstuffs with food system by-products could free up 72–103 million tonnes of cereals, 3.8–6.0 million tonnes of vegetable oils from oil seeds, 8–19 million tonnes of pulses, and 2.9–3.9 million tonnes of fish for

[g] We acknowledge some hold the view that because meat and other foods derived from animal products tend to have high environmental impact, feeding farmed animals with food waste is undesirable because it lowers the input costs of such systems while increasing the carbon emissions from producing the food compared to if it were eaten by people. Our hierarchy already places animal feed below feeding people, and despite variability in hierarchies, we are not unusual in placing animal feed above nutrient and energy recovery. The debate as to whether to include animals within our food production system is beyond the scope of this report.

human consumption.[182h] Feeding people directly with these products, rather than feeding them to animals to feed people, is a more efficient way to provide people with energy and nutrients – a prioritisation reflected unanimously across food recovery hierarchies.[17–19,23–30]

The potential doesn't just lie in by-product utilisation. For example, across 14 environmental indicators, a life cycle analysis (LCA) found that converting mixed municipal food waste to pig feed was better environmentally than composting or anaerobically digesting it, primarily given the environmental benefits of reduced virgin production of feed ingredients.[183] As for all LCAs, the scope, assumptions, and specific context will have a bearing on the modelled environmental outcomes (see section 6.1). MBIE has identified several areas where using FLW in animal feed could reduce greenhouse gasses (GHGs).[184]

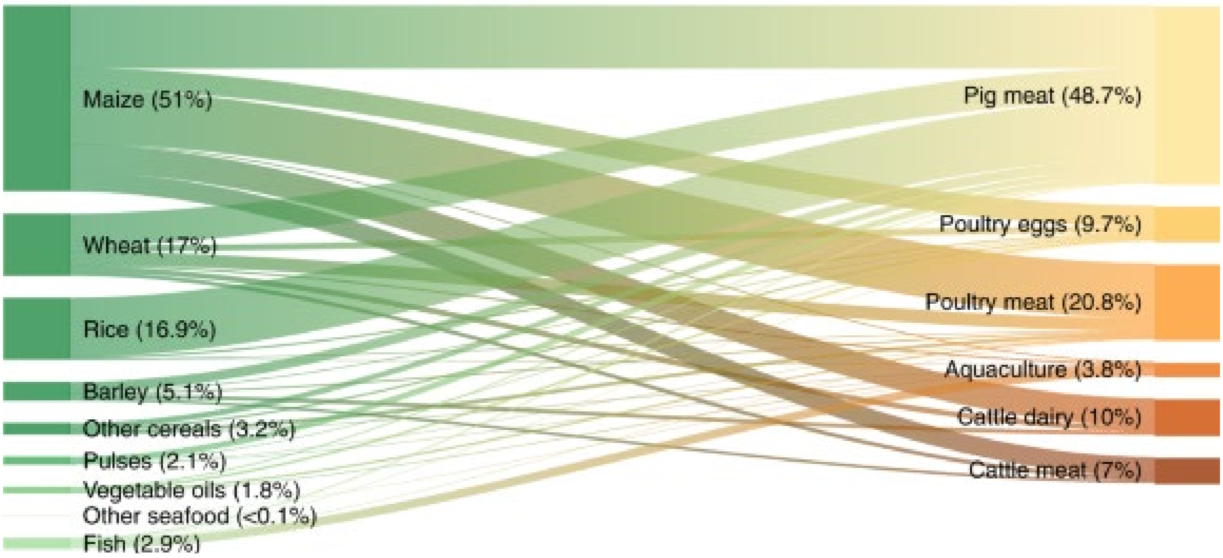


Figure 19: 840 million tonnes of animal feed ingredients (15% of animal feed produced globally) could theoretically be eaten by humans. The above figure shows where food-competing feedstuffs are utilised in global agricultural and aquaculture systems, demonstrating that large volumes of cereal crops are grown for pig and poultry feed, and that aquaculture uses a substantial volume of human-edible fish. Image credit: Sandström and colleagues.[182]

[h] This is based on the maximum possible replacement of conventional feedstuffs without compromising productivity and allowing for food system by-products left on fields as part of sustainable agricultural practices.

By-products and food at risk of going to waste are already used in Aotearoa in manufactured agricultural and aquacultural feed [10,185,186] and in petfood.[185] Based on 2022 data from the New Zealand Feed Manufacturers Association (NZFMA),[186] roughly a quarter of the raw materials used in manufactured feed production are by-products (see figure 20). To our knowledge, similar data is not available for petfood, but one estimate suggests 30% of New Zealand households also feed their own food scraps to their chickens, pigs, cats, dogs, and other pets at home.[187] We note that some food waste components may be poisonous to pets.[188,189] For further information on petfood see annex 8.

Reducing FLW is not a silver bullet solution to the challenges of methane emissions from ruminant animals.[178–180] It is not necessarily desirable for all by-products to be removed from farms and utilised, with some food system by-products forming part of sustainable nutrient cycling systems when left in the field.[182] However, using food waste as animal feed (and taking care not to substitute food waste streams into animal diets where they reduce productivity or increase enteric emissions) is one way to make incremental improvements to the emissions profile and wider environmental footprint of animal-based agricultural systems.

> …it is not necessarily desirable for all by-products to be removed from farms and utilised, with some food system by-products forming part of sustainable nutrient cycling systems when left in the field.

Case study 7 and case study 8 explore two pathways for this use of FLW: using waste from various sources as pig feed, and using grape marc as an animal feed supplement.

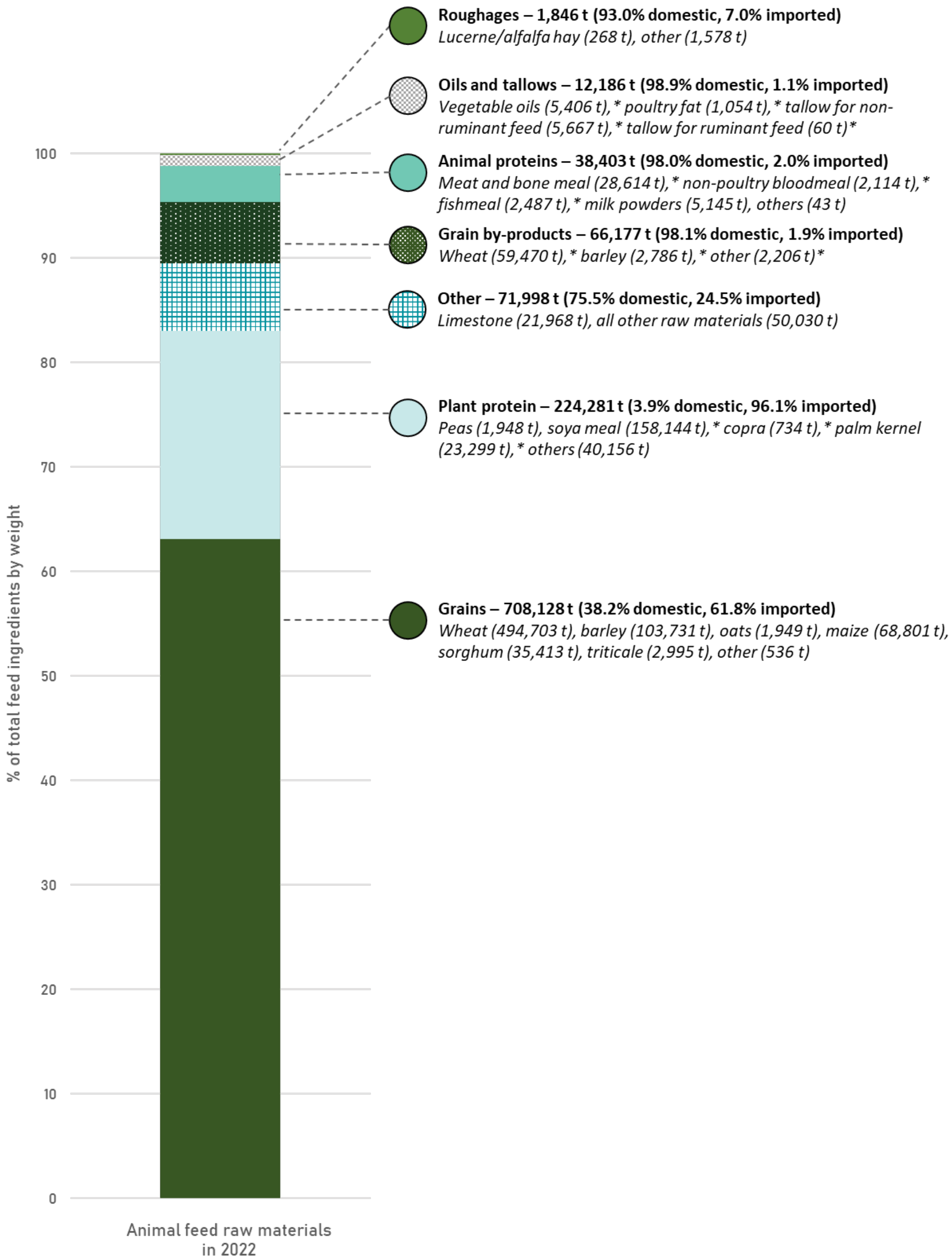


Figure 20: Approximately 1.1 million tonnes of animal feed were manufactured in Aotearoa in 2022, excluding blended feed. Purpose-grown grains were the dominant feed ingredient, over half of which was produced offshore. Food system by-products (or ingredients assessed as likely to be by-products) are indicated with an asterisk (*), and together comprise about one quarter of feed ingredients used in 2022. Data sourced from: NZFMA.[186]

Case study 7: The ins and outs of pig feed

Pigs are omnivores that eat a wide variety of feedstuffs, often delivered as compound or blended feed with ingredients selected to ensure the energy, amino acid, and micronutrient requirements of pigs are met at different stages of their lives.[190] Commercially farmed pigs in Aotearoa already eat a range of food by-products such as dairy wastes, vegetable trimmings, and spent brewer's grain, as well as surplus food at risk of going to waste such as stale bakery items, surplus dairy products, and out-of-spec products.[191,192] Mixed post-consumer food waste from households and hospitality venues is fed to pigs outside of commercial farms.[193,194]

As with all animals, a balanced diet is important for pigs.[190] Excessive feeding of one food waste stream can lead to poor nutrition, potential animal welfare issues, and potential defects in the meat produced (e.g. too much unsaturated fat in the diet can lead to body fat softening, where hard fat is more desirable for flavour).[195]

When considering feed ingredients that could be added to a pig's diet, including food system by-products or post-consumer food waste, there may be key feed characteristics to avoid or manage from an animal nutrition, product quality, and operational perspective, many of which apply to farmed animals generally (not just pigs).[190] Feeds should be avoided or will need special consideration or management if they:

- are unpalatable to pigs;
- are toxic or cause ill-health or discomfort;
- are not cost effective;
- restrict appetite;
- don't satisfy appetite;
- cause meat taint or off-flavours;
- reduce the physical quality of meat (e.g. soft fat);
- cause health or handling difficulties for feed producers or handlers;
- are costly or difficult to transport; and/or
- are highly variable in nature, making feed planning difficult.[190]

A further consideration in the pig feed landscape is the use of surplus food as a feed ingredient (e.g. bread). While better than sending these food products to landfill, these foods could be eaten by people (e.g. through food rescue (see *Food rescue in 2022: Where to from here?* or upcycling (see section 3.1))[17]

Case study 8: Hitting the mark with grape marc

When grapes are processed to make wine, 10–30% of their weight is left as grape marc residue.[196] This residue contains skins, stalks, moisture, tannins, sugar residues, and alcohol, with the exact amount and composition of the marc varying depending on the grape type, wine type, and processing method and equipment.[196] New Zealand's Marlborough region produces 46,000 tonnes of grape marc per year.[197] Grape marc in Aotearoa is primarily spread directly on land or composted and then applied to land. However, it is often held in anaerobic piles before composting, producing methane and leachate.[197] Applying grape marc directly to land can return nutrients to the soil. However, large amounts of land are required so as not to spread grape marc too densely and turn soils anoxic.[197]

A variety of approaches are used to process and make use of grape marc (see table 2), including its use as animal feed.[196,197] Studies examining grape marc as an animal feed supplement have focused on ruminants,[196] and ongoing research in Aotearoa concentrates on the use of microbiologically treated grape marc as dairy cattle feed, potentially reducing reliance on palm kernel expeller.[198–200] The focus on ruminants stems from the fact that grape marc's composition aligns most closely with ruminant diets (compared to fish, pig, and poultry diets, see annex 8). In addition, tannins have been shown *in vitro* and *in vivo* to be associated with reduced enteric methane emissions from ruminant animals, making grape marc feeding a potential part of the agricultural methane mitigation landscape.[201–203] Part of the methane reduction observed is attributable to tannins combining with carbohydrates and protein in the rumen and interacting with fibre,[201] and some is through the direct inhibitory effect of tannins on methanogenic bacteria.[201,204] There are some important caveats to the anti-methanogenic properties of grape marc. Not all *in vitro* studies report reductions in methane output per unit of gain or energy intake.[205]

Grape marc may additionally have potential in material recovery (see section 3.3) and is the subject of a $18.8 million research grant at Waipapa Taumata Rau | University of Auckland to explore this possibility.

Table 2: Highlighting the variety of products and uses that can be derived from grape marc through different means of processing.

Product	Process	Use	Development status
Animal feed.[201–203]	Raw or processed – ensiled or dried.	Palm kernel expeller alternative.	Experimental.
Compost and soil fertiliser.[206,207]	Anaerobic and aerobic microbial activity.	Agriculture and environment.	Established.
Dietary fibre.[208]	Pressing, maceration, and then chemical analysis.	An alternative dietary fibre source to cereals.	Experimental.
Ethanol (grape spirit).[196]	Fermentation.	Beverages like marc, pomace brandy, grappa, and aguardiente.	Established.

Product	Process	Use	Development status
Gas, tar, bio-oil, and biochar.[196,209]	Pyrolysis.	Further processing of bio-oil via hydrogenation and catalytic cracking can produce fuel products like refined petroleum, such as diesel and high-octane gasoline.	Experimental.
Phenolic compounds from lignin.[196,210]	Extraction of lignin and cellulose using an autohydrolysis pre-treatment followed by the use of organic solvents to solubilise cellulose and lignocellulose.	Inhibitors of microbial growth and natural antioxidants.	Experimental.
Phenols, tannins, pigments, & antioxidants.[196]	Chemical extraction using ethanol, methanol, and acetone.	Industrial, food, and health products.	Well studied.
Syngas, blended fuels, electricity.[196,209]	Thermal treatment of biostock through torrefaction, hydrothermal carbonisation, combustion, and gasification.	Variety of uses, including combustion in gas turbines or electricity and heat generation.	Experimental.
Tartaric acid.[196,211,212]	Chemical extraction using hydrochloric acid or water followed by tartrate precipitation with calcium salts. Alternately, bipolar membrane electro-dialysis (BMED) can be used.	Food and beverage.	Chemical extraction is established, BMED is experimental.

What table 2 does not show is how much wasted grape marc these processes could avert. For processes like compost where the entire marc is used, the waste averted is potentially high. For processes that rely on extraction or fermentation, however, there will still be residual waste, but to our knowledge this has not been quantified either for the process in general or, more usefully, in the context of the Aotearoa food system. This is another dimension of the data gap in this space.

Practical considerations for making animal feed

End consumers and companies looking to redirect their waste should be cognisant of regulatory requirements, particularly the *Agricultural Compounds and Veterinary Medicines Act* and the *Animal Products Act*. Requirements under these acts include ensuring feed will not cause harm, spread disease, or otherwise jeopardise the health and welfare of the fed animal, and when used in animals producing food for human consumption (e.g. pigs, cattle, sheep, etc.), ensuring there will also be no compounds or residues that can present a food safety risk. These requirements also apply where there might be indirect exposure, such as in compost (see section 4.3). Mitigation of biosecurity and infection risk is detailed in annex 6 and annex 7.

Animal feed that results from using FLW must fit a range of criteria to be viable, and these in turn create some logistical challenges. The food itself needs to be palatable, digestible, appropriately nutritious, and non-toxic to the target animals. Substituting feed derived from FLW cannot cause animal productivity per unit of food consumed to drop, so it will be necessary to determine the optimal substitution level for a given animal and food waste stream. [159,189]

> Substituting feed derived from FLW cannot cause animal productivity … to drop so it will be necessary to determine the optimal substitution level for a given animal and food waste stream.

These requirements and risks can create challenges to utilising food loss and waste. There is considerable variability in nutritional value between different waste streams, [182] and even within some individual streams, such as mixed post-consumer food waste.[189] In addition, not all nutrients in food are in a form that is digestible (i.e. able to be taken up and used by an animal), or digestion may be inhibited by anti-nutritional factors that are also present.[195] Some issues around palatability, digestibility and nutrition, and biosecurity and infection can potentially be mitigated with existing techniques (see annex 6), and, in the case of biosecurity and infection, are the subject of existing regulation (see annex 7). Commercial pig farmers tend to avoid feeding with food waste because of biosecurity concerns. In some jurisdictions, government investment has enabled more food waste to be converted to animal feed while maintaining biosecurity.[213]

Additional challenges relate to logistics. Useful by-products are not always produced near the animals that could utilise them as feed.[189] For example, over half of the country's pig farms are based in the South Island, as is the majority of our aquaculture industry, so food waste streams that might be suitable for pigs or salmon that are produced in the North Island would largely need to be transported. Fluctuating availability of food waste streams is another challenge. [10,189] The amount and type of food waste available can be unpredictable or seasonally variable, which can make feed planning difficult. Fish feeds have their own unique challenges with the need to be water stable.[189]

Farmed animals and pets are not the only animals that can be fed on food waste streams. To protect the eels of Te Roto o Wairewa (Lake Forsyth) and the way of life and cultural values they uphold, Rūnanga Wairewa is considering producing meal from caught perch and locally produced food waste streams, to be fed to mature eels in the lake or juvenile eels in hatcheries (see case study 9).

A more detailed understanding of what is currently being utilised and what remains to be utilised is being developed by a collaborative project between PFR, AgResearch, Scion, and Callaghan funded by the BPA, which seeks to map food processing by-products and waste that could be utilised as animal feed.[214] The pilot project, entitled Logistically Optimised Animal Feed (LOAF), is connecting with industry to build a database of bioresource suppliers and their resources, with the goal of connecting suppliers with makers of animal feed. This database can be a discovery tool, allowing animal feed makers to source feed ingredients locally and at a reduced cost, while giving suppliers the opportunity to valorise their secondary waste streams (e.g. spent grain). The researchers will look at transport costs and the animal feeds that could be replaced with by-products that we already have.[214] The approach could also be used in the context of upcycling by-products to human-edible foods or new materials (see section 3.1, upcycling and section 3.3, material recovery).

A more detailed understanding of what is currently being utilised and what remains to be utilised is being developed by a collaborative project between Plant and Food Research, AgResearch, Scion, and Callaghan…

Finally, we need to ensure that the way we incorporate food waste to our feed systems does not undermine the food recovery hierarchy.[17] At present, animal feed in Aotearoa and globally includes food which would have been perfectly good for humans to eat, or surplus food that could have been prevented at source (e.g. bakery surplus, fisheries by-catch, out-of-spec produce).[10,189,191] As efforts to prevent food waste at source and keep edible food in the human food supply chain increase, we need to ensure that our feed systems are resilient to a transition away from these feed ingredients and do not embed their continual production.

…we need to ensure that the way we incorporate food waste to our feed systems doesn't undermine the food recovery hierarchy.

Case study 9: Protecting the tuna (eels) of Te Roto o Wairewa

Te Roto o Wairewa (Lake Forsyth) is a shallow coastal lake on the southern flanks of Banks Peninsula (Te Pataka o Rākaihautū), just south of Ōtautahi Christchurch.[215] The management of Te Roto o Wairewa is led by the papatipu rūnanga of Ngāi Tahu, Wairewa Rūnanga, in a close co-management partnership with the Christchurch City Council and Environment Canterbury. Te Roto is culturally significant for all Ngāi Tahu, being one of three customary lake fisheries in Aotearoa.[216] Native shortfin and longfin tuna (eels) are seen as the mauri (lifeforce) of Wairewa Rūnanga, and customary tuna harvesting has been a key source of kai for many Ngāi Tahu and Wairewa whānau for generations (see figure 21).[216]

Figure 21: Drying eels on the banks of Te Roto o Wairewa (Lake Forsyth) in 1948. Image credit: Bigwood.[217]

The lake, which was formerly a tidal inlet before a barrier bar naturally formed prior to 1840,[218,219] like the majority of coastal lakes in Aotearoa, suffers from poor water quality and the presence of introduced perch, which negatively impact the lake's health and the prosperity of its tuna.[215,216,220]

The main cause of poor water quality in the lake is historic deforestation, pollution from surrounding settlements, and farmland and ongoing erosion of phosphorus-rich volcanic soils in the surrounding catchment, with previously deposited and newly introduced P driving cyanobacterial 'toxic algal' blooms since at least 1907.[220,221] These events have long been known as 'Te tutae o te Taniwha' the excrement of demons by the mana whenua of the area. During peak toxic algal blooms, fishing must stop, as toxins can accumulate in fish and can't be inactivated by cooking, posing a risk to human health.[216,222,223]

To address the falling lake water quality, in 2009, the Rūnanga constructed a canal at the lake outlet which has reduced the amount of time the lake is exposed to seawater incursions. Not only have the number of average monthly measurements of chlorophyll α (<10 micrograms/litre), indicative of safe swimming conditions increased from 0.67 months per year between 1994-2009, to 2.45 months between 2010-2023, but the frequency of toxic algal bloom events of *Nodularia spumigena* that cause eel deaths has dropped significantly.

In addition to the impact of toxic algal blooms, introduced perch (brought to Aotearoa in 1868 for angling) predate on juvenile ('glass') eels, further threatening the wellbeing of the lake, its tuna, and the customary fishers who rely on it.[216,224,225] Comparing current population data to oral histories, particularly from WWII when a mass harvest was conducted for the war effort, and archival photos (see figure 21) suggests that the tuna population in the lake today is smaller than it has been historically (see figure 22).[216]

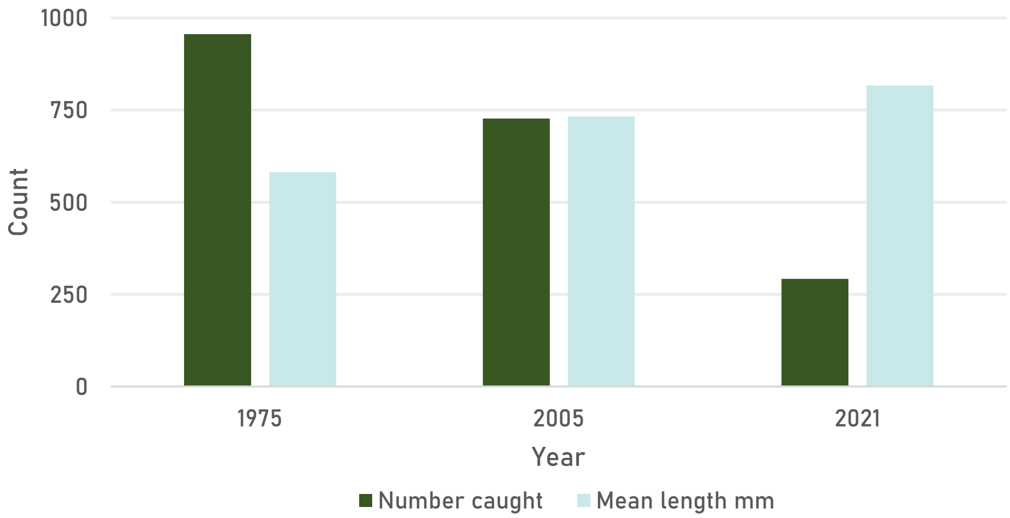


Figure 22: Tuna capture data from Wairewa Roto between 1975 and 2021 showing the number caught using comparable capture methods (dark green bars) and the mean lengths (light blue bars). Wairewa has consistently produced the highest abundance data for any coastal lake in Aotearoa, which remains the case now. In contrast to shortfin tuna, longfin tuna has significantly been increasing in abundance which may suggest something about the differing recruitment abilities of each species. In 2005, the entire population of tuna was predicted to crash but the Rūnanga-led construction of the canal has enabled longfin tuna to flourish when this species is falling in abundance in most places across Aotearoa. Data sourced from Shannan Crow (Te Atiawa), NIWA in conjunction with Wairewa Rūnanga.

As kaitiaki, Wairewa Rūnanga are exploring multiple interventions aimed at ensuring the prosperity of the customary lake tuna fishery. At present their efforts are focused on the development of a dynamic fish pass system to improve glass eel recruitment, the key to the survival of the eel fishery.[216] Research has shown that targeted and well-timed perch removals can allow native fish populations to grow including tuna,[225] so one of the proposed solutions is to catch perch from the lake to reduce their overall numbers.[216] The caught perch would be combined with locally produced food wastes to produce a meal that could be fed back to mature eels in the lake or glass eels in hatcheries, facilitating eel survival and population growth.[216]

In addition to perch management solutions, Wairewa Rūnanga, alongside the fish pass system, have designed a siphon for extracting sediment from the lakebed which can be processed along with other organic wastes, into a fertiliser product for use in the local area.[216] Soil conditioners and nutrient recovery are covered in section 4 of this report. In addition, holistic catchment management to reduce further erosion of the surrounding steep land will decrease the rate of sedimentation, contributing to improved water quality over time.[218]

Food waste to animal feed with the help of insects

Food system by-products and post-consumer food waste can be converted to a protein- and fat-rich animal feed by insect bioconversion (see figure 23).[226–228] Insects are raised on food waste, and then used as feed for pigs, poultry, fish, and reptiles.[227–229] The insect frass, residual food, and exoskeletons can be used as a fertiliser product.[227,228,230,231] Insect bioconversion is a growth industry,[227,228,232] but currently is not practiced at scale in Aotearoa, although pilot-scale efforts by PFR (see case study 10) and other businesses are underway.[233,234]

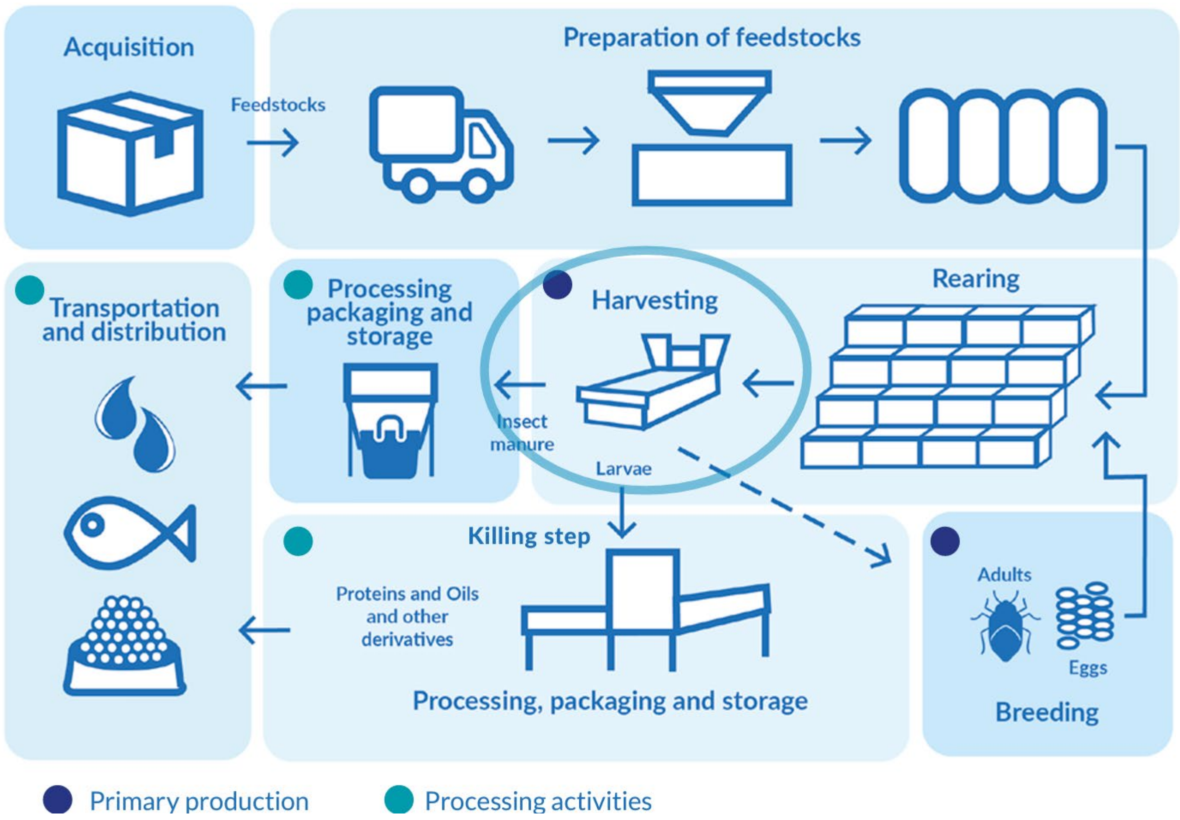


Figure 23: Overview of the process of insect bioconversion, starting with acquisition of a food waste feedstock, through to feedstock preparation, insect rearing, frass and insect harvesting, and distribution as feed and fertiliser, and potentially as biofuel (a less common application). Image credit: International Platform of Insects for Food and Feed.[235]

Insects raised on food waste can be fed directly to animals or processed into bio-oil and protein powder, which can be combined with other ingredients to make nutritionally balanced feeds.[228] While animal feed is the primary use of waste-fed insects, they can also be used as human food or for the extraction of useful components with applications including biofuel, lubricants, pharmaceuticals, and dyes.[227,228] Use of insects as human food in Western countries is limited; insects generally are unfamiliar foods, with consumer preferences and willingness to accept this new food category representing significant barriers.[236,237] Therefore, the environmental benefits of insect bioconversion come predominantly from the displacement of other protein sources, especially mammalian protein, in animal (or human) diets.[238]

While energy use in insect bioconversion is high (e.g. for temperature control, lighting, and aeration),[238–240] this environmental and emissions cost is generally offset by the reduced land use and context-dependent reduced greenhouse gas emissions associated with insect farming relative to the production of other animal-based proteins for animal feed or human food. [238–241] The environmental benefits of insect bioconversion seem to be inversely associated with the quality of the by-products on which the insects are raised.[242]

Insect bioconversion has implications in domains beyond the environment. The potential benefits and challenges are summarised in table 3.

Table 3: The key benefits and challenges of insect bioconversion of food waste to animal feed.

Key benefits	Key challenges
• If insects replace other protein-rich animal feeds, this food waste processing option can have a substantially positive impact on greenhouse gas emissions,[238] reducing emissions from the feed production industry by using food waste as a resource instead of growing animal feed anew. This emissions benefit far outweighs any electricity-associated emissions,[238] which can be quite high (e.g. for lighting, temperature regulation).[243] • Feeding food waste directly to animals can make it hard for farmers to ensure their animals are eating a nutritionally balanced diet for optimised productivity and wellbeing. Using waste-fed larvae instead helps to overcome this challenge.[244] • Selective breeding programmes can be used to increase the efficiency of bioconversion,[245] meaning that more of the nutrient and energy content in the food waste is converted to insect larvae for animal feed. • Compared to feeding untreated food waste to animals, bacterial, viral, and parasite[226] and other risks are reduced when food waste passes through the insects (e.g. viruses which are evolved to infect mammals can't readily replicate in insects) and can be further mitigated by managing the food waste streams that go into the process and by rinsing, blanching, and drying the larvae.[246]	• Inconsistent waste streams (e.g. mixed household food waste) can make process and product management hard[247] – the insects will develop differently with variations in the food waste they are raised on meaning that not all batches of insect larvae will be the same, and process variations might be needed. • If there are contaminants in the food waste,[247] some are broken down by the insects (e.g. some organic pollutants, toxins, pesticides, and pharmaceuticals), but others (e.g. heavy metals) may either be taken up by the insects or end up in the frass mixture, creating possible health risks for the animals that eat the larvae or soils where frass is applied, and food derived from them. These risks are best managed by tight control over inputs.

With insect bioconversion research expanding and an increasing number of companies emerging (see case study 10 as well as an example in Australia called FlyFarm),[227,228,247] government regulation of the sector is struggling to keep pace.[248] In some countries, use of insects as animal feed is outright banned, in some it is completely unregulated, and in others it is tightly regulated.[247,248] Policies have been reviewed and developed in the EU, US, and Canada over the last decade.[248] Aotearoa does not have any specific regulations relating to the use of insects as animal feed. If not addressed, this regulatory grey zone may serve as a barrier to growth of the sector or alternatively may create an overly permissive environment with potential risks going unmitigated.

> Aotearoa doesn't have any specific regulations relating to the use of insects as animal feed.

Case study 10: Plant and Food Research - bringing insect bioconversion to Aotearoa

In 2022, PFR established their Insect Bioconversion Facility in Palmerston North, a pilot plant which uses black soldier flies (*Hermetia illucens*) to convert bioresource streams into high-protein animal feed. The PFR facility aims to optimise the use of black soldier flies as a bioconversion tool in New Zealand, with a focus on using New Zealand sources of organic waste to produce a nutritious and functional feed for a growing aquaculture market.

PFR's Insect Bioconversion Facility is divided into three sections designed to breed, rear, harvest, and process black soldier fly larvae to larval meal:

- *Breeding section*: This initial section comprises both outdoor and indoor breeding facilities dedicated to housing adult black soldier flies (see figure 24). Temperature and light conditions are carefully maintained to ensure the successful reproduction and maintenance of a healthy fly population.
- *Rearing section*: The second section encompasses facilities for thorough egg inspection and four specialised rearing rooms, each catering to different developmental stages, starting from eggs and progressing through various larval instars until pupation (see figure 24). During the larval stage, which lasts approximately 14 to 21 days, the larvae are fed with organic waste or waste by-products. Once the larvae reach the pre-pupal stage, they cease feeding and subsequently, transition into the pupal stage, which typically lasts around 7 to 10 days. After hatching, the adult flies are transferred back to the breeding cages for continued breeding and egg production.


Figure 24: Left Black soldier flies in an adult breeding cage. Right Black soldier fly larvae in the rearing section during the feeding stage.

- *Processing section*: The third and final section houses the main lab, where larvae are harvested and undergo processing to create a larval meal. This critical stage involves careful extraction and preparation of the larvae to produce a highly nutritious and sustainable protein source for animal feed. The larvae are separated from their frass (excrement and remaining food) and washed, before being blanched or frozen. The insects are then dried before being ground to a fine powder (see figure 25).

Figure 25: Black soldier fly larvae processing to the larval meal.

Over their first year of trials, PFR experimented with a variety of feedstocks, including spent grain, grape marc, kitchen waste, rejected fruit and spent coffee grounds. The black solider fly larvae will eat most sources of organic waste, but early trials suggest that kitchen waste results in the best weight gain by larvae relative to the amount of food they receive (the 'feed conversion ratio'). In PFR trials, it took roughly two kilograms of mixed food waste to produce a kilogram of larvae, a ratio substantially more efficient than that of cattle or pigs, and on par with many species of fish. The Palmerston North facility is designed to produce about 300 kilograms of larvae a week, and the team are producing up to six grams of fly eggs per day on average.

Black soldier fly larvae form the basis of the insect meal produced at PFR's Insect Bioconversion Facility. This insect meal is incorporated into pelletised fish feed. Trials on juvenile snapper fed a prototype feed containing 30% black soldier fly meal showed that fish had similar feed intakes and growth rates to those fed a control diet. In line with international regulations around fish feed, the larvae used to produce fish feed are fed with horticultural products only.

PFR is exploring multiple avenues for optimising insect bioconversion in the New Zealand context. This includes making use of process by-products like frass, either as a fertiliser (see section 4.3 on nutrient recovery) or source of insect feed for other animals. Additionally, PFR is focussed on process optimisations as they look to scale up their pilot work, build out a reliable supply chain for both feedstocks and insect colonies, and collaborate with a range of stakeholders and experts to bring insect-derived feedstocks to market. PFR is currently working with Veolia New Zealand as part of a SFF Futures funded pilot project investigating the suitability of various NZ organic waste streams as feed for Black Soldier Fly. This research will help confirm if the insect meal produced is suitable for animal feed and aquaculture.

Food system by-products can be used in cellular agriculture too

While this section of the report has focused on the use of food system by-products as animal feed in conventional agricultural systems, there is also potential to use by-products in the fast-growing field of cellular agriculture. Cellular agriculture uses cell cultures to produce products that are 'biologically equivalent' [249] to products like meat, milk and eggs, allowing such products to be produced in the lab. Cellular agriculture products are predominantly in the research and development phase,[250] although a limited number are available for purchase overseas.[251]

Cellular agriculture requires growth media and, for structured meat products (e.g. steak), scaffold materials.[252] There is potential for food waste to be used in both growth media and scaffold materials. By-products from conventional animal agriculture are the most common scaffolds at present, particularly collagen and gelatin.[249] Chitosan derived from shellfish exoskeletons can also be used,[253] and polylactic acid from dairy by-products has recently been developed as an edible film.[249] Food system by-products turkey collagen and eggshell membrane have been shown to have potential as microcarriers for cultured beef cells.[254]

Plant-based scaffolds are increasingly being explored, including some which could utilise by-products from conventional plant-based agriculture.[249] Proteins from soy, peas, and corn show promise as scaffold materials, as do plant-derived polysaccharides such as cellulose, starch, and pectin.[249,252] A recent field of exploration is the use of decellularised plants as scaffolds, with cells being mechanically, chemically, and/or enzymatically removed from plants while their extracellular matrix and/or vasculature remains intact, providing a tissue-like structure for cultured meats to grow on.[252,255,256] This has been demonstrated in lab conditions with spinach, apple, jackfruit, and broccoli (see figure 26).

Plant-based scaffolds are increasingly being explored, including some which could utilise by-products from conventional plant-based agriculture.

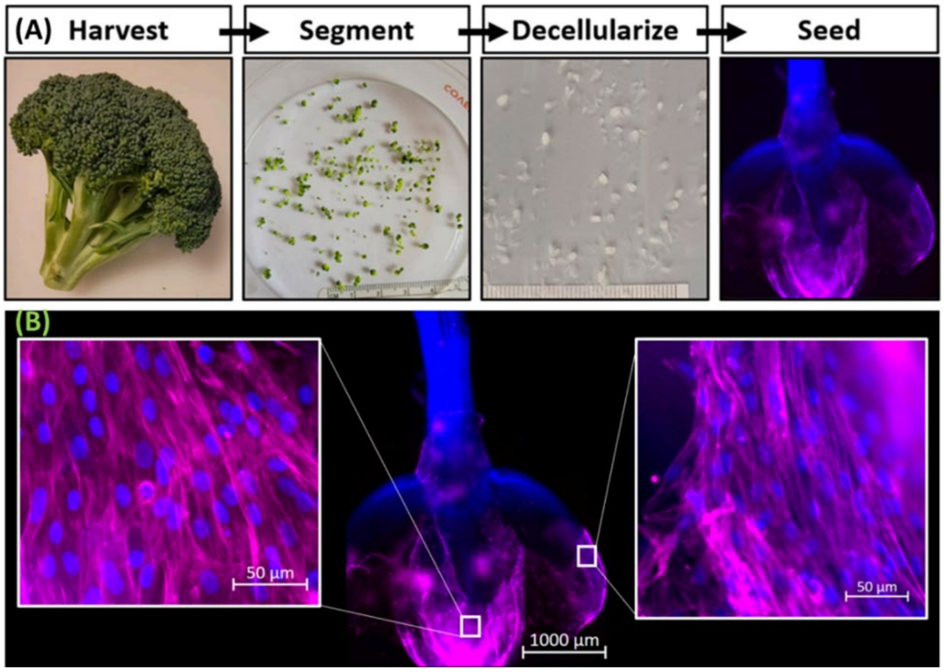


Figure 26: Decellularisation of broccoli florets for use as edible carrier scaffolding for bovine cells. Panel A shows the process of decellularisation, which in this experiment was achieved by chemical treatment, and inoculation of the decellularised broccoli scaffold with bovine cells. Panel B depicts the growth of bovine cells in the broccoli scaffold, where blue indicates the presence of DNA and purple indicates the presence of cytoskeletal actin. Image credit: Kumar and colleagues,[252] adapted from Thyden and colleagues.[256]

Food system by-products can also be used as a growth media for bacteria or fungi, which can be alternative proteins in themselves (e.g. oyster mushrooms cultivated on grape marc)[196] or can be used to produce growth media or scaffolds needed for cellular agriculture.[253] For example, bacterial cellulose, which can serve as a cultured meat scaffold, can be produced by bacteria grown on grape skin extracts and spent sulphite liquor from the pulping industry, and chitosan scaffolds can be produced from fungi grown on industrial waste, cassava waste water, and corn steep liquor.[253]

Food waste must have certain qualities to be viable as an input into cellular agricultural processes. For example, scaffolds should be edible and add nutrient and sensory value to cultured meat (if not, they either need to degrade during culturing or be removed during processing).[249,252] Identifying suitable food waste materials will be an important research task.

3.3 Food processing by-products can have valuable material properties

Food production results in a considerable amount of waste during primary production and during processing and manufacturing before the food reaches distribution chains. Figures are not available for Aotearoa but a study of food waste in the EU found that 25% (by mass) of food loss and waste is generated at the primary production stage and 24% during processing and manufacturing.[257] As discussed above (see section 3.1) some of this material can be used to create new food products or animal feed but the remainder provides a significant resource for recycling into non-food materials. The products are often described as 'biobased materials' [258] but for simplicity we refer to this tier of the food recovery hierarchy as 'material recovery' (see figure 27), defined as the use of inedible components of food to produce useful materials.

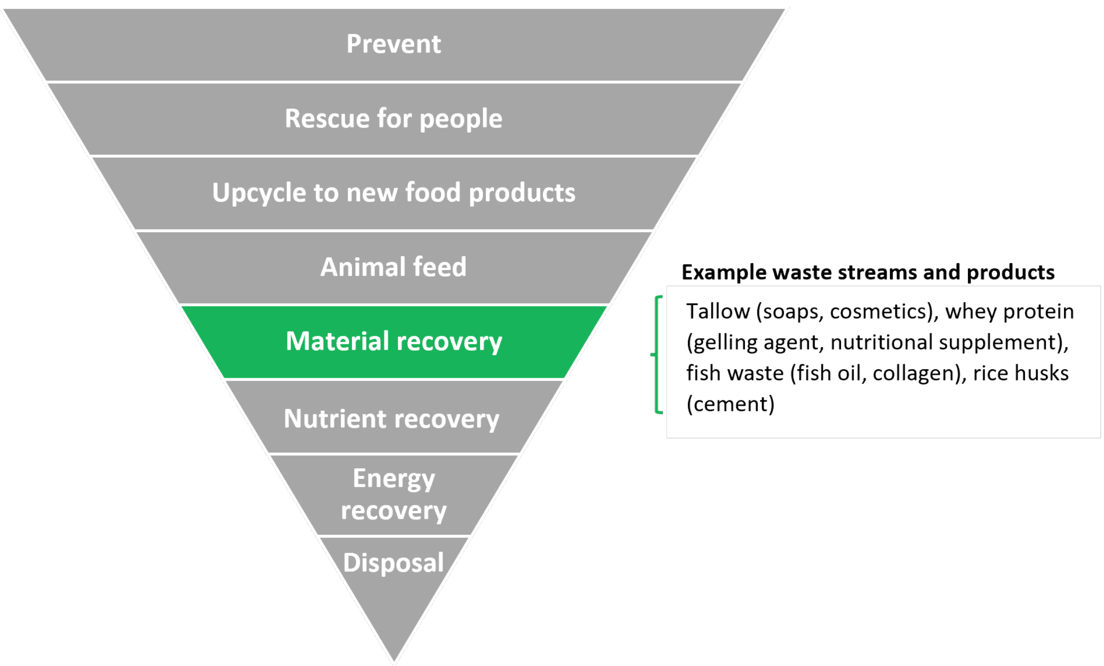


Figure 27: Situating material recovery strategies within the food recovery hierarchy, with examples of waste streams used and their resulting products.

Deriving other useful materials from plants and animals used principally for food has a long history. The use of animal hides for leather to make clothes, receptacles, and even living quarters; bones as tools, musical instruments, and jewellery; cereal straw as a building material, and so on, has been known since antiquity. Living in a resource constrained environment, pre-technology cultures made the best use of the materials that came to hand. As these materials found synthetic substitutes that were easier and cheaper to produce, the original food-derived products have either become luxury items, or their use has been lost.

However, in the face of climate change and the need to improve sustainability, efforts to fully utilise plants and animals grown for food have increased, both to boost financial returns from food production, and to reduce waste and the impacts of climate change.[259] This includes traditional uses as well as the development of new products from beneficial materials isolated from plants or animals that are difficult or impossible to manufacture synthetically, and the residues from food production provide an economical source that is available at scale.

Aotearoa's economy is largely based on food production and traditional by-products, such as wool from sheep, leather from farmed animals, and velvet from deer antlers, all of which are widely produced and make a contribution to export earnings.[260] The country also has a number of companies based on more sophisticated products and the MBIE funded BPA, involving three Crown Research Institutes and Callaghan Innovation, has been set up to work with the primary industries to get better value out of biological by-products.[109] For many companies, going from lab trials to market is a challenging step. There is scope for more work in this space, and MBIE has recently published a relevant report series.[261]

Materials from animals grown for food

Once an animal has been slaughtered, between 20% and 60% of the animal can be used directly for food,[262] with the rest needing to find other uses or wind up in landfill. In Aotearoa the meat processing industry sends very little of the processed carcasses to landfill[263] but many of the uses are low value, for example blood and bone meal, which is used as a fertiliser, although sales are increasing as markets look for an organic alternative to synthetic N fertilisers (see section 4.3). The meat processing industry continues to seek higher value uses, to improve returns per carcass, to reduce waste disposal costs, and to reduce environmental impacts.[264]

Once an animal has been slaughtered, between 20% and 60% of the animal can be used directly for food...

Although they have little impact on the volume of material wasted, a variety of niche products including health products and cosmetics can be derived from animal carcasses, such as replacement heart valves, wound treatments, and medications. International examples of companies adopting this approach include Johnson & Johnson,[265] Edwards Lifesciences,[266] Pfizer,[267] and Kerecis,[268] while work is also being undertaken in New Zealand (see case study 11).

Animal derived products from New Zealand

The scale of milk processing in Aotearoa makes by-products an abundant resource for other useful, non-food, products. Cheese and casein production leave a high protein liquid, whey. In the early 1980s, growth of the New Zealand milk industry was stalled because of the difficulties in disposing of whey from casein production, which at the stage was dumped untreated in waterways or sprayed on paddocks.[269] Staff at the New Zealand Dairy Research Institute had been looking at the problem for a number of years and developed the process of reverse osmosis to isolate the proteins from whey economically at scale, implementing it across the industry in the late 1980s. In 2021, Aotearoa exported US$66 million of whey protein, mainly for use as a gelling agent and as a nutritional supplement aimed at sportspeople. The liquid left from removing the protein from whey is high in lactose which can be fermented to ethanol.[270] The bulk of industrial ethanol, including that used in biofuels, available in New Zealand is derived from whey (nearly 20 million litres per year[271]). Lactose from milk can be also used as in inert material in tablet formulation.[272,273]

The health status of animals farmed in Aotearoa, in particular the absence of prion diseases such as bovine spongiform encephalopathy and scrapie, make the country an ideal source of animal-derived human health products. Southern Lights Biomaterials was started in 2004 to manufacture collagen products for regenerative medicine (e.g. collagen scaffolds for replacement heart valves) from animal processing waste[274] and has since been acquired by the large American company Collagen Solutions.[275] New Zealand Pharmaceuticals was set up in the 1970s to extract high value products from meat processing by-products, focussing on bile acids from beef processing for use in the pharmaceutical and nutraceutical industries. Waitaki Biosciences in Christchurch produces health supplements including a collagen/chondroitin sulfate[i] mix for joint health,[276] and Gelita in Christchurch has been producing gelatine for a variety of uses since 1913.[277]

Auckland-based Aroa Biosurgery[278] (see case study 11) uses tissue from sheep fore-stomachs to produce a regenerative wound healing product. The stomach tissue is stripped of its cells leaving the extracellular matrix containing a variety of growth stimulating molecules to simultaneously patch and stimulate regrowth in wounds.

Case study 11: Aroa BioSurgery

Founded in 2008, Aroa Biosurgery launched a proprietary extracellular matrix (ECM, AROA ECM™) to support tissue generation. AROA ECM is processed from sheep forestomach tissue, resulting in ECM of similar composition to human soft tissue that can be used for managing wounds and ulcers caused by diseases or injury. The ability of the ECM to establish blood supply and provide reinforcement for the growth of functional tissue makes the product valuable for clinicians as it is one of a few commercially fabricated products used to manage wounds that are difficult to heal (see figure 28).[279] There are other commercially available products that do not utilise animal-derived tissue, such as human-derived tissue, devices that utilise negative pressure or gels, and engineered biomaterials. However, the abundance and availability of animal sources have popularised research on their viability.

Aroa's first product after 10 years of research was the Endoform™ Dermal Template, launched in the US in 2013 after gaining US Food and Drug Administration clearance.[278] Since then, Aroa has developed a few more products using the ECM technology to target different types of wounds, and the success of these products led to Aroa being listed on the Australian Securities Exchange in 2020.

Figure 28: Wound management progress using Myriad Morcells, a product utilising AROA ECM™. Abbreviation: ECM = extracellular matrix. Image credit: AROA.[280]

Animal processing waste can also be used as a source of other novel biomaterials. One application is the development of a biodegradable plastic from bovine blood protein by Waikato based company

[i] A complex carbohydrate from cartilage.

Aduro Biopolymers, which has been used as compostable consumables in the animal processing industry.[281]

Utilisation of fish products

Internationally, the use of fish processing waste has gained significant momentum in recent years as a sustainable source of non-food products.[282] This waste, consisting of fish heads, scales, bones, and other by-products, is being recycled to extract valuable chemicals, like collagen and omega-3 fatty acids, which are widely used in cosmetics and health products. Additionally, the conversion of fish waste into biodegradable materials and biofuels contributes to a more circular economy.

Based on a gutted fish with its head on, processing typically generates 35-40% edible meat and the remaining non-edible tissues are bones, skin/scales, swim bladders, intestines, roes, liver, blood etc., which are a rich source of valuable components such as protein, fats and oils, enzymes, bioactive peptides, pigments, flavours, vitamins and minerals. Globally, 20 million tonnes (approximately, 12% of total fish production, 171 mega tonnes) is used for non-food purposes, out of which, 15 mega tonnes is reduced to fishmeal and fish oil and the remaining 5 mega tonnes is used for added value products.[283]

Globally, 20 million tonnes (approximately, 12% of total fish production, 171 mega tonnes) is used for non-food purposes, out of which, 15 mega tonnes is reduced to fishmeal and fish oil and the remaining 5 mega tonnes is used for added value products.

Products derived from fish processing in Aotearoa

Fishing companies in New Zealand throw away thousands of tonnes of fish waste, comprising unused fish heads, guts, and frames, each year.[284] As discussed in our report *The Future of Commercial Fishing in Aotearoa New Zealand*[285] there are a number of products that can be made from fish besides food to ensure that all of the fish is used, including fish oil, fish meal, and marine collagen.

Fish processing waste can be further processed to extract oil which is rich in omega-3 fatty acids for use as human health supplements. Valuable oils, principally squalene, can also be extracted from shark livers (in Aotearoa, mostly dogfish) which is used in cosmetics and as an adjuvant in vaccine delivery. There are several New Zealand producers of fish oils, including Sanford, Omega Innovations, Aroma, and Seadragon. The country exports around 4,000 tonnes of fish oil annually.[286]

Collagen from fish waste is used in the food, cosmetic, and pharmaceutical industries. Collagen from fish has a lower melting temperature than collagen from terrestrial animals, which is suggested to make it easier to digest. The Danish company Ferrosan developed a marine collagen product, Imedeen, in 1991 which drove the global popularity of marine collagen as an oral beauty supplement,[287] although more research is likely required to assess efficacy.[288] The global market is expected to reach over US$1 billion by 2026 and Sanford have developed a product in Aotearoa based on collagen extraction from sustainably caught hoki skins.[289]

Materials from arable and horticulture crops

In theory, almost any material that can be made from petrochemical sources can be made from biomaterials, which, depending on the emissions released during processing and impacts related to disposal and leakage into the environment, may make them sustainable. However, growing crops specifically to replace petrochemicals, as with bioethanol production from corn, requires large areas of land which could otherwise be used for food production. Using the non-edible parts of crops grown for food to replace non-sustainable materials avoids this problem. Adding value to the non-edible parts of food crops also improves the economics of food production and reduces waste to land fill and the need to burn crop residues, which gives rise to harmful smog. Waste from arable and horticultural crops includes prunings and thinnings, materials such as straw from cereal crops left after harvest, and material remaining after processing, such as meal left over from oil pressing, or grape marc from wine production (see case study 8).

Lignocellulosic waste from food crops, such as rice, corn and wheat stalks and sugarcane bagasse, can be used to produce ethanol or lactic acid, after removal of the lignin and digestion of the cellulose to allow fermentation of the resulting glucose.[290] This allows the production of biofuels and bioplastics, such as polylactic acid, as by-products of food production rather than growing special crops competing for space with food. The isolated lignin can then be used in resins for binding particle board and other composite wood building materials[291,292] - although typically this comes from wood processing waste.[293] Synthetic vanilla flavouring can also be derived from lignin.

Straw has traditionally been used as a biodegradable packing material. Fibres from food crops, particularly hemp, can be used to replace petrochemical derived fibre in a number of packaging[294] and biomaterial applications, including products currently made from petrochemicals that are used in horticulture.[295] Hemp and linseed harvest waste has been proposed as a source of fibre for yarn to make carpets.[296] The New Zealand company Zespri, along with research institute Scion, has developed the Biospife, a tool for eating kiwifruit that incorporates kiwifruit processing waste and can be composted along with the skins after eating the fruit.[297]

Construction materials such as concrete, masonry, insulation, and reinforcement material can be made from a diverse range of crop processing wastes. While the total market for sustainable building materials was estimated at US$300 billion in 2021 and expected to grow at a compound annual growth rate (CAGR) of 12.7% to reach US$980 billion by the end of 2031, it is not clear how much of this is derived from the use of crop processing waste rather than purpose grown crops, such as bamboo, or recycled building materials. A recent report found nearly 700 articles on potential uses for agricultural waste, including coffee grounds, in building materials with the majority as additives to concrete.[298] Very few have been adopted by industry. The exception is rice husk ash, which is very high in silica, and provides a replacement for Portland cement.[299] The global market for rice husk ash was US$1.3 billion in 2021 and expected to double by 2031 with 40% being used in the manufacture of building materials.[300] New Zealand researchers are exploring the potential of straw in prefabricated structural insulated panels to be used in home building.[301]

4. Recovering nutrients and energy

4.1 Not all food loss and waste streams are suitable for upcycling, animal feed, or material recovery…

Aside from foods used in upcycling, the waste streams discussed in this report are all inedible to humans. While some of this waste may be suited to animal feed and material recycling, the majority is ill-suited to this set of solutions. For example, household food scraps mixed for collection and inedible foods like used cooking oil or rotten fruits have little to no application to feeding people or animals and are of limited use to material recycling efforts.[17] Importantly, the scale of these waste streams is significant. For example, in the US, an estimated 48% of all food waste comes from households,[65] by far the biggest contributor to waste along the American food supply chain. In Aotearoa, households throw out almost 160,000 tonnes of food a year,[302] most of which ends up in landfills. Although much of this waste is preventable, plenty is not.[303]

…the scale of these waste streams is significant. For example, in the US, an estimated 48% of all food waste comes from households…

Unpredictable sources of food loss and waste also present a challenge to waste management systems. A range of scenarios can see tremendous volumes of food become suddenly inedible, including extreme weather events, or supply chain or infrastructure failures.[4,17,304,305] Such scenarios can result in substantial amounts of food unavoidably going to waste, (e.g. to ensure safe food practices).[120,304,306,307] Without adequate planning or regulation, such food can quickly slip to the bottom of the hierarchy and end up in landfills, even though options like composting or AD represent better end destinations for this waste (see annex 2).

4.2 …but there are still opportunities to capture value

Food loss and waste has nutrient value and its calorific content can be transformed into useful energy sources. In the food recovery hierarchy (see figure 29), 'nutrient recovery' refers to the process of extracting valuable nutrients from food waste so that they can be used in agricultural systems, gardens, and to regenerate natural environments.[17] In this the context, 'nutrients' is often used as a catch-all phrase for substances that improve soil quality for plant growth, typically referring to N,P,K, and trace elements like magnesium, calcium, iron, and zinc (see box 1),[308,309] but also soil organic matter content which plays a key role in C cycling and maintaining soil structure.[310,311] Capturing the nutrients in food loss and waste provides the opportunity to 'close the loop' in nutrient cycles,[15,308,312] whereby the nutrients found in food waste can be used as feedstock for another cycle of food growth.[57] A variety of different processes enable nutrient recovery from food waste (see section 4.3), with commonly practiced methods including composting, vermicomposting, ploughing back in to soils, and AD.[31]

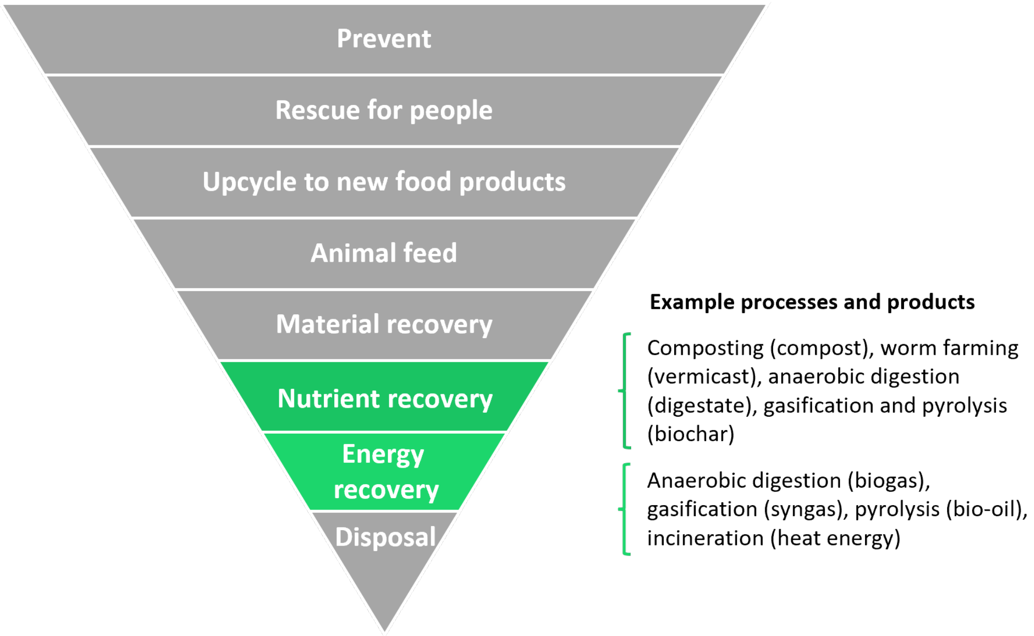


Figure 29: Situating nutrient and energy recovery within the food recovery hierarchy, with examples of processes used to treat food waste and their resulting products. Nutrient recovery is defined as capturing nutrients from food waste so that they can be used in agricultural systems, gardens, and to regenerate natural environments. Energy recovery is defined as capturing the energy held in food waste so that it can be used to generate heat or electricity, or as a fuel or natural gas equivalent. Note, this report does not seek to fix specific process to particular tiers of the food recovery hierarchy – processes can sit across multiple tiers at once or move between as dictated by their product application and specific context.[17] Thus, the location of the processes shown is indicative of their possible use cases, but not their only use cases.

Recovering energy in the form of heat, electricity, or sources of fuel from organic waste is a long-standing practice in many parts of the world,[313] with the dual benefit of reducing the volume of waste sent to landfill and energy generation with less need for fossil fuels.[314] In light of these benefits, EfW technologies capable of recovering energy from organic waste streams have gained prominence in waste management systems in recent decades.[69,315] To many, EfW technologies have become synonymous with burning waste,[316–318] yet a range of biological and thermochemical methods exist, each with its own benefits and considerations.[314,319] Examples of EfW technologies applied to food waste include AD, incineration, and gasification[320–322] all of which are explored in further detail below (see section 4.4). Statistics from the former Australian Department of the Environment and Energy show that in 2014–15, 22% of Australian food waste was recycled, mostly through composting, and 16% was used for energy recovery, mainly through methane capture at landfills. In New Zealand, investing in more biodigestion facilities could further cut down the amount of food waste that is landfilled, as well as support our energy security.

Ideally, nutrients and/or energy from wasted food are processed after higher value products have been extracted (like upcycled food, animal feed, and new materials; see section 3) and displace virgin materials like synthetic fertilisers or natural gas. In the following sections (4.3, nutrient recovery and 4.4, energy recovery), we profile a range of processes which capture nutrients and/or energy from food loss and waste, highlighting techniques used, strengths, weaknesses, and use cases. (See also our web resource.[3]) Here, we've assigned different processes to either nutrient or energy categories based on their primary outputs,[17] while noting that some processes can span both nutrient and energy recovery tiers depending on their application (see section 4.3, opportunities).

4.3 Recovering nutrients from wasted food

Healthy soils underpin the productivity of food systems and extractive practices pose a significant threat to soil health.[323] Soil degradation threatens food security, with erosion, salination, compaction, acidification, and chemical pollution affecting a third of all land globally.[324] In Aotearoa, a range of soil health indicators suggest there is much that can be improved (see figure 30). Many of our soils are overly compacted, which can reduce plant growth, restrict soil drainage of excess water, and diminish biodiversity.[325] Additionally, we are losing soils, with approximately 84 million tonnes lost per year in areas that are intensively farmed (approx. 44% of all soil loss in New Zealand).[325] Capturing the nutrients contained in wasted food presents an opportunity to restore our soil structure, microbial functioning, and nutrient composition. Additionally, MBIE has identified economic opportunities associated with nutrient recovery.[184]

Capturing the nutrients contained in wasted food presents an opportunity to restore our soil structure, microbial functioning, and nutrient composition.

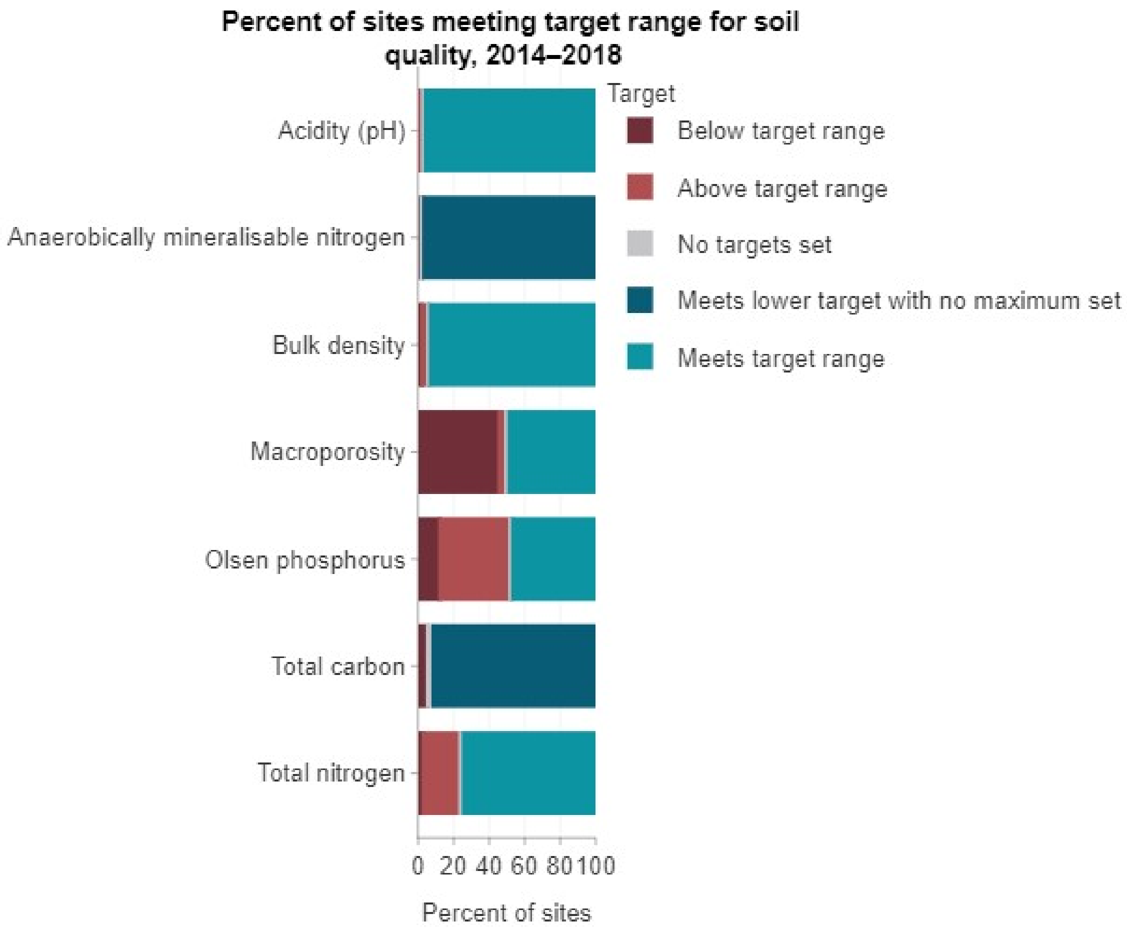


Figure 30: Indicators that are used to determine soil health across the various sites tested in Aotearoa between 2014-2018. Image credit: StatsNZ.[326]

We are strongly reliant on mineral fertilisers. Excessive use of fertilisers, along with pesticides, disrupts soil processes and may contribute to the deterioration of soil health, microorganisms, and biodiversity.[327] Figure 31 shows that many areas of Aotearoa already have excess N in soils. There is potential to displace fertiliser use with nutrients recovered from lost and wasted food in the form of soil amendment products such as compost, vermicast, digestate, insect frass and biochar (all of which we discuss in more detail in the remainder of this subsection).[328–330] Returning nutrients from our food waste to our soils is an opportunity to reduce costs and close nutrient cycles.[331]

However, work is required to understand how this substitution can be made while maintaining product yields and quality. For example, the majority of the research with the use of digestate or comparisons of digestate and mineral fertiliser[332–334] are based in controlled settings or centre around specific plant species;[335,336] it would be beneficial for more longitudinal field studies focusing on New Zealand crops.

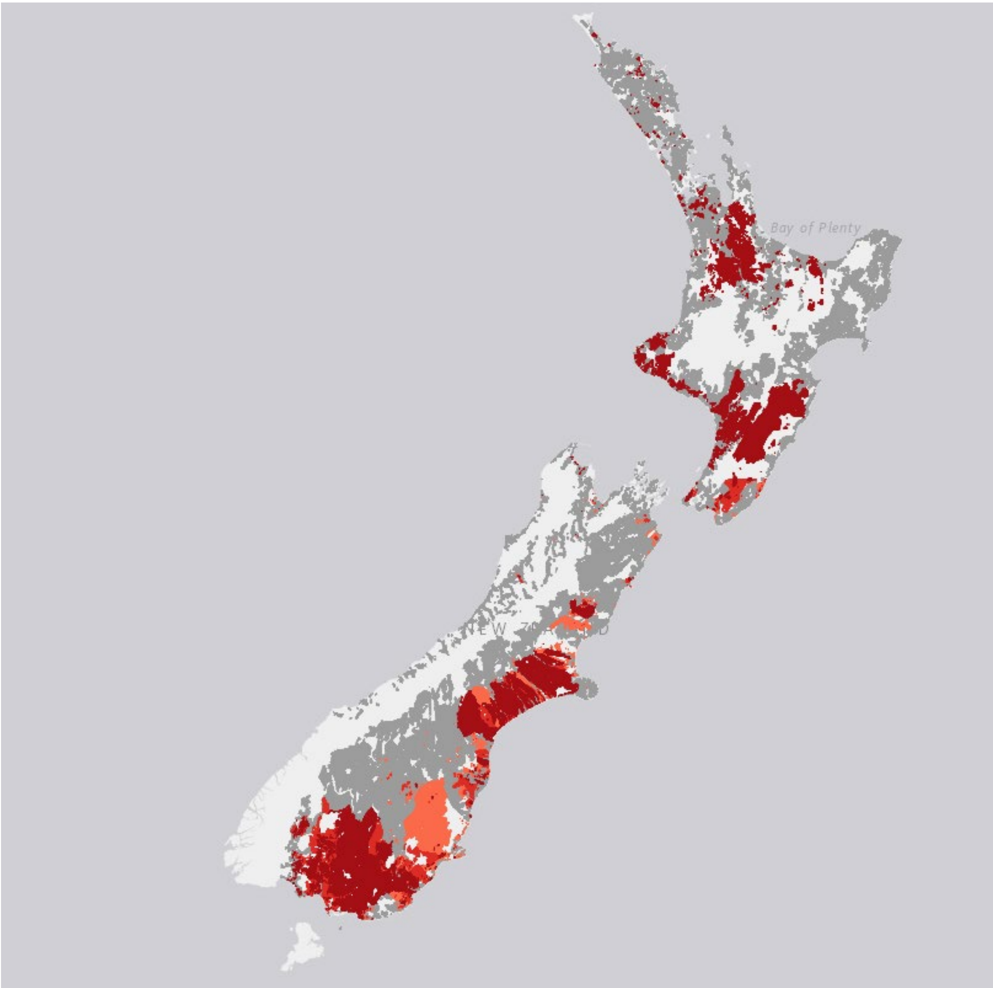


Figure 31: Map of total N in excess of current national rules. Dark red regions show very high levels of total N, in excess of national rules. Grey areas show no excess. Image credit: AgResearch.[337]

What technologies and processes can we use to capture nutrients in FLW?

Composting

Composting is the controlled biological decomposition of organic matter into a stable product called compost.[338] The process is driven by microbes which break down organic matter in the presence of oxygen[339] and accelerated by mixing carbon-rich feedstocks like dry leaves or wood chips (also called 'brown matter') with nitrogen-rich feedstocks like food scraps and manure ('green matter') to boost microbial activity.[338,340] Typically, this C:N ratio is 30:1 by weight.[341] In some cases, specific microbe formulations can be added during composting to optimise the process further.[342,343] Generally, facilitating the composting process is relatively simply, as active microbes just need sufficient air and water to maintain decomposition (see figure 32).

Compost is a soil conditioner, with multiple benefits for soil health and plant growth. Relative to synthetic fertilisers, compost contains a relatively low concentration of N, K, and phosphate – approximately 1-3% of by weight[344,345] – but long-term application can increase nutrient availability and contribute to healthy soil ecosystems.[346] Importantly, not all composts are created equal, so understanding a compost's origins and properties is important in determining its application, especially our food systems. See table 4 for a list of benefits and challenges of composting.

Importantly, not all composts are created equal, so understanding a compost's origins and properties is important in determining its application, especially our food systems.

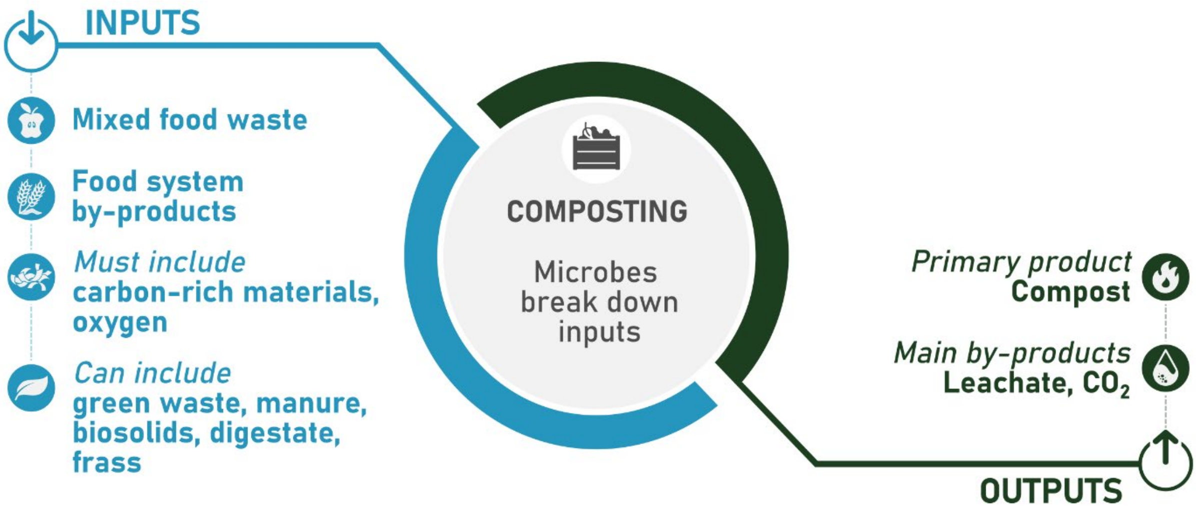


Figure 32: The main inputs and outputs of composting, a food waste processing option that can be applied in the home, community, or by large-scale, centralised enterprises.

A variety of composting techniques emerged in the 20th century, driven by the need to reduce landfill use, the desire to reduce the environmental impacts of organic waste streams, and the realisation that compost can be a valuable end product.[339,347] Modern-day composting techniques comprise a plethora of approaches, including the use of open and closed windrows, turned piles, aerated static piles, and enclosed and in-vessel systems.[46,340] Composting occurs at a variety scales, taking place at home (see our web resource[348]), within communities (see case study 12), and at large-scale, centralised facilities (see case study 13).

Table 4: Composting key benefits and challenges.

Key benefits	Key challenges
• Relatively simple process which works at a variety of scales and in multiple contexts.[340,347,349] • The decomposition process is thermophilic, reaching temperatures of approx. 65 °C, which can neutralise weed seeds and numerous pathogens.[339,350] • Long term application of compost can improve nutrient availability in soils, as microorganisms convert soil organic matter to available forms of nutrients over extended timeframes.[345,351] • Compost contributes substantial organic matter to soils, which can increase soil organic content, promote plant growth, improve soil properties such as water retention, aeration and compaction, and increase soil microbial biomass and activity.[345,350] • Large-scale facilities can handle a variety of feedstocks, and co-process inputs like animal products, sewage sludge, and digestate.[352–354] • When undertaken in communities, be it at home, compost clubs, or social enterprises, composting provides a range of social and environmental benefits (see box 5). • When the process is done effectively and the displacement of synthetic fertiliser is factored in, emissions from composting can be close to or better than net zero (see box 4).[31] • Composting reduces the weight and volume of the initial waste.[355]	• Poor management results in emissions like leachate and GHGs, with methane being particularly problematic in piles which are insufficiently aerated.[46,356–358] • As a biological process, external factors such as rainfall and temperature can affect process efficacy in outdoor settings.[339] • The process requires an adequate mix of nitrogen- and carbon-rich feedstocks, as well as additional water supply in drier months, to maintain microbial communities. • Different composters have different abilities and willingness to accept and process biodegradable and compostable products. These products can be a source of contamination (e.g. microplastics, chemicals including PFAS) in compost. • In certain contexts, odours produced from large-scale composting operations can negatively affect neighbouring communities.[359] • Composts derived from an excess of nitrogen-rich sources (e.g. biosolids, manures, or grass clippings) can lose excess N by ammonia volatisation, both a waste of feedstock and potential pollutant.[309]

Depending on its quality and the regulatory context, compost is used in a variety of settings, including agriculture, horticulture, urban gardens and farms, landscaping, and in landfills as cover material (see annex 10).

Box 4: Can composting sequester carbon?

Carbon in compost is part of the short-term C cycle, which is why the Intergovernmental Panel on Climate Change (IPCC) guidelines[356] for calculating climate-warming GHG emissions from composting don't include the CO_2 released during the composting process. Adding compost to soils adds C to soils in the short term but after 100 years, almost all this C is back in the atmosphere. There is some debate around what the addition of this C does to soil's overall ability to store C but it has been estimated that:

> "When we extrapolate… figures for added organic C or microbial mass [from compost] over 100 years to ten decimal places, essentially none of the added C remains. If the humic acid and inert C already present in soil are included, about 5% of the original C would remain but it would largely be ancient C already in the soil, not formed by one addition of compost: it would take decades of C additions to accumulate. Compostable waste (e.g. green waste) contains approximately 200 kg of plant carbon/fresh tonne (IPCC Guidelines 2006). About 60% to 82% of this is oxidized during composting (Smith et al. 2001 and Hellebrand, 1986), leaving about 80 kg of organic carbon (OC) per tonne of fresh compost. Assuming that this is the resistant (lignified) component of the OC, it would decompose at a rate of 30% per year (Jenkinson & Rayner 1977). Averaged over 100 years, about 1.87 kg of OC would be stored, avoiding almost 7 kg of CO_2."[360]

Composting in New Zealand is well-established, with hundreds of thousands of tonnes of organic waste making their way to large- and small-scale composting sites around the country each year. According to a 2021 nationwide stocktake of resource recovery infrastructure commissioned by MfE,[63] Aotearoa has 62 active large-scale facilities that process organic waste, defined by the report as wood and timber waste, garden waste, animal manures, commercial sludges, and other putrescibles. Most of these facilities are composters, the most common type being windrow composting (40%) followed by in-vessel processing (15%), vermicomposting (11%), aerated windrow (8%) and mulching (8%). Additionally, a wide network of compost clubs and social enterprises operate across the country to compost food waste within communities (see box 5). Global estimates suggest that millions of tonnes of compost are produced each year (see annex 1) from a wide variety of feedstocks, including materials high in N like food scraps, coffee grounds, grass clippings, digestate, biosolids and manure, as well as carbon-rich materials like dried leaves, straw, sawdust, wood chips, bark, paper waste, and cardboard.[341,361,362] Estimates from the stocktake[63] suggest 5% of New Zealand's recovered food waste is composted within a communities, although this is a likely an underestimate given the stocktake's narrow scope.

Estimates from the stocktake suggest 5% of New Zealand recovered food waste is composted within communities, although this is a likely an underestimate given the stocktake's narrow scope.

Box 5: Composting in communities

Community enterprises such as community gardens, urban farms, and dedicated composting enterprises have been working hard for many years to enable Aoteaora to sustainably manage their food scraps close to home, thereby keeping resource and waste flows to smaller, more localised scales.[45,363,364]

Composting is a particularly common solution used for food waste within New Zealand communities. Community composting efforts can be broadly divided into volunteer-run 'compost clubs' and decentralised social enterprises that have emerged as a community response to food waste. Unlike composting clubs, composting social enterprises are often commercial operations, reliant on contracts and customers to support their business model. Enterprises like Kaicycle (see case study 12) use a subscription-based model, charging fees for collecting and composting food waste from households and business. In contrast to larger scale industrial processors of food waste, social enterprises are embedded within the communities they serve, collecting and recirculating resources on local scales. Many composting clubs and social enterprises are keen to scale out across multiple communities to be a larger part of the solution going forward.[365]

As New Zealand sets up to expand its organic waste collection and processing capabilities,[27] there is an emerging debate about what practices and infrastructure to invest in to better manage and use organic waste.[45] Proponents of community-led organic waste management point to a range of associated benefits of dealing with food waste at local scales,[46] including community building and resilience, sustainability education, intergenerational knowledge exchange, physical and mental wellbeing, and links to Māori soil and kai sovereignty.[366]

In 2022, the Aotearoa Composters Network was formed, to support communities, businesses, households, and institutions to process food scraps and organics locally through the network of over 100 distributed composting clubs and compost service providers. With a focus on knowledge, resource and best practice methodology sharing, the network seeks to empower change towards circular systems, food sovereignty and healthy soils. When factoring in community and social good, a French study found that an urban farm and composting school delivered a 2:1 return on investment over a one-year period, forecast to reach 27:1 over ten years.

In our web resource, we highlighted Manaaki Whenua's live map of community composters, Kore Hiakai's map of community gardens and other community food initiatives, MakeSoil's global map of composting initiatives and neighbourhood initiatives such as the ShareWaste website.[46,367,368]

Case study 12: Composting and urban farming with Kaicycle

Kaicycle Composting[369] is a subscription-based community composting enterprise which processes 40 tonnes of household and office food waste in Wellington each year. Since it started operating in 2015, Kaicycle Composting has processed an estimated 230 tonnes of food scraps, in addition to arborist waste, coffee chaff, and untreated wood shavings. The resulting compost is used at the Kaicycle Urban Farm in Newtown, and any extra is donated to City Housing and local community gardens. Kaicycle Urban Farm produces fresh vegetables for the local community, with people able to buy a share in the outputs of the farm.

Kaicycle currently uses composting boxes in Newtown and is at capacity, but a new site in Rongotai and an in-vessel composter, which fully contains and automatically stirs compost, will enable Kaicycle to process an additional 90 tonnes of food scraps per year. As capacity grows, Kaicycle will look to sell surplus compost to supplement its income from the urban farm and scraps collections. Figure 33 and figure 34 illustrate different parts of Kaicycle's process.

Figure 33: Compost manager Kate Walmsley building a compost pile with collected food scraps.

Kaicycle collects food scraps from around 200 offices and households, including from groups in multi-unit dwellings where home-based solutions for food scraps are often limited. Collections are done by e-bike, reducing transport-related emissions from Kaicycle’s activities. In addition, about 65 household subscribers drop scraps off at three sites across the city.

Figure 34: Liam and Tom, former Kaicycle staff members, collecting food scraps by e-bike in Wellington's central business district.

Figure 35: Aerial view of the Kaicycle urban farm in Newtown, Wellington. Image credit: Te Kawa Robb, Toroa Creative.

Kaicycle uses scales to measure the ratio of nitrogen-rich food waste to carbon-rich garden waste, coffee chaff to regulate water content, and thermometers to ensure compost piles reach at least 55 °C so that harmful microbes and seeds are killed. See figure 35 for a view of the farm set up. Compost nutrition and contamination testing at Eurofins and Hill Laboratories helped Kaicycle improve its processes when it was getting started, and it intends to do more testing this year to continuously improve its product.

The voluntary compost standard in Aotearoa (*NZS 4454*[370]) focuses on the chemical composition of compost rather than its biological health (other than a limit on the presence of *E. coli*, a pathogen), but Kaicycle is keen to understand the diversity and relative levels of beneficial microbes in its compost too. The standard acknowledges biological health is important for the release of nutrients but doesn't provide a methodology for assessing this. Labs like Soil Foodweb New Zealand[371] which analyse the microbial health of compost and soils are scarce.

Kaicycle works to ensure its subscribers know what to include in their scrap bins. It recently undertook an education campaign explaining why it doesn't accept any compostable packaging, highlighting that compostable packaging risks introducing contaminants while bringing little to no nutritional value to the compost.

While well-managed compost piles mean odour and pest risks are minimised, Kaicycle works with Predator Free Wellington to support trapping efforts and the wider predator free kaupapa.

Kaicycle employs the equivalent of 4.5 fulltime staff, split across fulltime and parttime roles in the composting, farm, and community engagement arms of the enterprise. Kaicycle also provides many education and community engagement opportunities through public volunteer sessions, community events, workshops, and an urban farm school (see figure 36). The urban farm school is delivered with education provider Papa Taiao Earthcare.[372] In 2023, the urban farm school will have more than 25 local high school students attending a year-long, National Certificate of Educational Achievement (NCEA) accredited programme. In the last year Kaicycle has hosted 125 volunteers at the farm.

Figure 36: Kaicycle hosting local community members at a farm open day with pumpkin soup made from farm pumpkins. Open days usually include workshops, seedling sales, shared kai (food), live music, and farm tours.

While all composting leads to some greenhouse gas emissions (albeit substantially less than emissions from landfilling food waste, see annex 2), Kaicycle works to keep methane emissions to a minimum by managing the composition of its compost piles, turning them regularly to ensure they are oxygenated, and inoculating piles with Beneficial Anaerobic Microbes (BAM) like those used in bokashi. Using BAM reduces the frequency with which the compost piles must be turned, reducing labour and allowing beneficial fungal networks to develop with less disruption.

As with many district plans, the Wellington District Plan is ambiguous about the legal status of community gardens, urban farms, and community composting. Wellington's plan is currently being updated and looks to include composting at community gardens as an expected and permitted activity. Kaicycle hopes to see community composting directly included as well, to clarify the status of and rules associated with small- and mid-scale composting enterprises.

Kaicycle is currently undergoing a three-year process to attain Hua Parakore verification for its operations. The Hua Parakore verification scheme[373] is a kaupapa-based approach to organics certification developed by Te Waka Kai Ora, the Māori Organics Authority. Drawing on mātauranga, tikanga, te reo, and the wisdom of tupuna, Hua Parakore empowers Māori food producers.

Case study 13: Living Earth, Aotearoa's largest compost operator

Living Earth is a New Zealand-based composting business owned by Waste Management. Living Earth has been in operation for more than 20 years, with primary sites in Christchurch and Auckland, and is New Zealand's largest organic waste to compost operator.[374] Annually, Living Earth's composting facilities can process over 100,000 tonnes of garden and food waste, turning it into compost. Compost is sold as a soil amendment, used by gardeners, farmers, and landscapers to improve the fertility, structure, and water retention of their soils.

Living Earth's composting operations differ between its two sites. At its Organics Processing Plant in Bromley, Christchurch, Living Earth composts 60,000 tonnes of mixed garden waste and food waste annually in 18 in-vessel composting tunnels, generally at a C:N ratio of 30:1. Much of this waste is collected from households in Christchurch, as part of the city's organics kerbside collections. Once organic material is shredded, it is placed in windrow tunnels for two to three weeks before being moved outdoors and offsite for maturation to manage odour. During maturation, organic material is broken down by microbes over the course of two to three months. During this process, the microbes are kept active and efficient by ensuring that air, temperature, and moisture levels remain consistent within composting material by mechanically turning the windrows and adding water as needed during summer months. Water runoff from the windrows is managed using a pond system. Typically, composting material at Living Earth sits at 50 - 60 °C (a result of the metabolic process of microbes), temperatures which help kill off pathogens and weed seeds in the organic material. Given the site's close proximity to local residents, there have been concerns raised about odour issues from the composting process.[359] This has resulted in a re-evaluation of on-site composting, as well as the long-term future of the facility, with an AD facility set to replace the existing set-up in the next three years.[359] Currently, compost from the Bromley site is primarily sold in bulk to farmers in the Canterbury region, as well as local gardeners and Christchurch City Council for restoration projects.

In Auckland, Living Earth runs an outdoor windrow composting system on Puketutu Island, a site which spans 12 hectares (eight of which are currently used for open-air composting, with four hectares set aside for potential expansion) and located some three km from the nearest residential areas. At its Puketutu site, Living Earth processes 30,000 tonnes of green waste annually, sourced from yard trimmings and plant material, primarily from waste transfers stations and residential collections. It takes microbes three to four months to break down green waste and convert it into compost. As composting operations at Puketutu are outdoors, up to 200 cubic meters of water is added to windrows per day in summer months to maintain the moisture content (see figure 37). Water and leachate runoff is diverted to large storage ponds. Once compost at Puketutu has fully matured, it is mixed with angular sand, pumice, and aged bark to improve its properties as a soil amendment product. This compost product is primarily sold into the Auckland urban landscape market, both in bulk and in bags, as well as to infrastructure projects in and around the region.

Compost sold from both of Living Earth's facilities meet voluntary New Zealand standards[370] for compost, soil conditioners and mulches, while some of their products are certified for use in organic production by BioGro or AssureQuality.

Living Earth works to mitigate several challenges which often affect large-scale composting. For example, micro-contaminants, including heavy metals and herbicides like clopyralid, can reduce the quality of compost. At Living Earth, batches of compost are tested regularly on- and offsite for micro- and macro-contaminants, nutrient value, maturity, and growth performance. During the composting process, Living Earth also monitor and control process parameters, especially temperature, moisture, and oxygen (see figure 38). This ensures that compost undergoes pasteurisation and prevents windrows from becoming anaerobic and producing methane.

Living Earth currently employs 13 staff in Auckland and 18 in Christchurch. Beyond its business activities, Living Earth sponsors a restoration project on Motutapu island and supports a number of community initiatives.

Figure 37: Windrows of composting material at Living Earth's site on Puketutu Island.

Figure 38: George Slim (left) and Living Earth's Logan Dingle (right) stand in front of piles of mature compost ready for market. A compost screening machine stands to their right.

Vermicomposting

Vermicomposting is similar to the composting where waste is decomposed under aerobic conditions, but uses earthworms to consume and digest biomass, and facilitate aeration in the process.[375] The end product is called vermicast (see figure 39 for other inputs and outputs of the process). Differences between composting and vermicomposting are often context-specific, but can include factors like feedstock, time to maturity of product, and process variations.[376] Like composting, feedstock for vermicomposting requires a combination of carbon- and nitrogen-rich sources (the latter can include a range of food waste streams) and the process can be carried out in closed vessels or windrows. Unlike the high temperatures generated during composting, the worms require a much lower range of temperatures (25 - 40 °C) and higher humidity levels (~80%), creating potential issues with sanitisation if the feedstock is contaminated with human pathogens.[377]

> …require a much lower range of temperatures and higher humidity levels [than composting], creating potential issues … if the feedstock is contaminated with human pathogens.

Vermicast is considered to have a positive effect on plant growth[378,379] and is commonly added to soil as an amendment. Further benefits are listed in table 5. By-products of the vermicomposting process include leachate and vermicompost 'tea's (see box 6), and greenhouse gas emissions of CO_2, methane, and nitrous oxide at varying quantities.[380] Even though methane and CO_2 emissions are generally lower[380] for vermicomposting and composting, these emissions are dependent on the feedstock and the conditions by which decomposition occurs such as aeration, moisture content, temperature, pH, C:N ratio, and the bulking agents used in the process. For example, extreme temperatures and moisture levels can kill earthworms and increase methane emissions in anaerobic conditions created from a lack of aeration.

While vermicomposting, commonly known as worm farming, is widely recognised and well-established globally and in Aotearoa, in communities and homes, the extent of its practical uptake and use is under-researched. Its industrial use is common to deal with large scales of agricultural waste and municipal waste.[381,382] A number of companies make and provide worm farms for households and businesses, including MyNoke, New Zealand's only large-scale enterprise (see case study 14).

Table 5: Vermicomposting key benefits and challenges.

Key benefits	**Key challenges**
• Similar or slightly lower emissions profile when compared with composting, including with C sequestration and fertiliser displacement benefits.[383] • Vermicast is typically a stable, nutrient-rich substance which can be used as a soil conditioner.[384] The vermicomposting process also reduces the volume and weight of initial organic waste. • Unlike composting, no pile turning is required to keep the system aerobic – the worms do this work themselves,[385] reducing	• Need to manage the process and design facilities to avoid leachate (e.g. windrow rotation across farmland, maintaining the correct C:N ratio). • There is less literature on the emissions profile of vermicomposting than for compost,[386] making comparative emissions-based assessments of this food waste processing approach challenging. • As with composting, plastic-based biodegradable and compostable packaging can be a source of contaminants.[387]

labour and processing emissions (if compost turning is done by machine).

- Can process a wide variety of inputs,[384] including mixed food waste, biosolids, digestate from AD, industrial effluent, paper, and a variety of fibre-based packaging.
- Pathogens such as aerobic bacteria, viruses, and fungi found in organic waste are broken down as they pass through the digestive system of worms.
- As vermicomposting is not a thermophilic process (it doesn't get hotter than about 35 °C),[380] vermicast may need to be pasteurised to produce a seed-free product and remove any pathogens which are unaffected by worms' digestive systems.

Vermicomposting has no specific standards or regulations in New Zealand. However, there is a voluntary New Zealand Standard (*NZS 4454:2005 Composts, soil conditioners and mulches*) that provides guidance on requirements, compliance, sampling, and testing for products.[370] MyNoke adheres to this voluntary standard.

Box 6: Distinguishing leachate and vermicompost tea (worm tea)

The difference between leachate and vermicompost teas (worm tea or vermi-tea) and their suitability for use are often conflated, and their use as fertilisers is also confused.[388–390] Leachate, in this context, is a liquid runoff from the vermicomposting process collected at the bottom of a vessel[370] and there are some studies that have utilised this product for promoting plant growth. However, this is carried out with controlled feedstock.[391,392] It conflicts with some of the guidance given for vermicomposting at home, where the leachate produced may not be viable as fertilisers.[370,389] Vermicompost teas are brewed for plant growth using the vermicasts and large amounts of water[393] (some suggest aerated water) and with additives like sugars or other nutrients.[394]

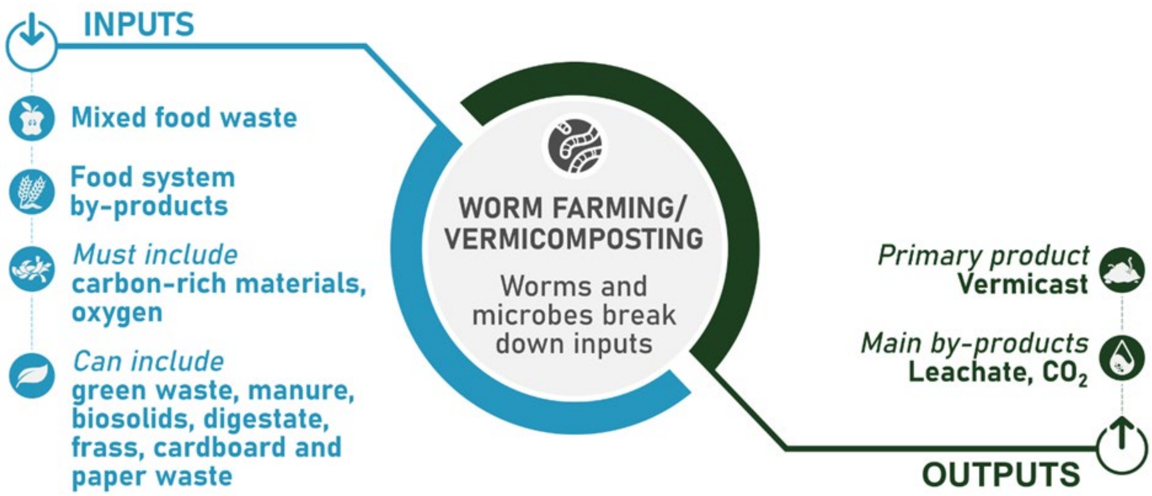


Figure 39: The main inputs and outputs of vermicomposting, a food waste processing option that can be applied in the home, community, or by large-scale, centralised enterprises.

Case study 14: The team of three billion at MyNoke

MyNoke is a New Zealand-based vermicomposting business that uses earthworms to process dairy waste residues, food waste, paper and cardboard waste and wastewater sludge, wood ash and other feedstocks at multiple sites across the North Island. MyNoke was started by soil-scientist Michael Quintern in 2007 and today has sites in Ohakune, Taupō, and Tokoroa. Across these sites, MyNoke estimates some three billion worms eat 160,000 tonnes of organic waste annually, converting it into vermicast. Vermicast is primarily used as a soil conditioner to improve fertiliser efficiency and substitute some synthetic fertiliser.

To produce vermicast, trucks collect various organic waste from customers and unload it onto concrete slabs at MyNoke's vermicomposting sites. Here, the waste is sorted to remove contaminants such as plastic, glass, wood, and plastic lined cups. Organic waste is then mixed with fibrous, carbon-rich materials (e.g. newspaper, egg cartons, sawdust, or cardboard) and laid out on fields in long piles (called windrows) using agricultural machinery. The first of these windrows are seeded with worms (typically *Eisenia fetida* and *Eisenia andrei*); see Figure 40 for illustration. As the worms eat their way through waste, they reduce its volume up to 80% and leave behind vermicast. In addition, worms keep the windrows aerated as the move through the pile, helping soil microbes to break down waste further. Once the worms have eaten through the organic waste in one windrow, they migrate to the next windrow in line (see figure 41). A single windrow, which can contain more than 100 tonnes of organic waste, is typically processed by worms and soil microbes within 9–12 months. Vermicast is harvested from windrows annually and is mechanically screened to remove remaining physical contaminants like stones and plastic.

Figure 40: Earthworms are put into a mixed feedstock of biosolids from wastewater (black and dark brown material), dairy wastes (orange), and paper pulp (grey) on the concrete slab where MyNoke mixes their inputs. Feedstock mixes like this are subsequently laid out in large windrows on fields.

The nutrient content of vermicast depends on the feedstock used, but vermicast generally contains high amounts of water-soluble nutrients like N and P. Earthworms can remove pathogens (e.g. fungi, aerobic bacteria, and viruses) as they consume organic waste, and vermicast can be further pasteurised using (geothermal) heat to kill off weed seeds. Unlike composting, windrows do not reach high temperatures, instead maintaining temperatures below 35 °C. A benefit of the lower temperature is that it reduces odour emissions from windrows. To protect soils, MyNoke rotates the location of its windrows across paddocks to mitigate soil compaction and prevent the accumulation of excess nutrients.

Figure 41: Team member Jacques with MyNoke's General Manager Phil Holland standing in front of a freshly harvested pile of vermicast at MyNoke's Taupō site.

The majority of MyNoke's vermicast is sold in bulk to farmers and orchards in Aotearoa, with a smaller share sold to retailers as packaged product for home gardeners. Although vermicast sold to New Zealand markets is not pasteurised, it meets the voluntary New Zealand standard for compost, soil conditioners, and mulches (*NZS 4454*). When MyNoke's vermicast is on the international market, it is pasteurised by steaming it to 72 °C for a couple of hours before it is tested and shipped overseas.

MyNoke currently employs 30 staff across its three vermicomposting sites on the North Island. The company is planning to expand, with several new sites planned for the North and South Island. In total, MyNoke has a growth goal of 16 sites across Aotearoa and further expansion into Australia.

Insect-based bioconversion

Insects are increasingly being used for food or as animal feed (see section 3.2) and the remaining excrement - known as frass - can be added back to soil to closing the nutrient cycle. The addition of frass to soil has been investigated over the last two decades, with various plant species in field studies and in controlled settings; however, the body of studies remains relatively modest.[231] Some of the benefits include the addition of N, improving microbial activity, and promoting plant growth,[395] and could be considered as a viable component of soil amendment plan. Frass is produced in New Zealand at small scales through companies like Herbi[396] and iNZect Direct[397] and studied by PFR using species like mealworms, black soldier flies, and crickets (see case study 10).

Anaerobic digestion

As well as energy, AD produces a digestate, which has considerable potential as a biofertiliser. This is discussed in section 4.4.

Dehydration

Dehydrated food waste can be produced using a centrifuge system at temperatures over 100 °C, rapidly evaporating water and reducing food waste volume.[398] The dehydration process slows down decomposition of the waste which can be stored before later use. Application of the dehydrated food waste directly to soil may not be beneficial for plant growth due to its acidic nature and nutrient variability and salinity levels.[398,399] Dehydrating food waste is presently being trialled in Australia in places where many people reside in apartments, and where food waste collection has not been feasible.[400] Since the volume of food waste is reduced, sometimes by up to 80%,[399] it can be transported at a later stage for further processing like composting. However, due to the required high temperature of the process, high energy requirements make it unlikely that dehydration processes have more than niche uses in dealing with food waste (see annex 1).

… high energy requirements make it unlikely that dehydration processes have more than niche uses in dealing with food waste.

Ploughing back into fields

Ploughing unharvested food back into soil is another pathway for returning nutrients into the soil, although its environmental impacts and benefits have been poorly studied.[31] A 2019 LCA based on Californian context[401] suggested that this approach can prevent food loss from landing in more environmentally costly disposal destinations, but the nutrient-capture benefits will vary widely with different food loss feedstocks.[31] Notably, this pathway is ranked near the top of the US Environmental Protection Agency's (US EPA) food waste scale.[31] Clearly further investigation into the merits and drawbacks of this approach is needed in a New Zealand context.

What are the benefits of nutrient recovery?

Improving the state of our soils

Beyond supporting our food systems, healthy soils offer other benefits including C storage, retaining and filtering water, nutrient cycling, and providing physical support and stability.[335,336,402,403] Aotearoa's soil has specific challenges unique to our geological environment,[325] and major export industries such as dairy, agriculture, horticulture, and forestry depend on good-quality soil.[404] Low macroporosity is a condition that affects much of the soil in Aotearoa (see figure 30).[325] The smaller pores in the soil associated with low macroporosity affect soil drainage since water cannot penetrate the soil (which causes nutrient leaching and poor water quality) and disrupts C and N cycling as well.[325,404,405] Macroporosity of soil may be improved by adding biological waste products like compost, increasing the soil's ability to retain water and thus plants' ability to absorb nutrients, especially if applied frequently and with modification of the size of compost particles.[406] Other soil health indicators are shown in figure 30. Recovering nutrients from food loss and waste presents an opportunity to improve an array of these indicators, as explored in detail below.

Reducing our reliance on imported mineral fertiliser

Mineral fertilisers and synthetic fertilisers have enabled growth in food production to feed a growing global population[404] but are resource-intensive to create and generate GHGs.[407] Globally, the production of ammonia for N fertiliser consumes 2% of the world's energy and generates 1% of global CO_2 emissions. For every tonne of N fertiliser made, 13.5 tonnes of CO_2e are emitted.[408] Per hectare of land, Aotearoa is third in the world for fertiliser consumption (1,725.9 kilograms),[408] and our use of N has been steadily increasing since the early 1990s (see figure 42). The environmental externalities caused by artificially adding nutrients back into New Zealand soils over decades are well-publicised,[404,409–411] with the biggest issues arising from the use of N and P.[409] K is another crucial nutrient required for plant growth, and much of it also needs to be imported along with N and P as intensive agricultural land use has depleted K reserves in the soil.[412] Additionally, reliance on importing minerals like P may make New Zealand's food system vulnerable.[413]

Per hectare of land, New Zealand is third in the world for fertiliser consumption (1,725.9 kilograms), and our use of nitrogen has been steadily increasing since the early 1990s.

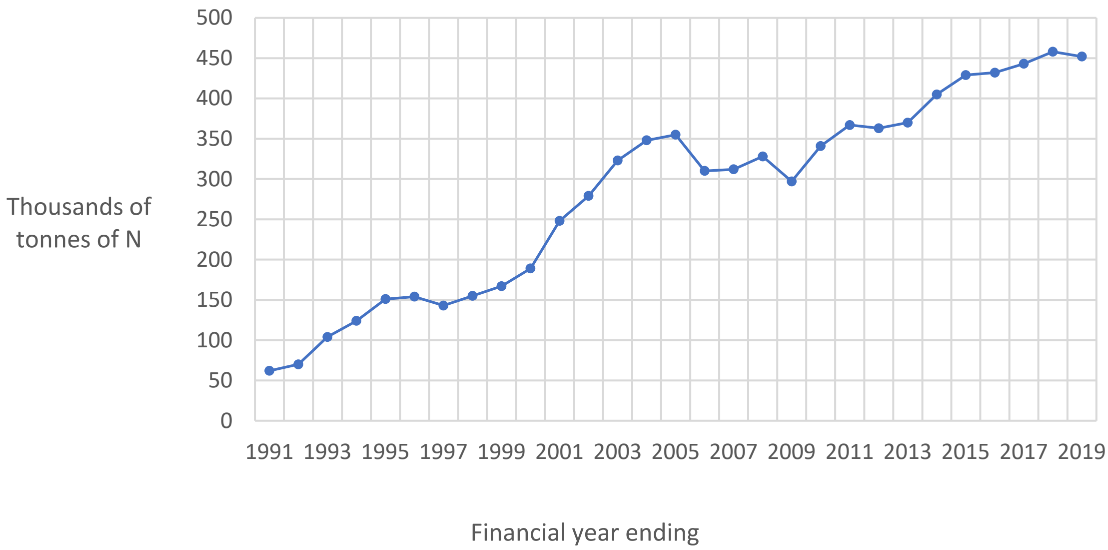


Figure 42: Trends showing sales of N in fertilisers in Aotearoa, 1991-2019.[409]

A third of our soils have elevated P levels[325] and the abundance of N has become a challenge in regions such as the Waikato, Manawatū-Whanganui, Marlborough, and Canterbury (see figure 31), with adverse consequences for water quality.[337] It is more difficult to retain N in the soil than other nutrients, resulting in groundwater contamination[327] which led to the introduction of a synthetic N cap in 2021 as one of several regulations for grazed land.[410]

The market for compost and digestate is a challenging one due to uncertainties and inconsistencies in current products. Agriculture is the dominant market segment for both compost and anaerobic digestate, but sale prices are far below their theoretical potential. Globally, the market value of digestate is zero or negative because it is treated as a waste disposal issue. In 2022, compost had a weighted average price of only EUR 10.1/ tonne (fresh mass) across all market sectors in Europe.[414]

The market for compost and digestate is a challenging one due to uncertainties and inconsistencies in current products.

Keeping nutrients in cycle

Nutrient cycling ensures that minerals such as C and N that are used by plants to grow are returned the soil to be used by microorganisms and other plants. Managing New Zealand soil's nutrient needs by region and land use are complex, but there are strategic and effective solutions that can enable us to reduce our reliance on importing nutrients. Diverting food loss and waste from landfills into the soil offers a partial solution. Historically,[415] these practices were carried out by Māori[416] to grow food, with archaeological evidence[417] supporting some of the variation in practices carried out in the regions.

Providing social benefits for communities

There are individuals and communities that have already taken proactive measures to establish initiatives, like composting, either at home or within a community space to educate, reduce, and manage food waste. The advantages include engaging in separation of food waste, avoiding logistical costs, and utilising end products to grow food.[418] Furthermore, it engages individuals to be mindful about the food waste generated, enhances social cohesion, and encourages circularity.[418,419] For example, the Para Kore Marae[62] and Papatūānuku Kōkiri Marae[420] work towards zero waste in a way that enables mana motuhake through building relationships and supporting communities. One study of local composting in Aotearoa estimated that there were 94 full- and part-time jobs and over 125 weekly volunteers at the 41 composting enterprises included.[421]

Local composting organisations can support communities in mitigating some of the risks associated with compost production. These risks are primarily around safety resulting from incorrect feedstocks and pathogens from improper management,[422] as well as quality issues related to salinity, heavy metals, and unsanitary compost.[423] Composting workshops, training, soil microscopy, and soil testing are among the ways individuals, compost clubs, and compost service providers offer support.

How much nutrient capture is already happening in NZ?

Globally, millions of tonnes of compost are produced each year (see annex 1) from a wide variety of feedstocks, including materials high in N like food scraps, coffee grounds, grass clippings, digestate, biosolids (i.e. sewage waste), and manure, as well as carbon-rich materials like dried leaves, straw, sawdust, wood chips, bark, paper waste, and cardboard.[341,361,362]

Figure 43 from Eunomia's report[63] highlights some of the current nutrient recovery processes taking place in New Zealand, including rendering of agricultural waste and composting in agricultural, residential, and commercial contexts. The diagram highlights the most comprehensive information published, based on (necessarily incomplete) data collected in 2020. Some programmes to capture value from food waste have already begun, such as Auckland Council redirecting food scraps to Ecogas as a part of a 20 year contract to use AD to convert waste into biogas and liquid biofertiliser at the Reporoa organics processing facility (see case study 15).[78,424]

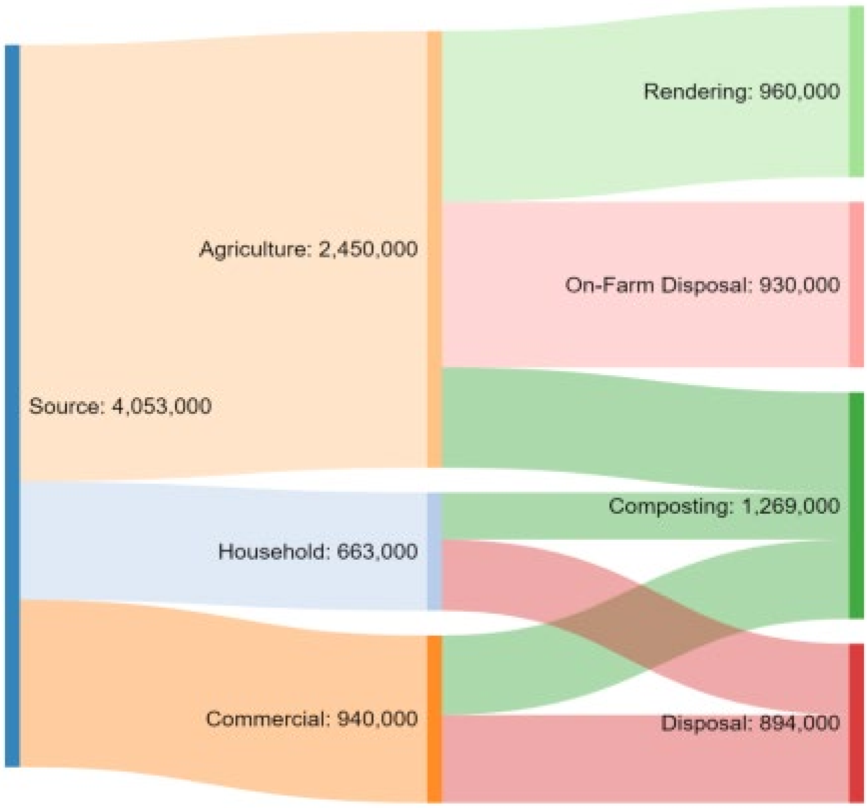


Figure 43: Flow of organic material in tonnes from generation to recovery or disposal. Image credit: Eunomia.[63]

What are the barriers/opportunities to getting food waste -derived nutrients back into our agricultural systems?

While it is clear that there is large theoretical potential in using food waste to support our agricultural systems in Aotearoa, the realisation of this potential requires significant investment in infrastructure and logistics to make it a practical reality. A coherent regulatory framework, careful consideration of how contamination levels limit usage, development of markets for alternatives to synthetic fertilisers, and a wider understanding of the multiple options available are all required to enable progress. There are no simple generic solutions, and wide adoption of soil amendments for use on farm will require a deep understanding of what soils need in a local context and building trust amongst the farming community. Looking abroad, some of this work has begun.[425]

> There are no simple generic solutions, and wide adoption of soil amendments for use on farm will require a deep understanding of what soils need in a local context and building trust amongst the farming community.

4.4 Producing energy from wasted food – two birds, one stone?

To transition away from fossil fuel use, Aotearoa will need to make use of more renewable energy sources such as biomass[15,426] (see annex 11). This could include FLW, depending on its composition and suitability as a feedstock. Here, we discuss several technologies used to produce energy (and other products) from food-derived waste streams, noting that many existing technologies have only limited application to these waste streams. Importantly, EfW technologies based on fossil hydrocarbon feedstocks, such as waste plastics, are not renewable sources of energy and are considered largely out of scope in the context of this report.

What are the opportunities for recovering energy from food loss and waste in Aotearoa?

Generally speaking, there four broad approaches to generating energy from waste. Figure 44 and table 6, from the Queensland Government, describe these as biological, chemical, mechanical, or thermal, based on how these processes yield energy.[53] Energy recovery sits near the bottom of most food recovery hierarchies, and the Queensland Government created a tiered strategy to prioritise different EfW approaches. Importantly, this energy hierarchy[j] is designed for waste generally, but nevertheless has application to food-derived waste streams. Biological processes are ranked higher than chemical, mechanical, and thermal options because they are generally better at returning materials and nutrients to the biological cycle (being biological processes) than thermal options. Moreover, biological approaches are generally better suited to feedstocks with a higher moisture content, such as mixed food waste and many trade wastes (e.g. dairy effluents or brewers waste), than thermal alternatives like incineration or pyrolysis (described below).[427,428]

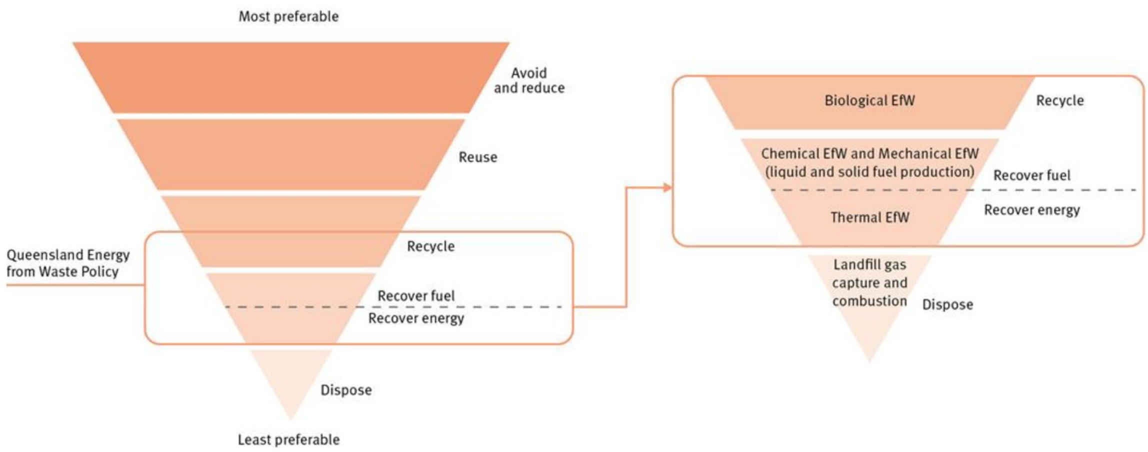


Figure 44: Queensland's Waste and Resource Management Hierarchy (left) and EfW Hierarchy for residual waste (right). Abbreviation: EfW= energy-from-waste. Image credit: Queensland Government *Energy from Waste Guideline*.[53]

[j] The hierarchy used in the guideline differs somewhat from the one we have applied in this report, but is shown to contextualise the positioning of EfW technologies.

Table 6: Overview of EfW technologies. Abbreviation: EfW= energy-from-waste, MSW = municipal solid waste. Image credit: Queensland Government *Energy from Waste Policy 2021*.[429]

Technology type	Description	Examples
Biological EfW	Breakdown of organic waste by microorganisms and enzymes to produce a combustible gas or liquid fuel	• Anaerobic digestion of organic wastes to produce biogas, and digestate • Fermentation of food processing wastes to produce ethanol
Chemical EfW	Chemical agents are used to convert the waste feedstock into a liquid fuel	• Conversion of waste fats and oils into biodiesel using chemical catalysts
Mechanical EfW	Processing of waste using mechanical and physical processes such as shredding, screening, dehydration and pelletisation, to produce a fuel (often solid)	• Production of refuse derived fuel (RDF)
Thermal EfW	Breakdown of waste using heat (typically greater than 200°C) to release the embodied energy, usually in the form of heat (hot flue gases), a synthesis gas, or liquid fuel	• Combustion with energy recovery of mixed MSW to produce heat and/or electricity • Pyrolysis of end-of-life tyres to produce pyrolysis oil, syngas, heat, electricity

For any given technology or process, certain types of waste will be more suitable than others. While biological, chemical, mechanical, and thermal EfW technologies are capable of capturing energy from a wide range of organic feedstocks, including things like forestry slash, biosolids, waste timber, and animal manure, these are beyond the scope of this report. Here we focus on the of role food loss and waste as a feedstock in the context of several common energy-from-waste technologies (see annex 11). Importantly, little of the evidence related to the potential costs and benefits or performance of many EfW technologies is based specifically on food waste feedstock but waste feedstocks more generally.

Here at home, MfE has published guidance[314] on EfW approaches, including four principles policy makers and businesses should apply when considering EfW proposals. These are:

- The proposal should support a move up the hierarchy and towards a circular economy.
- Environmental impacts, especially GHGs, must be well managed.
- Project must have long term commercial viability.
- Project should have community and Treaty partner support.

As with the Queensland Government *Energy from Waste Guideline*,[53] this MfE guidance is applied in the context of waste generally, not FLW specifically. However, given the limited suitability of many EfW technologies to food-derived waste streams, these principles become increasingly relevant.

Anaerobic digestion

As introduced in section 4.3, AD is a process whereby organic materials broken down by microbes in an anaerobic environment, converting the feedstock into biogas and nutrient-rich digestate (see figure 45).[31] Food-derived waste streams, including things like mixed food waste from households, food processing effluents, and crop residues, can be digested alone, or co-digested with a variety of other organic materials.[31,430,431] Digestate can also be derived from other materials (see annex 11), including sewage waste, but these are out of scope for this report.

Biogas, which consists primarily of methane and CO_2, can be burnt to generate heat and electricity, or upgraded to serve as a substitute for natural gas.[430] Digestate – the wet mixture of liquid and solid residue that remains after biogas is extracted – is a high-volume by-product, with an estimated 0.2 - 0.5 tonnes produced per tonne of food waste processed (a volume that will vary with different feedstocks).[432] Given digestate can be rich in N, P, K, and residual complex organic matter,[433] it has a potential use as a biofertiliser[351,434] and is widely used in agricultural settings abroad (see annex 10).[432,435] However, digestate derived from food-based waste streams can be subject to contaminants,[436] especially when co-digested with other waste streams,-[437–440] and requires proper management and/or quality control before land application.[361,441]

Table 7 lists some of the benefits and challenges of AD in the context of food loss and waste.

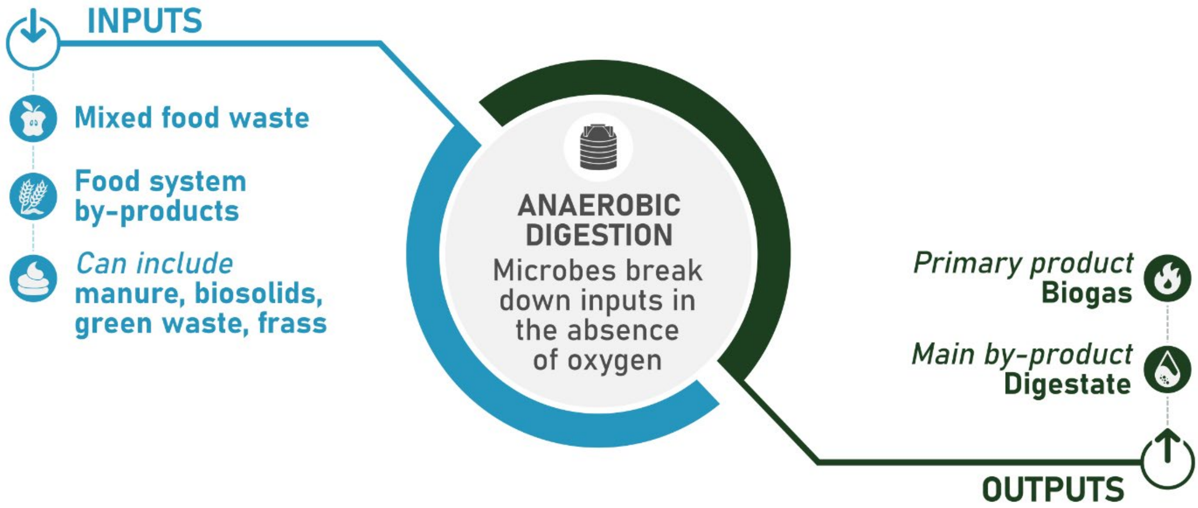


Figure 45: The main inputs and outputs of AD. A wide variety of inputs are possible, but here we focus on food-derived waste streams. The process relies on the exclusion of oxygen so that the inputs break down anaerobically, producing methane-rich biogas that can be used to generate heat and electricity, or as a replacement for natural gas. Digestate is the primary by-product. With adequate quality controls in place (see annex 10), digestate derived from FLW can generally be used as a fertiliser directly or with further processing.[436,441]

Box 7: The fate of digestate matters

Whether digestate is landfilled or applied to land productively can make a significant difference to the overall emissions profile of AD. As noted in several studies[442,443] (see annex 2 for details), when digestate is landfilled – and therefore doesn't displace mineral fertiliser use – AD can become a carbon positive process (albeit with significantly fewer GHG emissions than many alternatives, in particular landfilling FLW directly). Beyond having a poorer emissions profile than land application, landfilling digestate can also cause challenges for landfills with instability and capacity issues arising (an issue already happening with biosolids from WWTPs in New Zealand[444]). Incinerating digestate to reduce its volume is undermined by the energy intensive-nature of pre-drying a mostly liquid feedstock. These problems emphasise the importance of safely and effectively returning digestate to land as a source of nutrients.

Where and how digestate is applied to land is also important, with the existing N content of the soil and risks of leaching into fresh waterways being important considerations.[435] Thought also needs to be given to suitable methods for the land application of digestate so as to minimise ammonia volatilisation (the loss of N from soils), with further study needed to determine the long-term effect under various climatic and soil conditions.[445] Current research and best practice guides suggest digestate injection into soils should reduce ammonia volatilisation during land application, while digestate spraying should be avoided.[351,445,446]

Digestate production creates both opportunities and challenges. On the one hand, there is significant potential to use digestate to displace mineral fertiliser use,[434,435,447] a factor which can determine the emissions profile of the technology. However, the volume of digestate production can present management challenges, with countries like Italy, Denmark, Germany, and the Netherlands – all heavily invested in AD – reportedly struggling with excessive nutrient loads from digestate,[433] although much of this volume in these countries comes from feedstocks like animal manure and/or biosolids. Recognising that digestate use is one of the bottlenecks for the biogas industry,[432] a variety of post-treatment processes have been developed to improve digestate nutrient recovery and increase its suitability for land application,[447,448] including composting, vermicomposting, drying, and pyrolysis[432,433,449] (see section 6.3). Several countries process digestate by composting it (see annex 10), with several benefits (e.g. pathogens are neutralised, and the product can be verified as meeting compost standards). While many of these approaches are undertaken in the context of digestate derived from biosolids and/or manure, they can have application for problematic food-derived waste streams. Additionally, a multitude of industry standards, regulations, and guidelines can aid the safe and effective use of digestate in agricultural settings (see annex 10).

The total volume of digestate produced from food-derived waste streams in Aotearoa is unclear, with Ecogas (see case study 15) only having recently begun operations. BECA estimate that some 300,000 tonnes of digestate could be produced annually from source-separated food waste in New Zealand, as a maximum theoretical potential.[430]

Trials for the land application of food-waste derived digestate are ongoing at Ecogas[450] (see case study 15) with plans to apply digestate to farmland in accordance with N limits set by New Zealand's synthetic fertiliser cap.[410] Currently, decisions on the dispersal of digestate to land lie with regional councils, who determine if it's a permitted, controlled, or discretionary activity (and hence whether a resource consent is required). The absence of a regulatory framework in Aotearoa (see annex 10) remains a barrier to the effective use of digestate.[430]

Specific to food waste, New Zealand's AD market is in its infancy. Currently, we have one AD facility dedicated to food waste (see case study 15) and two facilities which process industrial effluents from dairy manufacturing. For further context on AD in Aotearoa and abroad, see annex 11.

> …New Zealand's anaerobic digestion market is in its infancy.…

Table 7: The key benefits and challenges of AD of food waste streams.

Key benefits	Key challenges
• Provides an additional source of energy, biogas, which can displace some fossil derived fuel sources. • Where inputs and processes are well controlled, digestate can be used as a biofertiliser in agricultural settings.[351,434] • AD facilities can be carbon negative or carbon neutral when biogas or its purified form, biomethane, is used as a substitute for fossil fuels to produce electricity, heat, or transport, and when digestate is used to displace fertiliser.[443,451–454] • Can process a wide range of organic waste types including mixed food waste, crop residues, biosolids, manure, and industrial effluent.[430] • Potential to use the generated CO_2 in greenhouses and elsewhere (e.g., as food grade CO_2).[455] • AD facilities are fully contained.[451,456] This means that, unlike landfills with gas capture, they recover almost all the methane produced. Containment also reduces odour risks meaning anaerobic digestors can be situated closer to major population bases than many other food waste processing options.	• Requires significant investment in infrastructure to capture and process the methane from organic waste.[457] • Biogas needs to be purified (removing the CO_2, water vapour, and trace gases) before it can be readily used as a natural gas substitute.[458] • Application of digestate to land needs to be done according to the best nutrient management practice in order to maintain nutrient value, and more research on its use in agronomic settings is needed.[445] • Excessive or uncontrolled application of digestate can harm plants, leach excess nitrate, and produce odours (mostly from ammonia) and greenhouse gas emissions.[433,435,459] • Controlling the quality of feedstocks from residential or urban organic waste streams can be a challenge, with potential knock-on effects for digestate quality.[70] Adequate sorting and pre-processing technologies need to be selected to minimise the risk of product contamination.[70]

Case study 15: Anaerobic digestion with Ecogas

Ecogas is a New Zealand-based company which specialises in the AD of organic waste from households and businesses. Food waste is used to generate biogas (i.e. a fuel source) and digestate (i.e. a potential fertiliser). Ecogas, a partnership between Pioneer Energy and Eco Stock Supplies, is new to the AD scene in Aotearoa, having opened their flagship facility in Reporoa in mid-2022.

Once fully operational, Ecogas plans to process 75,000 tonnes of organic waste at its Reporoa facility – including a mix of household food scraps, commercial and retail food waste, and dairy waste – producing biogas and digestate from these feedstocks. Kerbside food scraps from Auckland are set to make up to 38,000 tonnes of Ecogas' feedstock as collections is rolled out during 2023. After being collected, this household food waste will be consolidated in Ecogas' sorting and consolidation centre in Papakura, and then sent to the Reporoa Organics Processing Facility using freight trucks that otherwise would have been empty on their return journey from Auckland to Reporoa. There it will be separated from contaminants like plastic, biodegradable packaging, and metal prior to processing in anaerobic digesters.

Biogas, the primary product of AD, is a mixture of methane, CO_2, and small quantities of other gases. To create biogas, feedstock at Ecogas' Reporoa facility is machine-sorted, passed through a grinder, and fed into large airtight tanks, where microbes are used to break down organic matter in the absence of oxygen, releasing biogas in the process (see figure 46). Biogas is taken from the top of digestion tanks, conditioned (i.e. cleaned to remove unwanted sulphur compounds and moisture), and stored for use (see figure 47). Biogas can be used in place of virgin natural gas, providing energy without the environmental tolls associated with natural gas extraction. Concurrently, biogas produced from food waste mitigates methane emissions that would otherwise occur if waste was sent to landfill. Presently, Ecogas generates electricity and heat for their Reporoa facility by burning a portion of the biogas produced on site. Once fully operational, Ecogas plans to send the heat and CO_2 from biogas to a local tomato glasshouse to improve growing conditions. Looking forward, Ecogas plans to upgrade the biogas it produces into biomethane to inject into the natural gas grid.

Figure 46: Sorting hoppers which receive and filter organic waste streams at Ecogas' Reporoa plant.

Beyond biogas, the AD process also produces digestate, a wet mixture of processed solids and water. Where digestate is primarily derived from food waste – as is the case for Ecogas – it typically contains high levels of nutrients like N, P, and K, minerals, and trace elements. Given that most of the C in the feedstock is converted into biogas, digestate contains little C relative to other soil amendment products like compost. At Ecogas, digestate will be pasteurised before being sent to farmers as an alternative to mineral fertilisers. This is a common practice in several European countries, as well as parts of North America and Asia. To help inform the introduction of digestate on the New Zealand farming market, Ecogas has run trials with digestate at a small pilot plant in Wiri to compare the effects of digestate on pasture growth with those of common fertilisers and soil treatments, although results aren't yet available. In addition, Ecogas, in partnership with the Bioenergy Association, is working on an industry-lead set of standards for digestate use and certification in Aotearoa.[434] This is a key step in ensuring that there are end markets for digestate, especially as it is currently considered a waste product in Aotearoa.[430] Ecogas' approach to these standards seeks to mirror initiatives abroad (e.g. the *PAS110*[441] in the UK and the *SPCR 120*[460] in Sweden) which control digestate quality, optimise its efficacy as a fertiliser, and minimise any potential adverse effects of its application.

Figure 47: The digester tanks at Reporoa which hold up to 3.5 million litres of organic waste. Methane rises to the top of the tanks and are captured using a hose system.

Ecogas currently provides fulltime employment for seven people, which will potentially increase to 10 to 15 as capacity at Reporoa increases. There are plans to expand Ecogas' operations in Aotearoa in the future, with discussions ongoing for new facilities in Canterbury and Manawatu in the next five years.

Incineration

Incineration, where waste is burnt in the presence of oxygen,[461] is an end-of-life waste management solution. Incinerators reduce the mass of waste and, depending on the feedstocks used, produce heat energy that can be used to generate power but otherwise does not yield any useful products. Food waste is not usually a targeted feedstock of incineration, typically because food-based feedstocks have a low calorific value and a high moisture content and consume more energy than they produce.[428,461] This means that incineration of food waste is not a form of energy recovery, it is a form of disposal.[12,31] Only under circumstances where food-based feedstocks are dry enough – potentially waste streams including some crop residues or processing waste like nut shells – does incineration have application to food loss and waste as a

Only under circumstances where food-based feedstocks are dry enough – potentially waste streams including some crop residues or processing waste like nut shells – does incineration have application to food loss and waste as a method of energy recovery.

method of energy recovery. However, as with landfilling, the nutrients in food waste are lost when it is incinerated. Incineration also produces fly ash and flue gas, which must be cleaned before discharge, and the residues from cleaning must be dealt with, generally as hazardous waste. Table 8 has listed the benefits and challenges of incinerating food waste.

In Aotearoa, there is no large-scale incineration of municipal waste, let alone food waste. However, there are sites being considered, such as the proposed Te Awamutu[462] and Waimate[463] incineration plants, although it is unclear whether these would target food-derived waste streams. Small scale use of incinerators are mostly for hazardous waste (New Plymouth), clinical waste, farm waste, and sewage sludge (Dunedin), although the use of incineration has declined over time.[464,465] WasteMINZ' Behaviour Change Sector Group has proposed a moratorium for any large EfW facilities,[466] citing a shift to a circular economy, addressing emissions issues, and potential burdens placed on local governments. See annex 11 for further context on incineration as an EfW technology in other contexts.

Table 8: Benefits and challenges of incineration of food waste streams.

Key benefits	Key challenges
• Reduces the volume of waste and can be processed faster than techniques like AD.[428] • Can produce energy, but only if feedstocks don't require additional drying.[461]	• Limited application to a majority of food-derived waste streams given high moisture content; incinerating high-moisture waste consumes more energy than it produces.[428,461] • Nutrient value in wasted food is lost. • Produces difficult-to-manage by-products, some of which are hazardous, for example incinerator bottom ash, fly ash, reagents, and heavy metals.[467] • Can release harmful pollutants, including flue gas that contains dioxins, furans, and particulate matter,[467,468] requiring sophisticated air pollution control technologies to mitigate pollution risks. • Can discourage the use of waste-reduction solutions higher up the food recovery hierarchy due to the need for waste to keep incinerators functioning.

Pyrolysis and gasification

Pyrolysis and gasification are two similar processes for converting organic waste to biochar and energy; waste is partially combusted in the absence of oxygen (in the case of pyrolysis) or presence of a limited amount of oxygen (in the case of gasification). These processes are typically applied to a variety of feedstocks (see annex 11), and have limited (current) application to food-derived waste streams.[427,469]

Generally, the main products of these processes are gaseous (syngas, primarily hydrogen and carbon monoxide, but also CO_2, methane, and other minor gases), liquid products (bio-oils including acids and alcohols), and solid products (carbon-rich char, as well as ash, tars, other residues). However, this technology has seldom been applied to food-derived waste streams,[427,428] so product and by-product ratios and compositions from these wastes are poorly understood. There is a limited role for these technologies in processing uncontaminated, low-moisture such as waste stream, e.g. peanut shells, potato peels, mango seed waste, peanut crisps, and some citrus wastes.[469–472] For these types of clean waste streams, there is potential to produce biochar as a method of C sequestration,[469,473,474] as well as biofuels.[471,472] Thus, the composition and properties of food-derived feedstocks must be understood to evaluate the impact of these processes. For example, if food waste is mixed with municipal solid waste in the use of pyrolysis and gasification, the resulting char or ash will likely be sent to landfill.[475] As with incineration, if the food-derived feedstocks have a high moisture content, then the efficiency of the processes is compromised (see annex 1).[476] Table 9 shows some of the benefits and challenges associated with the pyrolysis and gasification of food waste.

The use of these processes for organic material processing in Aotearoa is limited to demonstration and pilot scale operations.[319] Proposals for large scale facilities in remote towns have not been successful so far with consent applications for a pyrosis plant in Fielding being withdrawn earlier this year.[477] However, large-scale facilities are unlikely to incorporate most types of food loss and waste given inefficiencies of pyrolysing wet feedstocks.

Table 9: Key benefits and challenges of pyrolysis and gasification of food waste.

Key benefits	**Key challenges**
• Biochar can sequester C[478] for centuries because the C in biochar exists in a stable form which lasts for a lot longer than untreated food waste.[473] • Biochar can also be used as a fertiliser or fertiliser complement,[474] improving availability of nutrients, making soils better at retaining moisture, and improving soil chemistry. Evidence also suggests it can be used to improve the efficiency of composting[479] and AD,[480] as well as the quality of products from these processes. It can also help control odours.[481] • Biochar can be used to remediate soils and waterways because it can adsorb things like heavy metals and persistent organic pollutants.[482]	• The quality and properties of the biochar depend heavily on what is fed into the process and, if contaminants are present, it might not be suitable to apply to land.[483] • Limited application to a majority of food-derived waste streams given high moisture content. A lot of energy is consumed when food waste is dried to an acceptably low moisture level.[319] Thus processing high-moisture waste can consume more energy than it produces. Energy is also expended when the feedstock is chopped into small pieces (which is necessary to ensure rapid heat transfer). • While bio-oil has the potential to be used as a diesel- or petrol-like fuel, it generally requires upgrading – often it can contain too much water to combust efficiently and could cause engine rusting.[484] • While air pollution can be kept in line with air quality regulations by filtering and scrubbing before discharge, this creates contaminated wet scrubber wastewater which needs careful disposal. Some of the pollutants produced are toxic and environmentally persistent.[485]

Hydrothermal processing

Hydrothermal processing converts waste into its by-products in the presence of high heat and water in a closed system[486] (see figure 48). Compared to other thermal approaches, it is better suited to a variety of food-derived waste streams as it can efficiently handle biomass with higher moisture content.[487] Its main products are similar to those of pyrolysis and gasification, and include bio-oils, syngas, and hydrochar. The product ratios and properties of these depend on biomass composition, temperature, and pressure of the hydrothermal process. Hydrothermal carbonisation is one variation of the hydrothermal process and has been assessed to be more efficient and form better solid fuel than pyrolysis,[488] as it does not require a drying process.[489] In addition, hydrochar can be produced faster and at much lower temperatures than through pyrolysis, which can require about 450 °C.[486] The char can also be used as a soil amendment and to sequester C,[486] although its usefulness is dependent on feedstock composition. Saqib et al.[427] provide a useful overview of the potential of hydrothermal carbonisation for food waste in a New Zealand context, concluding that the technology shows promise in capturing energy but its efficacy as a solution is highly dependent on process parameters and the fluctuating cost of equipment, labour, and transportation.

Globally, the technology remains novel, with hydrothermal processing of food waste at large scales is yet to be established, however, Indonesia built a hydrothermal facility in 2017 to manage non-segregated municipal solid waste, which has shown promising results.[490] The presence of heavy metals and organic micropollutants, the availability of raw materials, and the novelty of the technology present limitations.[490]

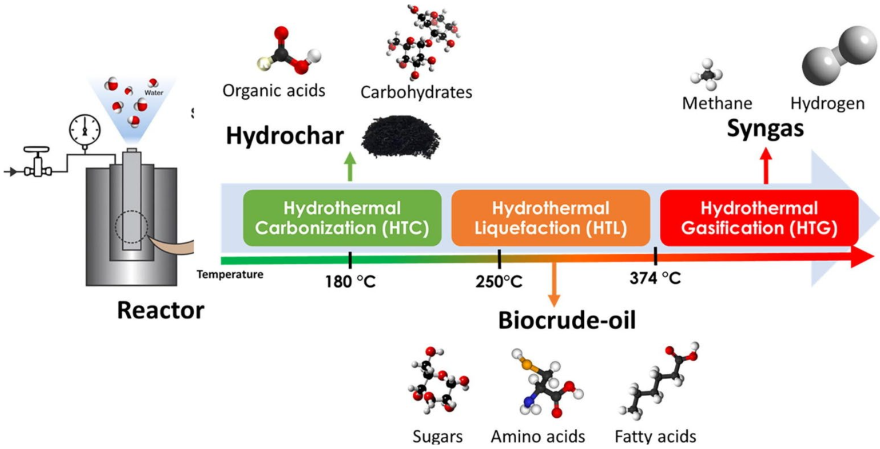


Figure 48: Hydrothermal processing techniques and products. Figured amended from Lachos-Perez.[490]

Emerging energy-from-waste technologies

There are alternative processes that are emerging as waste-to-energy technologies that are still being tested and not yet widely adopted to deal with food waste. These include, but are not limited to, transesterification,[491] alcoholic fermentation,[492] microbial and microalgae fuel cells, and photobiological hydrogen production.[484] These generally have low technology readiness, have niche applications, or are not highly applicable to FLW feedstocks but are mentioned for completeness.

Potential of EfW for food-derived waste streams in Aotearoa

EfW supplied by food-derived waste streams will only play a minor role in solving our energy challenge

As indicated by the preceding overview EfW technologies, potential for energy generation from food loss and waste mostly lies in biogas production from AD, with other technologies only suited to niche food-derived waste streams. A report jointly funded by industry and the Energy Efficiency & Conservation Authority suggests that biogas could generate 13.0 petajoules/year[k] and replace 7% of current natural gas consumption by 2050. In the interim, 1.6 petajoules/year is thought to be achievable currently, with increased investment, availability of feedstocks, and efficiency increasing

[k] Petajoules (PJ) 1 PJ = $1×10^{15}$ J

this over time. Importantly, these figures do not refer only to biogas production from food loss and waste, but instead capture biogas production from a variety of AD facilities with different feedstocks, wastewater treatment plants, and landfills with gas capture (see annex 10 and annex 11). Figure 49, taken from the same report, shows that at present, FLW is one of the most important feedstocks for biogas production, but over time this may diminish. FLW represents a relatively small portion of the 2050 headline figure, with 1.2 petajoules/year from food waste and 1.5 petajoules/year from crop residue.[430]

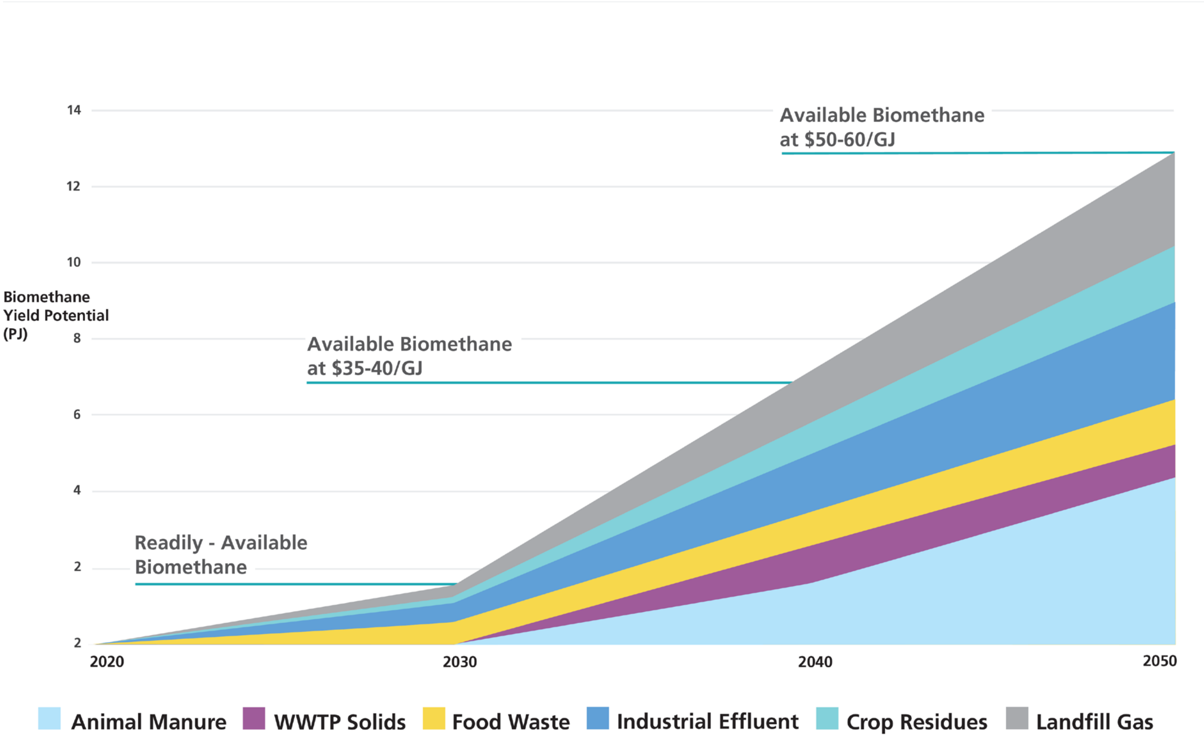


Figure 49: Projected availability of biomethane over time by source. Abbreviations: GJ= gigajoules, PJ = petajoules. Image credit: Energy Efficiency and Conservation Authority, Beca, Fonterra, and Firstgas Group.[430]

While biogas has potential as an energy source, particularly when upgraded to higher value products, MBIE's most recent report on energy in New Zealand notes that biogas is only about 30% efficient[426] at conversion to electricity. The Battery Project – a team within MBIE charge with scoping long term solutions to the dry year problem – ruled out biogas even as a component of a 'portfolio' approach[493] (albeit while noting that biogas could be useful at smaller scale to meet local needs - see section 6.2.

While the potential of using food waste to create biogas and displace 1.5% of natural gas use[l] or to supply 0.3% of our current energy needs[m] is clearly not going to provide us with energy security, it will also not have a trivial impact.

In short, energy generated from FLW is likely to be a very small contributor to meeting our energy needs. Nevertheless, we can recognise the potential of the AD industry in aiding a transition away from fossil derived fuels and remain open to the possibilities that emerging technologies may offer in generating energy from a variety of FLW streams. We will need to be thoughtful about how we invest in EfW infrastructure, to avoid entrenching a demand for food waste as feedstock that disincentivises or competes with preventive efforts (see section 2.2). In the case of biogas, figure 49 shows that this may not be intractable: initially FLW accounts for a large share of feedstock, but over time other feedstocks are expected to become available, potentially allowing the production of biogas to remain economically viable even as the supply of FLW as feedstock declines.

> We will need to be thoughtful about how we invest in EfW infrastructure, to avoid entrenching a demand for food waste as feedstock that disincentivises or competes with preventive efforts.

A better understanding of feedstock composition will help determine our approach to EfW technologies

As highlighted in section 2.1, as well as our first report on FLW,[1] we know very little about the composition, properties, and volume of FLW in Aotearoa. This knowledge gap presents a significant barrier to talking about the efficacy and potential of EfW technologies, as their utility for food-derived waste streams is tied to the properties of this waste.

What is increasingly clear is that New Zealand households, food manufacturers, and retailers produce hundreds and thousands of tonnes of waste each year, much which is likely to be wet and sludgy. Few EfW technologies are currently optimised for this type of waste, with AD being the important exception. Filling in knowledge gaps and developing a better understanding of the composition industrial food waste streams, as well as foods lost during production, will inform our understanding of the utility of other EfW options (e.g. pyrolysis) that are better suited to clean (i.e. not mixed) and inherently dry feedstocks.

---

[l] FLW contribution to biogas =1.2+1.5PJ, total biogas=13PJ, biogas replacing natural gas=7%; ((1.2+1.5)/13)*7%=1.5%

[m] 2022 natural gas =18% of total energy consumption; 1.5%*18%=0.3%

5. Doing away with disposal

New Zealand produces some of the highest amounts of waste globally, with municipal waste reported at 756 kilograms/capita compared to an OECD average of 535 kilograms/capita in 2018 (see figure 50).[494] Landfills are utilised to manage and control this waste generated, overseen by legislations such as the *Resource Management Act 1991* and *Waste Minimisation Act 2008* and implemented by TAs.[495,496]

> New Zealand produces some of the highest amounts of waste globally.

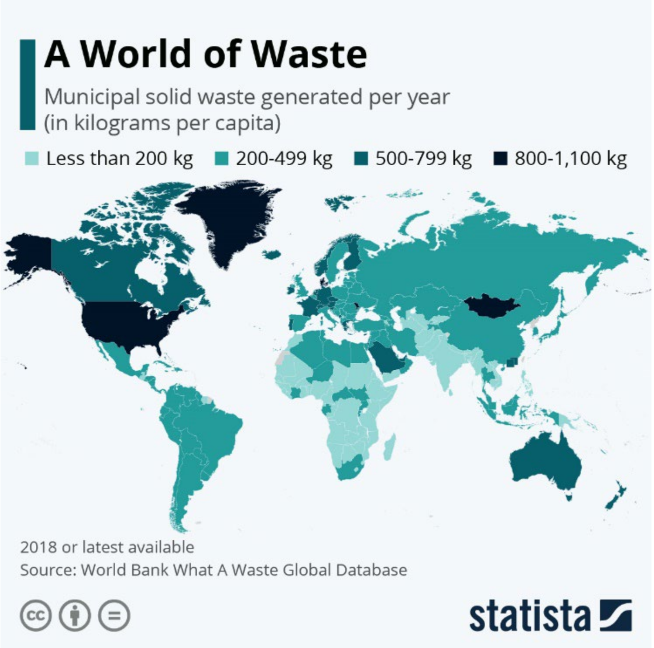


Figure 50: Municipal solid waste generated per capita by country. New Zealand is in the second highest tier. Image credit: Statista.[497]

5.1 Understanding our landfills

There are approximately 41 municipal waste landfills operating in Aotearoa, mostly owned by TAs that contract its use to private operators. There are different classes of landfills to manage the waste that Aotearoa produces (see table 10). Different types of waste require different waste management strategies; therefore, five different types of landfills are used in New Zealand. Certain kinds of landfills have waste disposal levies imposed on them as shown in table 10; however, these rates are considered quite low compared to those in Australia[498] or the landfill tax in the UK.[499]

Table 10: Types of landfills by classification and their management requirements.[494,500,501]

Classification	**Types of landfills**	**Types of waste accepted**	**Requirements**
Class 1	Municipal solid waste.	Household waste (including food waste), construction and demolition waste, industrial waste, and contaminated soil.	• High level of containment of waste. • Leachate collection. • An appropriate cap. • Gas management. • Monitoring and reporting of:

Classification	Types of landfills	Types of waste accepted	Requirements
			○ Waste. ○ Sediment runoff. ○ Surface water and ground water. ○ Leachate quality and quantity. ○ Landfill gas (for landfills that will accept over a million tonnes of waste). • A waste levy of $50 per tonne (as at 1 July 2023).
Class 2	Construction and demolition waste.	Non-putrescible waste, materials such as wood products, asphalt, plasterboard, and insulation. These landfills may produce mildly acidic leachate, landfill gas, and hydrogen sulphide. The feasibility of including gas capture is an additional ERP action.	• Environmental assessment. • Engineered liner. • Leachate collection and maybe treatment. • Groundwater and surface water monitoring. • A waste levy of $20 per tonne from 1 July 2023.
Class 3	Managed fills.	Inert material (e.g. selected inert construction or demolition material) or soils with specified maximum contaminant concentrations greater than applicable local background concentrations.	• Environmental assessment. • Monitoring of waste, ground water and surface water. • A waste levy of $10 per tonne from 1 July 2023.
Class 4	Controlled fill.	As for class 3, but with tolerances only for elevated trace elements but not contaminants.	• Environmental assessment. • Monitoring of waste, sediment runoff and ground water. • A waste levy of $10 per tonne from 1 July 2023.
Class 5	Clean fill.	Non contaminated soil, rocks, gravel, clay, or other natural materials with little to no attached biodegradable material like vegetation.	• Land does not require engineering environmental protection. • Surface water controls.

Classification	Types of landfills	Types of waste accepted	Requirements
			• Monitoring of waste, sediment runoff and operational controls.

5.2 What happens in landfills?

Landfills can be divided into cells which can be filled up in phases before moving to new active cells. A cover is added over the waste daily and in intermediary stages to manage issues like odour, vermin, air intrusion, and water flowing in. As decomposition occurs, they produce leachate and gas that need to be managed beyond the time a landfill is actively used.[502] Some classes of landfills require gas management and leachate capture to reduce risks of fire, subsidence, and contamination of the local environment and water systems.

Older landfills that have closed and did not have effective management strategies – for example, because they predated relevant regulation – risk leaking leachate, gas, or their contents into the environment.[44,503] Unfortunately, we still have to manage old landfills as they have been shown to be vulnerable to weather events and erosion, such as the Fox River landfill that washed out in 2019,[504] and these will require risk assessments, monitoring, management strategies, sometimes at a cost to the relevant regional councils.[44]

In the absence of a reduction in our waste, Waste Management Ltd[n] and others have argued that landfills are currently the most environmentally responsible solution available to New Zealand.[505] In the long term, this strategy of managing waste has long-term impacts on the environment that need to be mitigated. Monitoring and enforcing the requirements of these landfills are part of the responsibilities of the regional councils.[506] Modern, engineered landfills are much better at capturing landfill gas than open older-style landfills[507] (e.g. Redvale Landfill and Energy Park[508] in Auckland is estimated to capture and use more than 90% of the methane created, while Wellington's Southern Landfill is estimated to capture just 55%[509]). However, even at landfills with gas capture systems, some greenhouse gas escapes.[507] This is in part because gas capture systems may only be installed a few years after waste has been deposited,[510] during which time CO_2 (initially, while oxygen is present) and methane (later, when oxygen can no longer reach the waste) are released. For landfills with gas capture, an estimated 0.7 tonnes[511] of CO_2 are released per tonne of food waste landfilled, but this varies between landfills.[509]

> …even at landfills with gas capture systems, some greenhouse gas escapes.

5.3 Food waste in landfills

Some countries have used policy settings to rapidly reduce the amount of food loss and waste that enters landfills. For example, the *Loi Garot*, a French public policy, mandated that food retailers utilise the EU waste hierarchy system and donate surplus food to charities.[55] The policy can be considered successful in dealing with food waste and creating new markets for food valorisation, but

[n] Waste Management Ltd is one of our two largest waste companies and their business is largely collection and disposal of waste to landfills.

has also been critiqued[55] for not addressing the issue of excess food production and placing a considerable burden on food rescue organisations. This highlights the need to sequence FLW policy implementation, as has been done more successfully in Queensland (see case study 16). The New Zealand Government's new waste strategy sets out a vision for 2030 and 2050 in order to transition to a low waste economy, which includes diverting food waste from landfills.[27] By 2026, all municipal landfills are currently slated to be required to have gas capture systems in place,[15] subject to the development of Emissions Reduction Plan 2 priorities.

Case study 16: Insights from Queensland's Organics Strategy and Organics Action Plan

The Queensland Government's recent *Organics Strategy* and *Organics Action Plan* provide a good example of well-considered sequencing of household food waste policies.[512] The Queensland Government has signalled in its *Organics Action Plan* that it intends for at least 65% of households to have access to organics capture services of some kind by 2025, and 80% by 2030. [512] Brisbane City Council is pursuing this state government goal by supporting at-home food waste processing (with composting and worm farming workshops, and AU$70 rebates for eligible composting equipment), the provision of 28 community composting hubs, and the possible rollout of kerbside collection services (currently being trialled in a pilot involving 6,000 households).[513,514]

The Queensland Government is also consulting on a ban on organics to landfill. This gives organic waste processors a stable signal to invest in the infrastructure necessary to process organic waste, in the expectation that it will be diverted from landfill in increasing volumes over the next decade.[512]

In addition, the *Organics Action Plan* includes actions to support infrastructure development and stimulate market demand through government procurement policies and promotion of sustainable procurement among businesses. To further secure demand, the Queensland Government is supporting the review of the Australian Standard for Composting, which will give end users confidence in the quality of the output and will help the composting sector design processes which yield compliant outputs.[512]

This is all combined with actions to prevent household food waste, which are frontloaded in the *Organics Action Plan* to ensure food waste volumes drop before processing infrastructure develops around current volumes of food waste.[512]

The Queensland Government has also published an *Energy from waste guideline*, encouraging energy-from-waste processors to think about how reductions in waste volumes or changing waste composition will affect their processes and products.[53] The guidelines include a decision tree for energy-from-waste processors to ensure they are not processing food waste which could be utilised in another way, and specify that energy-from-waste facilities "should not undermine future options or innovations in waste avoidance, reuse, and recycling."[53]

Almost 300,000 tonnes of food waste currently enter New Zealand landfills each year.[6] Sending food waste to a landfill without gas capture is among the most emissions-intensive things we could do with our food waste;[515] food and other organic waste contributes to 4% of New Zealand's GHG emissions.[516] Without gas capture systems in place, the equivalent of 2.1 tonnes of CO_2 are released for every tonne of food waste.[511] Since 1995, the amount of food going into New Zealand's landfills has been declining, as seen in figure 51.

> …other organic waste contributes to 4% of New Zealand's methane emissions.

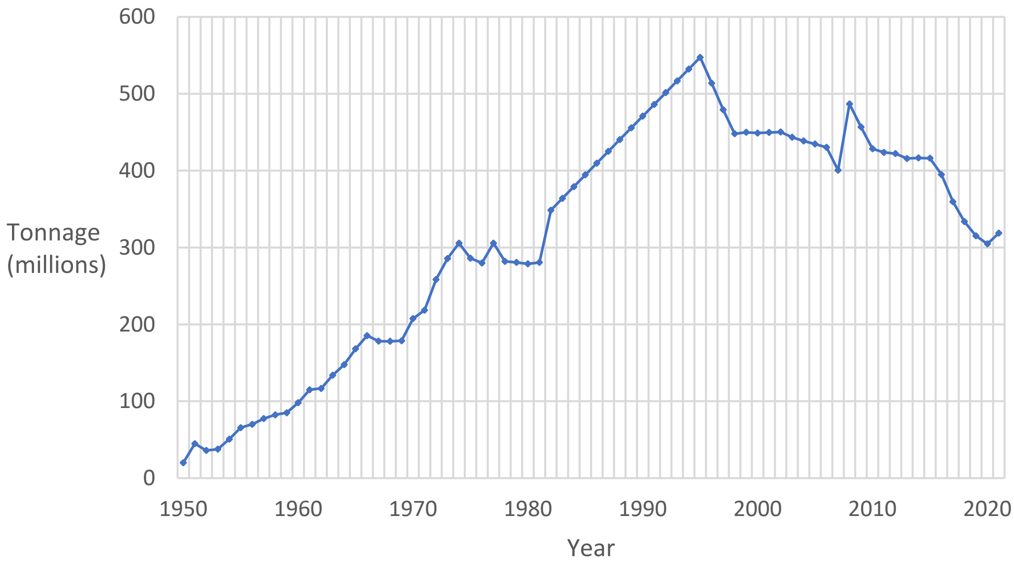


Figure 51: Total tonnage of food sent to New Zealand's Class 1 landfills as reported by New Zealand's Greenhouse Gas Inventory.[517]

6. The food waste problem is big enough for multiple solutions

6.1 Comparing food waste pathways: apples with oranges?

Converting food waste into products like compost or biogas, which can displace fertilisers and fossil-fuel derived sources of energy, is inherently better for the environment than sending food to landfills. However, this does not mean that treatment processes like composting, AD, or incineration are without their environmental impacts. Determining the scope and magnitude of these impacts is a complex undertaking, particularly as impacts are influenced by variation within treatment methods, feedstocks used, and the local contexts within which treatment methods are applied.[518]

While there are range of techniques applied to comparing food waste management pathways,[519–523] scientific researchers typically use LCAs to compare and rank different options based on their environmental impacts.[518] This internationally standardised approach, described in detail in annex 2, is a useful tool when applied to a specific context – for example the processing options for household food and green waste in New South Wales[524] – but has limitations in extrapolating findings to other contexts. The New South Wales[524] study authors found AD of food waste and composting of green waste to be the optimal strategy (in terms of environmental impact) for managing these waste streams. However, these findings are constrained by the assumptions, system boundaries, and goals of the study, which were tailored to a New South Wales context. While it is tempting to apply such findings to other contexts, this would neglect the underlying differences between contexts and potentially lead to a false understanding of environmental outcomes. Emphasising this point, Bernstad and la Cour Jansen[518] highlight how the data used in different LCA studies, but comparing the same technologies, can be significantly different – as illustrated by data on CO_2 emissions of incineration, landfill, AD, and composting in figure 52 below.

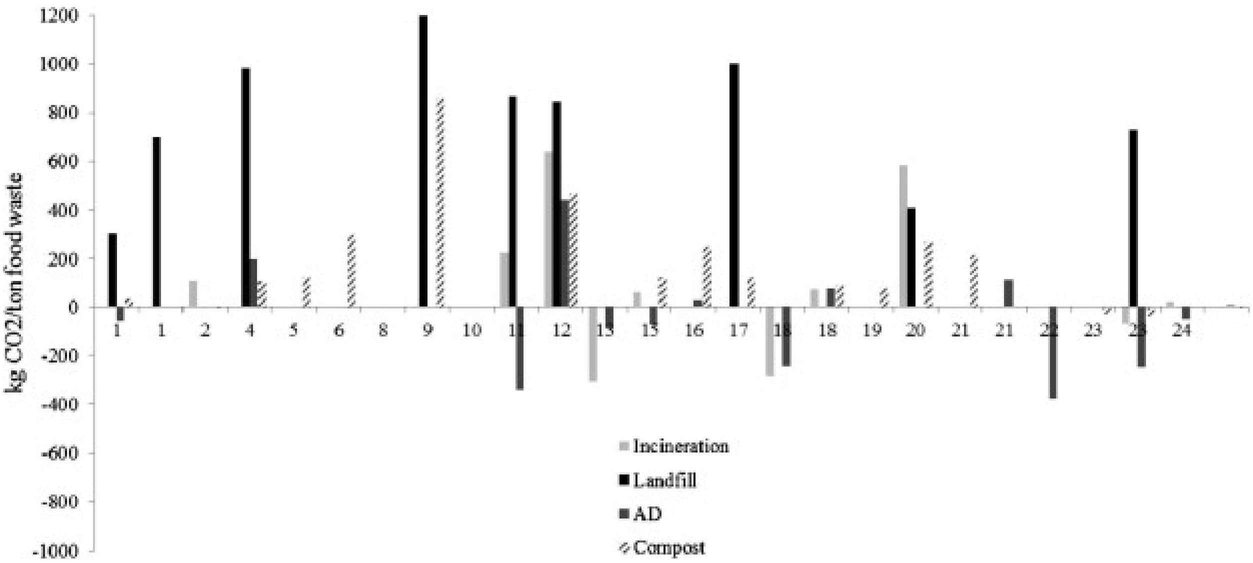


Figure 52: The amount of CO_2 it takes to process one tonne of food waste using different technologies. Note that the same technologies can be deemed carbon negative and carbon positive across 24 different studies (denoted by the x-axis). Image credit: Bernstad and la Cour Jansen.[518]

Bernstad and la Cour Jansen's research[518] collated a set of comparative LCA studies of food waste management systems produced between 2000 - 2010. To provide updated context, we have compiled and synthesised a series of comparative LCA studies undertaken since 2010 (see annex 2), limiting this analysis to studies that specifically address food waste (i.e. not municipal solid waste or other organic waste streams). Several important takeaways emerge from this annex:

- To date, no LCA studies have compared food waste management options in a New Zealand context. Given that much of the value of an LCA study comes from describing boundaries and assumptions that reflect local context, this represents a significant knowledge gap.
- AD (in 14 of the 15 included studies), incineration (9 of 15), composting (7 of 15), and landfill gas capture (6 of 15) are the most discussed technologies, likely because they are well established and can operate at large scales.

> … no LCA studies have compared food waste management options in a New Zealand context.

- Across all studies, landfill (with or without gas capture) was near-uniformly considered the worst option by study authors for managing food waste. Instead, animal feed conversion (2 of 3 studies), composting (3 of 7), AD (5 of 14), and incineration (3 of 9) were considered the 'optimal' choice by study authors.
- There is wide variation in the predicted environmental impacts of the different technologies. This is expected, given different contexts, methods, system boundaries, and assumptions.
- By their nature, the listed LCA studies overlook difficult-to-quantify benefits like community building, specific properties of products (e.g. soil improvement characteristics), and the real-world application of these technologies (after all, an LCA is a model of a system, not the system itself).

While we should always treat the results of LCAs with caution, especially when extrapolating results to other contexts, general trends emerge when we look across a variety of studies. In their recent evaluation of food waste pathways,[31] the US EPA used the findings from LCAs to inform the development of their own food recovery hierarchy.[525] Table 11 highlights the median impacts of different FLW pathways on various environmental indicators, including global warming potential (GWP), energy demand, acidification, eutrophication, water consumption, and land occupation.

Table 11: The relative environmental impacts of different pathways for food loss and waste, as measured by median LCA impact scores per metric tonne of wasted food in the US Negative values indicate a net benefit to environmental impacts, values near or at zero indicate little or no effect, and positive values indicate net environmental harms. The colour scale is based on trend median literature data, not statistical differences, whereby green = lower impact; yellow to orange = moderate impact; red = higher impact; and white = no data (n.d.). Numbers in brackets indicate the number of studies from which the median impact score is derived. Abbreviations: AD = anaerobic digestion, FLW = food loss and waste, GWP = global warming potential, m^2 = meter squared (area), m^3= meter cubed (volume), MJ = megajoule, n.d. = not defined, Neq = nitrogen equivalent, SO_2eq = sulfur dioxide equivalent. Image credit: *From field to bin: the environmental impacts of US food waste management pathways.*[31]

Impact Category	Median Impact/ metric ton FLW	Source Reduction	Donation	AD	Animal Feed	Compost	Controlled Combustion/ Incineration	Landfill	Upcycling
GWP	*kg CO_2eq*	-3,300 (4)	-570 (5)	-110 (48)	-210 (11)	53 (26)	14 (20)	510 (15)	-450 (3)
Energy Demand	*MJ*	-24,000 (2)	-17,000 (2)	-7,000 (14)	n.d.	470 (6)	-940 (5)	120 (3)	-8,200 (1)
Acidification	*kg SO_2eq*	-35 (1)	-57 (1)	5.50E-02 (18)	-1.3 (1)	0.76 (8)	0.087 (11)	0.24 (5)	-0.78 (2)
Eutrophication	*kg Neq*	-21 (1)	-2.3 (4)	0.087 (24)	0.15 (7)	0.32 (14)	0.029 (18)	0.022 (9)	-0.3 (4)
Water Consumption	*m^3 water*	-210 (2)	-230 (2)	-0.4 (10)	n.d.	97 (1)	-67 (4)	-18 (4)	-1.6 (1)
Land Occupation	*m^2.yr*	-4,400 (2)	n.d.	0.6 (12)	n.d.	0.27 (3)	-0.04 (5)	2.3 (4)	n.d.

There are caveats in interpreting the data synthesised by the US EPA (see table 11).[31] First, the estimates presented are median values and do not reflect the variation found among studies.[31] Second, there are big disparities in the number of studies for each pathway, a factor which undermines comparisons of median values. For example, AD has received significantly more research attention than alternate pathways. Third, as with all LCA studies, there are context-specific assumptions that underpin estimations of environmental impact.[518] For example, all AD studies included in the US EPA's synthesis assume that digestate is applied to land, a factor that significantly improves the AD's environmental outcomes (see box 7). And fourth, LCAs do not measure all environmental impacts. For example, LCAs do not quantitatively measure impacts on soil health, as there is no scientific consensus on the indicators that make up this metric,[526] although work is underway.[527] As such, the value of processes that can contribute substantially to soil health, like composting (see section 4.3), is not fully reflected in LCA results.

LCA comparisons represent just one approach among a myriad options to compare different pathways and processes, as the US EPA report acknowledges by including a circularity assessment to complement its LCA approach.[31] Other options include, but are not limited to, social impact assessments, cost-benefit analyses, and techno-economic assessments.[519–523]

6.2 Giving some thought to scale

Capturing value from food waste happens at multiple different scales: in the household, within communities, in industrial contexts, and across regions. The sheer volume of our waste streams means that there are numerous opportunities to valorise food waste at different scales (see table 12).

Table 12: Examples of what food waste pathways can look like at different scales.

Pathway	Small scale (e.g. household)	Medium scale (e.g. neighbourhood or specific industrial plant)	Large scale (e.g. city or whole region)
Upcycling	Making jam at home.	Collecting stale bread from local supermarkets or bakeries for repurposing.[90,528]	Regional networks for food waste valorisation exist (e.g. Sustainable is Attainable), with upcycling-specific networks in the works.[529]
Animal feed	Households feeding their dogs, pigs, or chickens with some scraps.	Farmers feeding excess crop to their animals. Insect bioconversion of specific waste streams from industry.	City-wide collection of food scraps to create animal feeds, as seen in South Korea[530] and Japan.[531]
Material recovery	Household cleaner from lemon peel.	Face masks derived from fish collagen.[532]	Rice husks in cement.[533]
Nutrient recovery	Composting, worm farming, bokashi are commonly undertaken in the home as a way to manage household food scraps and pep up gardens.	Community-scale composting and/or vermicomposting is widely undertaken in NZ, both as composting clubs and commercially-operating social enterprises.[3,45,365,534]	Large-scale composters[374,535] and vermi-composters[536] deal with hundreds of thousands of tonnes of food scraps and industrial food waste streams each year, creating products that are used in a variety of end markets.
Energy recovery	Not common practice in NZ for households to derive energy from food waste, but China has pioneered this approach for much of its rural population by providing household digesters (and the resulting biogas) to millions of people.[537]	Some incineration facilities or pyrolysis plants are not necessarily designed for large volumes of waste but rather for specific (and sometimes hazardous) waste streams that are otherwise difficult to dispose of. Again, in China, medium-scale AD facilities	AD facilities are typically used to process large volumes of waste, be it industrial by-products, sludges, or household food scraps. Incineration facilities across Europe, and particularly in parts of Scandanavia, process huge volumes of waste (which sometimes

Pathway	Small scale (e.g. household)	Medium scale (e.g. neighbourhood or specific industrial plant)	Large scale (e.g. city or whole region)
		service can neighbourhoods rather than entire regions.[537,538]	includes food waste), often needing to do so to keep their facilities economical.

A 2021 survey[188] published by MfE suggests that over half of New Zealanders manage at least some of their scraps at home by worm farming, composting, or using a bokashi bin (see annex 12). A variety of online resources, primarily produced by councils and environmental organisations, are aimed at informing and encouraging managing food scraps at home, including work by the Compost Collective[534] and our own web resource *What can I do with my food waste?*[3] Making compost, vermicast, or bokashi with food waste produced at home can help fertilise pot plants, keep garden soils and veggie gardens healthy, and is an efficient way of processing this waste in place. However, not everyone has access to the tools and/or space needed to manage food waste at home, which is where solutions at larger scales can play a role.

As explored in section 4.3, composting, as well as in our web resource,[3] community enterprises such as community gardens, compost clubs, urban farms, and dedicated composting enterprises play an active and important role in managing food waste, helping to keep resource and waste flows to smaller, more localised scales.[45] Community-level composting operations process at least 5% of New Zealand's recovered food waste (a likely underestimate)[63] and offer a range of broader benefits,[45,364] including the place-based used of products that improve local soils, community building and resilience, local employment and training, sustainability education, and links to Māori soil and kai sovereignty.[366,539]

The role for industrial-scale food waste processing is set to grow in Aotearoa in coming years.[540] In March 2023 the Government announced policy initiatives to require TAs to offer household food scraps or FOGO collection services and to require businesses to separate their food waste (see box 3). If these policy initiatives are enacted, mandatory kerbside collection of household food scraps and the touted collection of food waste from businesses[27,541,542] would require an increase in processing capacity, to the tune of hundreds of thousands of tonnes each year. For those councils already offering kerbside food waste collection, composting is the dominant method,[16] although processes like AD (see case study 15) and vermicomposting (see case study 14) are proven alternatives. As discussed in section 4.3, there are numerous barriers and opportunities in rolling out this infrastructure. The emergence and development of industrial processes options can complement home- and community-based solutions, both by helping to manage the large increase in food waste diverted from landfills and in tackling challenging feedstocks that are not suited to home or community environments. Importantly, as our ongoing efforts[5,302,543] to prevent food waste gain momentum and reduce waste volumes, careful consideration must be given to offramps (e.g. alternate feedstocks) for these industrial-scale efforts to ensure their long-term sustainability.

6.3 We can also combine different technical solutions

While much of this report discusses different technical solutions to food waste valorisation in isolation, there are many instances where different processes can work in a complementary fashion to maximise the value extracted from wasted food. For example:

- When food waste is upcycled to new food products where only small fractions are utilised (e.g. for nutraceuticals, flavour compound extraction, oils, etc.), a large volume of solid residue may remain after processing, necessitating pairing with other food waste processing options.[544]
- Digestate from AD can be composted, vermicomposted, or pyrolyzed to improve its soil amendment properties and help reduce the risk of pathogens.[361,545] Abroad, this is common practice; composting of digestate is a requirement in countries like Italy and the Netherlands as part of their fertiliser regulations (see annex 10).
- There is potential to anaerobically digest or compost frass from insect bioconversion, producing either biogas and/or a soil improver.[546,547]

In addition to inter-linking technological processes, we can also combine their products, playing to their relative strengths. For example, in recovering nutrients, AD, and composting can play complementary roles, with digestate capable of providing readily-available nutrients in comparable proportions to those found in mineral fertilisers,[548] while compost can help restore soil structure, microbial ecosystems, and functioning (see section 4.3).

6.4 Final thoughts

Beyond recommending a food recovery hierarchy, this report does not seek to prioritise specific technologies, recognising that the problem of food loss and waste is big enough, and diverse enough, for multiple solutions. Context-specific factors like the volume, availability, and variety of food feedstocks, existing infrastructure, policy shifts, funding opportunities, local priorities, end-markets for products, and the success of prevention efforts will likely shape the short- and long-term future of a variety of localised solutions to New Zealand’s food waste problem.

Annex 1: Options for capturing value from unprevented food waste - key considerations

Table 13: An overview of the key options for capturing value from unprevented food waste, including details about the process and products, and key considerations. Table abbreviations: AD = anaerobic digestion, BAM = beneficial anaerobic microbe composting, DAF = dissolved air flotation (a technique used to treat dairy wastewater), ERP = Emissions Reduction Plan, FOGs = fats, oils, and grease, GHG = greenhouse gas, PAHs = polyaromatic hydrocarbons, PCDD/Fs = polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzo-*p*-furans (also called dioxins), PFAS = perfluoroalkyl and polyfluoroalkyl substances, PM = particulate matter, POPs = persistent organic pollutants, SPICE = static pile inoculated compost extension, WAS = waste-activated solids (dairy biosolids), WWTP = wastewater treatment plant.

Food rescue

See Food rescue in 2022: Where to from here?

Upcycling

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
Food loss and waste is turned into new products. The loss and waste used can take many forms, from blemished or overripe produce to by-products of the manufacture of another product.	• There is no single product or process. • We are referring to commercial applications.	• Some energy will be used in producing new products.	• Companies will need to explore optimal branding/market positioning for their upcycled products – no labelling vs premium product vs virtuous product. • Certification may give consumers protection and confidence if upcycling becomes a feature of marketing.	• Currently few mechanisms supporting producers of waste to connect with potential manufacturers who could use that waste. • Some food waste streams are variable, creating challenges around uncertainty for upcycled product manufacturers.
Given these considerations, what could a best-practice future state for the conversion of food waste to animal feed look like in NZ? *Upcycling is an approach to value capture which not only averts sending food to landfill, but also maximises the amount of food that is directly eaten by people. For producers of food waste, upcycling at worst avoids costs associated with disposal of waste, and at best increases revenue generated from existing stock. Mechanisms to connect producers of food waste with potential manufacturers support upcycling uptake in some sectors.*				

Make animal feed

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
'Standard' animal feed production Food loss and waste is used as animal feed, following varying degrees of treatment and processing (e.g. heating, blending, grinding, drying, and pelletising).	• Long-established process, including in NZ. • Can be simple (e.g. vegetable food waste with minimal processing) or more complex (e.g. dehydration, pelletisation, and conversion to liquid feed).[549] • Using mixed food waste streams presents biosecurity risks (e.g. pathogen transmission, especially when meat is present) and nutrition challenges (e.g. ensuring balanced diet for animals, especially important in commercial farming settings), which need to be managed.[549]	• Process emissions and water use vary depending on degree and type of processing. • Using FLW as feed can reduce environmental impact of producing feed and/or importing feed and feed ingredients.[182]	• FLW held ahead of processing or feeding can be odorous. • Without maintaining stringent regulation of FLW to animal feed processing, NZ's strong biosecurity reputation could be damaged.[549]	• Need to comply with biosafety law and regulations (especially when food waste contains meat).[549–553] • Homogenous, pre-consumer agricultural, and business food loss and waste are better suited to this process due to better ability to control nutritional composition and reduced biosecurity concerns.[182,549]
Given these considerations, what could a best-practice future state for the conversion of food waste to animal feed look like in Aotearoa? *Animal feed production from food waste streams is a carbon negative approach to food waste valorisation, enabled by efficient management processes, the use of renewable energy sources, and waste-derived animal feed products that displace animal feeds derived from virgin resources. There is a strong emphasis on food safety in feedstock sourcing and management, waste/resource flows are kept local, and there are minimal emissions from transport. Animal feed products are viable alternatives to existing products, with a focus on nutrition, safety, and animal welfare. The industry is well regulated; users of animal feed (e.g. large-scale dairy operations or people with backyard chickens) understand the benefits and risks of animal feed and apply best practice techniques in ensuring food safety. Animal feed production facilities are designed to be flexible, accommodating changes in waste composition and volume over time.*				
Insect-based bioconversion (also called protein farming) Insects (especially black soldier flies) are raised on FLW feedstocks and fed to animals (especially pigs, chickens, fish, and reptiles). Insects generally undergo processing (e.g. drying,	• Emerging process,[227] being piloted in New Zealand (see case study 10). • Requires entomology expertise.[227,247] • Using mixed food waste streams poses process	• Emissions-intensive process, but could be highly climate positive if protein-based animal feed is replaced by insects and where feedstocks that aren't readily absorbed into the food system are utilised.[238,247,549]	• Scope to use waste-fed insects as human food, but perceptions and food safety considerations are barriers.[237,549,554] • Need to consider treatment of insects (e.g. rearing conditions, killing	• Homogeneous agricultural and business food waste streams are better suited to this process due to better ability to control insect lifecycle and quality (including contamination) of both insects and frass.[226]

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
milling, and oil extraction) before being used as feed. Extracted oil also has the potential to be used as a biodiesel. Residual material, mostly frass, and to a lesser extent shed exoskeletons, dead insect parts, and potentially uneaten feedstock, has the potential to be used as a soil amendment, although may require further processing.	control and nutrition challenges and contamination risks.[228] • Evidence around performance of frass as a soil amendment is emerging, but promising.[227,228,230,247] • More research needed into prion transmission; bacterial, viral, and parasite risks are non-negligible but can be mitigated (e.g. by feedstock control and pre-treatment).[226]	• Black soldier flies break down mycotoxins, pharmaceuticals, and some pesticides, but take up some heavy metals; contaminants not taken up by insects end up in frass, creating possible soil contamination risks from frass if feedstock is contaminated.[227,247] • See annex 9 for more information.	procedures), an area which is underdeveloped in the regulatory space internationally.[549,555,556] • Can be odorous. • Could also consider for sewage sludge and/or animal manure processing, although contaminant risks and possibly social and cultural concerns would likely need to be addressed.[247]	• While not the desired product, frass is the dominant product by volume (and to a lesser extent shed exoskeletons, dead insect parts, and potentially uneaten feedstock).[227,228,247]
Given these considerations, what could a best-practice future state for insect bioconversion of food waste look like in NZ? *Insect bioconversion is a carbon negative approach to food waste valorisation, enabled by efficient management processes, the use of renewable energy sources, waste-derived animal feed products that displace animal feeds derived from virgin resources, and the safe use of frass as a soil amendment. There is a strong emphasis on food safety in feedstock sourcing and management, waste/resource flows are kept local and there are minimal emissions from transport. Animal feed products are viable alternatives to existing products, with a focus on nutrition, safety, and animal welfare. Frass is not landfilled, instead it is sent on to other processing solutions (e.g. AD or composting) or land applied in accordance with best-practice guidelines for the application of organic materials to land. Users of frass or frass-derived soil amendments (e.g. gardeners and farmers) understand its benefits, limitations, and best-practice methods for its application. Insect bioconversion facilities and processes are designed to be flexible, accommodating changes in waste composition and volume over time.*				

Material recovery

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
By-products of food processing and manufacturing are used in new, non-food products.	• Processes vary depending on the by-product and desired material. • Can be simple (e.g. using sheep fleece to make wool or cow hide to make leather) or more complex (e.g. extract proteins or chemical compounds).	• Some energy will be used in producing new products.	• Materials derived from animals in non-traditional/non-obvious ways may need to be labelled as such as more people try to avoid animal products.	• Investment and research may be needed to discover new possibilities for material recovery.
Given these considerations, what could a best-practice future state for material recycling of food waste look like in NZ? *Material recovery averts sending waste to landfill while also providing sources of materials which would otherwise need to be produced synthetically. Both of these aspects offer environmental advantages, as well as enabling extra value to be otained from the initial raw materials.*				

Recover nutrients for soils

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
Composting Microorganisms convert food loss and waste and green waste to compost, in the presence of oxygen. Compost can be used as a soil amendment.	• Well-established process, including in NZ. • Can be done by commercial enterprises, in the community, and at home.[46] • Several process variations, including bin composting, windrow, aerated static pile, in-vessel, SPICE, BAM, Johnson-Su composting, and more.[46,557] • Feedstock can include FLW, green waste, manure, biosolids, paper fibre, and ground wood-based waste.[358] • Food waste must be mixed with dry/woody materials.[558–560] • Simple process requiring aeration and water replenishment, although at scale, can require machinery and large area.[368] • Compost benefits for soil well established.[339,423,557,559]	• Composting operations often a minor source of GHGs.[557] • Compost use can reduce the need for fertiliser but quantifying displacement is difficult; where compost displaces synthetic fertiliser, emissions can be close to or better than net zero.[443,558] • Compost can be used to regenerate 'unproductive' soils, contributing to soil health and ecosystem functioning.[345,350] • Requires moisture content of 45-60% by weight[559], moisture derived from feedstock (e.g. wasted food) and/or additional watering. • Leachate can be environmentally problematic if poorly managed.[358]	• At local scales, community composting facilities provide a range of social and environmental benefits.[45,46,367,368] • Community composting has links with Māori soil and kai sovereignty[36,366,539,561] and reflects perspective of regenerative place-based relationships.[562] • Odour can be a problem,[559] particularly in large-scale open-air composting operations near residential settlements. • Contaminants such as human hair or biosolids may limit culturally acceptable end uses of compost in te ao Māori (e.g. may be deemed inappropriate for use in the food system).[563,564]	• Although NZ has a composting standard,[370] grading and quality assurance of compost remains an issue. • Compostable plastics can pose challenges to composters and negatively affect the quality of the end product without adding any nutrient value.[565,566]
Given these considerations, what could a best-practice future state for composting of food waste look like in NZ? *Composting is a carbon neutral approach to food waste valorisation, enabled by efficient management processes, as well as compost products that displace the use of (some) mineral fertilisers and restore/contribute to high-functioning, healthy soils. Composting is undertaken at a variety of scales, retaining the socio-environmental benefits of household and community-scale composting efforts, as well as the capacity and feedstock-variety benefits of industrial composters. For feedstocks and resulting products, there is strong focus on preventing contaminants at source, keeping waste/resource flows local, and minimising transport emissions. Pre-processing facilities/stages are effective in removing contaminants and preparing waste for composting. A variety of end-market exist for different grades of compost, but the industry primarily produces high quality compost for to go into a variety of food-growing systems (e.g. urban farms, school gardens, large-scale horticulture, etc.). Compost meets set industry-led and independently assessed standards (e.g. an updated NZS 4454:2005), with complementary verification systems (e.g. Hua Parakore) allowing for tailored use of processes/products in different food systems. Users of compost (e.g. gardeners and farmers) understand*				

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
its benefits, limitations, and best-practice methods for its application. Composting practices and compost use adhere to relevant environmental regulations (e.g. nitrate leaching) and do not harm soil health or contribute to water pollution. Compost systems are designed to be flexible, accommodating changes in waste composition and volume over time.				
Vermicomposting (also called worm farming) Worms convert food loss and waste to vermicast, in the presence of oxygen. Vermicast can be used as a soil amendment.	• Well-established process, incl. in NZ. • Can be done by commercial enterprises, in the community, and at home.[46] • Feedstock can include a variety of food and organic waste streams, but need to be mixed with carbon-rich materials (e.g. certain green wastes, cardboard, wood shavings, jib boards, etc.).[567,568] • Vermicast and worm tea can be used as soil amendments, with benefits for soil fertility and composition.[567,569]	• May require additional water inputs to maintain functioning in dry months, although this can be mitigated by wet climate and high moisture content feedstocks.[567] • Leachate can be environmentally problematic if poorly managed; rotating windrows, drainage systems, and leachate collection provide mitigation options. • Similar emissions profile to composting (potentially with less methane and nitrous oxide),[383] including possible fertiliser displacement.	• Many social and cultural considerations shared with composting (e.g. value of community scale operations, odour risk). • Contaminants such as human hair or biosolids may limit culturally acceptable end uses of vermicast in te ao Māori (e.g. may be deemed inappropriate for use in the food system).[563,564]	• Large pieces of green waste not suitable as feedstock, so potentially not compatible with FOGO collection. • Compostable plastics viewed as a contaminant/undesired input to process.[567]
Given these considerations, what could a best-practice future state for vermicomposting of food waste look like in NZ? *Vermicast is a carbon neutral approach to food waste valorisation, enabled by efficient management processes, as well as vermicast that displaces the use of (some) mineral fertilisers and restores/contributes to high-functioning, healthy soils. Vermicomposting is undertaken at a variety of scales, retaining the socio-environmental benefits of household and community-scale vermicomposting efforts, as well as the capacity and feedstock-variety benefits of industrial-scale operations. For feedstocks and resulting products, there is strong focus on preventing contaminants at source, keeping waste/resource flows local, and minimising transport emissions. Pre-processing facilities/stages are effective in removing contaminants and preparing waste for vermicomposting. A variety of end-market exist for different grades of vermicast, but the industry primarily produces high quality vermicast to go into a variety of food-growing systems (e.g. urban farms, school gardens, large-scale horticulture, etc.). Vermicast meets set industry-led and independently assessed standards (e.g. an updated NZS 4454:2005) and land application is informed by relevant guidelines and/or regulations. Users of compost (e.g. gardeners and farmers) understand its benefits, limitations, and best-practice methods for its application. Vermicomposting practices and vermicast adhere to relevant environmental regulations (e.g. nitrate leaching) and do not harm soil health or contribute to water pollution. Vermicompost systems are designed to be flexible, accommodating changes in waste composition and volume over time.*				
Dehydration Food loss and waste is thermally dried, sometimes in the presence of microorganisms and enzymes (i.e. bio-dehydration) to produce	• Emerging FLW management solution,[398] not used in NZ to our knowledge. • Dried food waste generally needs secondary processing	• Reduced volume and weight of dehydration decreases collection and transport emissions, but drying consumes a lot of energy.[570]	• Dried product must be kept dry; it is gets wet it will rehydrate, potentially growing mould, becoming	• Potentially suitable for multi-unit dwellings to store wasted food without odour concerns between collections, but not

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
biologically inert dried food waste. Dried, it has the potential to be used as a soil amendment, although this may require further processing, or as an animal feed ingredient.	(e.g. via composting) before being applied to land.[398,570] • When applied to land, dried food waste contributes soil carbon and nutrients but there is a risk of short- and longer-term toxicity impacts on plants.[398,570]	• C sequestration means the process can be carbon neutral, but only if renewable energy is used for drying.[570] • To compost, dried food waste may need to be rehydrated, thereby using water.[571] • Need to manage liquid condensate and exhaust gases.[570]	odorous, attracting pests, etc.[571]	broadly useful for household food waste.[570,571] • Efficiency drops if not operated at full capacity.[570]

Given these considerations, what could a best-practice future state for the dehydration of food waste look like in NZ?

Dehydration provides niche solutions to valorising food waste streams in Aotearoa, for example, by playing a role in food scraps collections in multi-unit dwellings. Energy requirements of the process are powered by renewable energy sources, while land application and/or further processing of outputs are in accordance with well-developed guidelines on the application of organic waste to land.

Recover energy[o]

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
AD Microorganisms convert FLW feedstocks to biogas, in the absence of oxygen. Digestate (i.e. the wet mixture of liquid and solid residues left behind) has the potential to be used as a soil amendment, although may require further processing.	• Well-established process, new to NZ for mixed food waste streams but used for wastewater treatment, manure, and industrial effluent (especially dairy industry).[430] • Relatively complex process, requiring infrastructure and machinery for waste capture and sorting, pre-heating, digestion, biogas capture, scrubbing, storage, power and heat generation, and solid and liquid digestate management.[572] • Produces biogas as an energy source. Various bio-reactor types suited to different feedstocks, while co-digestion of different wastes can change methane yields.[572] • Wide range of feedstock including mixed food waste, crop biomass, fruits and vegetable waste, manures,	• AD facilities can be carbon negative or carbon neutral[572] when biogas is used as a substitute for natural gas and digestate displaces mineral fertiliser.[451,453,454] • Water is used to adjust moisture content of organic content early in AD process (although less than is typically required for composting).[368] • Unprocessed digestate applied to soils may produce uncontrolled GHG emissions and be potentially phytotoxic.[434,560,572] • Ammonia losses and odour are the main risks associated with land application of unprocessed digestate; nitrate leaching is also a risk.[434]	• Contaminants such as human hair or biosolids may limit culturally acceptable end uses of digestate in te ao Māori (e.g. may be deemed inappropriate for use in the food system).[563,564]	• Digestate from AD in NZ is classed as waste and often landfilled[430] with no certification for digestate as a fertiliser or soil amendment product in NZ (regulatory context among other countries varies widely, see annex 10)[430,434] – work ongoing to change this. • Variations in feedstock volume and composition can present process challenges and impact digestate composition and biogas output.[434] • Uptake of digestate as a biofertiliser faces challenges in NZ,[430] but could displace the use of some synthetic fertiliser. • Compostable packaging doesn't readily break down during AD.[565]

[o] *NB: A range of other emerging processes can be applied to food waste feedstocks for energy conversion but are not included in this table, e.g. transesterification,[491] alcoholic fermentation,[492] microbial and microalgae fuel cells, and photobiological hydrogen production.[484] These generally have low technology readiness, have niche applications, or aren't highly applicable to FLW feedstocks, but are mentioned for completeness.

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
	industrial wastewater, and sewage sludge.[430] • Digestion effluents (liquid and/or solid digestate) have potential as biofertiliser,[351,434] and can be processed – to a greater or lesser extent – before land application or other uses.[545,565,573]			
Given these considerations, what could a best-practice future state for the AD of food waste look like in NZ? *AD functions as a carbon negative technology, enabled by biogas that displaces equivalent amounts of virgin natural gas and the safe application of digestate to land that displaces (some) mineral fertiliser use. Food loss and waste streams are collected effectively from households and industry alike, with a strong focus on preventing contaminants at source, keeping waste/resource flows local, and minimising transport emissions. Pre-processing facilities/stages are effective in removing contaminants and preparing waste for digestion. Biogas systems are designed to handle a variety of food waste streams, with energy recovery prioritising upgraded biogas (e.g. biomethane, biodiesel) over electricity generation where possible. Digestate is not sent to landfill (solid residues) or waste water treatment plants (liquid residues), but instead used as a biofertiliser in agricultural settings. There is a focus on nutrient recovery from digestate, with treatment methods like pasteurisation, separation of liquid and solid components, and composting (among others) used to enhance digestate's value as a soil amendment. Modelled on established systems abroad (e.g. PAS 110[441]), an industry-led and independently-assessed set of guidelines, standards, and/or certifications enable the safe use of digestate as biofertiliser, which includes identifying and minimising contaminants within feedstocks, defined testing regimes, and graded end-products. Users of digestate (e.g. farmers) understand its benefits, limitations, and appropriate methods for its application; digestate is considered an attractive option relative to synthetic fertilisers. Continuous monitoring ensures digestate use adheres to relevant environmental regulations (e.g. N limits) and does not harm soil health or contribute to water pollution. ADs systems are designed to be flexible, accommodating changes in waste composition and volume over time.*				
Pyrolysis and gasification To undertake pyrolysis, FLW feedstocks are dried and then burnt in the absence of oxygen, at atmospheric pressure. Biochar, bio-oil, and syngas result, with their relative yields depending on the feedstock and operating parameters such as temperature. Biochar can potentially be used as a soil amendment and to stably sequester C, among other possible	• Pyrolysis and gasification are well-established processes for some feedstocks, but emerging for biomass feedstocks (especially mixed food waste), and not currently practiced in NZ.[319,574–576] • Relatively complex, requiring pre-treatment equipment, the pyrolyser/gasifier itself, as well as syngas, bio-oil, and biochar management and storage.[484,577–579]	• The process consumes a lot of energy (mostly in drying to reduce to acceptable levels – ideally <25%).[584] • Biochar also received attention for its long-term C sequestration properties,[474,478,585] soil and water remediation,[484,581] and fertiliser potential,[474] but further research is needed. • If heavy metals are present in feedstock, they end up in	• Social licence to operate can be a significant barrier for any energy from waste process.[53] • Distinction between pyrolysis and incineration is not often understood, contributing to social licence barriers.[591]	• If pyrolysis feedstock isn't dry enough, the resulting bio-oil may be unsuitable as a biofuel.[484] • While air pollution control residues are produced (see environmental considerations column), when organic materials are used as feedstock the amount produced is generally less, and is also less

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
applications. Bio-oil and syngas are sources of energy. Gasification is a variant of pyrolysis, optimised for syngas and biochar production. This is primarily achieved by introducing a limited supply of oxygen to the system.	• Wide range of feedstocks, both organic and inorganic, can be used (including mixed feedstocks), but feedstock choice impacts the quality and utility of products.[474,484,575,576,579,580] • Biochar has potential to sequester C, mitigate soil leaching, and improve nutrient availability; other possible uses include environmental remediation and animal feed supplementation.[474,478,484,578,581] • Bio-oil can be used as fuel for power, heat, and transport,[484] but generally requires upgrading.[582] • Syngas, made up of methane, hydrogen, CO_2, carbon monoxide, and other gaseous hydrocarbons,[484] can be used to generate heat or electricity or used to produce liquid fuels.[583]	biochar fraction;[575,582] while they are stably bound, it's not known whether they could be released in the long-term.[578] • Biochar produced by gasification (vs pyrolysis) can contain a high amount of toxic metals and PAHs, limiting its application to soils.[578] • If PFAS is present in the feedstock, emerging evidence suggests it is effectively broken down, but more research is needed.[581,586] • Waste outputs include tars and bottom ash[53], air pollution control residues, which can be toxic and persistent,[485,587–589] and discharges to waste water from flue gas cleaning.[590]		than incineration (see incineration row).[485,587] • There is some fire risk associated with biochar applied to soil, although this can be mitigated by applying biochar at a minimum depth of 10 cm.[478] • The International Biochar Initiative has produced biochar standards, including contaminants to test for and recommended maximum concentrations.[592] • There is a verified C standard for biochar, developed by Verra to help companies claim C credits in voluntary markets for C sequestration achieved by biochar use.[478]
Given these considerations, what could a best-practice future state for pyrolysis and gasification of food waste look like in NZ? *In a pilot-scale approach in Aotearoa, pyrolysis and gasification is explored as a carbon neutral or negative approach for processing low moisture organic feedstocks. Given its emerging status, work on pyrolysis/gasification is research-focused, exploring the potential of end products like bio-oil and syngas in displacing fossil derived equivalents, the carbon sequestration and soil amendment properties of biochar produced from various waste streams, and opportunities to remove, treat, or minimise unwanted pollutants.*				
Hydrothermal processing FLW feedstocks are converted to a slurry and pressure-fed into a high-temperature reactor. A range of	• Hydrothermal processes are emerging, largely occurring at the lab-scale and in small operations or pilot	• Biocrude oil from hydrothermal liquefaction can be used as an alternative to heavy fuel oil but needs	• Given the immature status of technology and its absence from NZ, it is likely not well understood here, with public	• Lignocellulosic biomass and algae feedstocks are particularly common feedstocks[490,593,594]; food

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
liquid and gas energy products result, as well as hydrochar, which can potentially be used as a soil amendment and to sequester C, among other possible applications. Depending on the temperature and pressure, the process is known as either hydrothermal gasification, liquefaction, or carbonisation, with product ratios and composition varying between each.	plants,[484,487,490] and are not currently practiced in NZ. • Complex, hazardous, and expensive,[578] with multiple technical barriers (e.g. catalyst recycling,[593] slurry optimisation, high-pressure feeding system optimisation)[594] still being worked through. • A wide range of biomass feedstocks can be used, including lignocellulosic biomass, micro- and macro-algae, manure and animal by-products, sludge from wastewater treatment plants, AD digestate, food processing waste, and mixed food waste.[545,578,595] • High moisture feedstocks are suitable because water is a necessary solvent in the process.[484]	upgrading[594] and its high viscosity makes it hard to use.[484] • Hydrothermal liquefaction also produces light gas (which can be used for energy)[490] and an aqueous phase which is essentially a wastewater product that needs to be dealt with, although valorisation options are being explored.[490,596] • Hydrochar, the dominant product of hydrothermal carbonisation,[490] has similar possible applications to biochar, but is less studied; emerging evidence suggests it doesn't have the same ability to stably sequester C as biochar, but may work well as a replacement for coal.[578] • Syngas produced in hydrothermal gasification has the same applications as syngas from gasification.[490,583]	perceptions not known but potentially similar to other thermochemical processing options (see pyrolysis and gasification).	waste streams have received little attention as a possible feedstock, • Potential as a technology for further processing of digestate from AD (i.e. complementary technology).[545]
Given these considerations, what could a best-practice future state for the hydrothermal processing of food waste look like in NZ? *In a pilot-scale approach in NZ, hydrothermal processing is explored as a carbon neutral or negative approach for processing high moisture feedstocks, including food processing waste and digestate. Given its immature status, work on hydrothermal processing is research-focused, exploring the viability of end products like biocrude oil in displacing fossil derived equivalents, the C sequestration potential of hydrochar, and opportunities to remove, treat, or minimise unwanted pollutants.*				
Incineration (also called combustion) Wasted food, typically combined with other municipal solid waste, is burnt in the presence of oxygen,	• Well-established process (although modern air pollution control technologies have only been developed in	• Food waste has a high moisture content so there is a net energy expenditure when it is incinerated[461] (i.e. for food waste, incineration isn't	• Social licence to operate can be a significant barrier for any energy from waste process.[53] • Early failures and air pollution, while now more stringently	• Incineration of waste is predominantly practiced in places where available landfill space is limited and transport distances are small

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
generating heat and ash. The heat is a source of recoverable energy while the ash is a waste product.	the last few decades),[597] but not practiced in NZ. • Incineration is an end-of-life waste management solution which reduces the mass of waste and produces heat that can be captured, but other than that doesn't yield any useful products.[597] • Incineration itself is relatively simple but air pollution control is complex.[461] • A wide range of feedstocks are possible, but plastic, wood, paper, cardboard, rubber, and leather combust most readily and yield net energy gains[461]; separated food waste is a poorly suited feedstock (see next column). • Can accept mixed waste (i.e. don't have to separate food waste).	technically an energy recovery process). • Bottom ash needs to be dealt with; it can be mixed into concrete, further processed to be used in other construction materials, or landfilled.[461] • Flue gas contains air pollutants including dust, acidic gases, nitrous oxides, PDDD/Fs (i.e. dioxins), PAH, and mercury which need to be 'cleaned' out before discharge[461]; flue gas cleaning (e.g. by filtering, scrubbing) leaves air pollution control residues (also called fly ash) to be dealt with, typically by landfilling as a hazardous waste.[461,485,587]	regulated and manageable with modern technology, continue to impact public perceptions especially relating to perceived air pollution.[461,597]	(especially Europe), using municipal solid waste as a feedstock.[597] • Risk of undermining the food recovery hierarchy or (if other wastes are used) the waste hierarchy more broadly.[53]
Given these considerations, what could a best-practice future state for incineration of food waste look like in NZ? *Incineration is limited to highly contaminated (i.e. hazardous), small-scale, and unpredictable food waste streams. The need to incinerate such waste is evaluated on a case-by-case basis, recognising that incineration is a disposal destination, but one that can have better environmental outcomes than landfill in certain contexts (see annex 2).*				
Landfill with gas capture Food waste, typically combined with other municipal solid waste, is buried in a landfill. As it breaks down in the absence of oxygen, gas (predominantly methane) is captured. The gas can either be used as a source of energy or flared.	• Well-established process, including in NZ. • Can accept mixed waste (i.e. don't have to separate food waste). • Most levied waste in NZ is sent to landfills with gas capture.[598]	• Imperfect gas capture and GHG emission before gas capture begins means about 0.7 tonnes of CO_2 equivalent (CO_2e) is released for each tonne of food waste[511,600]; this is a generalisation, with variation between landfills (e.g. 55% at Wellington's	• Social licence for landfilling in NZ is waning; proposals for new landfill capacity recently challenged in multiple TAs.[509] • Out-of-site location of landfills (generally fringe areas) can lead to disconnect between people and their waste, limiting opportunities to	• Bioreactor landfills are an emerging variation on a 'regular' landfill, optimised for more efficient decomposition of material under anaerobic and/or aerobic conditions; liquids are circulated through the landfill to facilitate microbial

Process	Key details about the process and product	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
	• Doesn't produce any usable outputs other than energy from captured gas; gas capture rate is imperfect (see environmental considerations column), compared to AD where the majority of biogas is captured.[599]	Southern landfill and 90% at Auckland's Redvale landfill).[509] • While landfilling sequesters C and captured gas can be used for energy, net emissions produced by wasted food substantially outweigh any offset.[510] • Leachate (liquid which contains soluble components of landfill waste) can enter waterways and ground water,[502,601] although modern landfill design reduces the extent of leaching[602]; leachate contains compounds which are potentially hazardous to ecosystems and human health.[502] • Leachate and gases continue to be produced even after a landfill is closed, creating intergenerational environmental management challenges.[502]	increase waste awareness and ownership and encourage prevention of food loss and waste.[603]	movement and nutrient transport and air is used to accelerate biodegradation and biostabilisation and prevent methane generation.[604]
Given these considerations, what could a best-practice future state for landfilling food waste, with gas capture, look like in New Zealand? *Food waste to landfill is generally avoided, with a 2030 goal of halving food waste to landfill and a longer-term goal of zero food waste to landfill. Landfills provide a last resort option for highly contaminated streams of food waste. In these instances, food waste to landfills with gas capture is a priority ahead of landfills without gas capture. Collected biogas is used as an energy source and/or upgraded to more useful products, rather than being flared.*				

Dispose

Process	More about the process and products	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
Landfill without gas capture Food waste, typically combined with other municipal solid waste, is buried in a landfill. As it breaks down in the absence of oxygen, gas (predominantly methane) is released into the atmosphere.	• Well-established process, including in NZ. • Currently less than 10% of levied waste goes to landfills without gas capture.[598] • Doesn't produce any usable outputs. • Can accept mixed waste (i.e. don't have to separate food waste).	• About 2.1 tonnes of CO_2e is released for each tonne of wasted food.[511] • Small amount of C sequestration is achieved, but insufficient to meaningfully impact net emissions climate impact.[510] • As with landfills with gas capture, leachate is generated, and long-term environmental management of closed landfills must be considered (see landfill with gas capture row).	• Social licence for landfilling in NZ waning; proposals for new landfill capacity recently challenged in multiple TAs.[509] • Out-of-site location of landfills (generally fringe areas) can lead to disconnect between people and their waste, limiting opportunities to increase waste awareness and ownership and encourage prevention of food loss and waste.[603]	• Being phased out in NZ; the ERP signals the intention for all municipal landfills to be required to have gas capture systems by 2026.[15]
Given these considerations, what could a best-practice future state for landfilling food waste, without gas capture, look like in NZ? Food waste to landfill is generally avoided, with a 2030 goal of halving food waste to landfill and a longer-term goal of zero food waste to landfill. Landfills provide a last-resort option for highly contaminated streams of food waste. In these instances, food waste to landfills with gas capture is a priority ahead of landfills without gas capture.				
Send to WWTP Food waste is disposed of down the sink, joining other wastewater at wastewater treatment plants. Wastewater is treated and discharged and the remaining biosolids must be managed.	• Well-established process, including in NZ. • Occurs within households, but also in large industrial facilities. • To reduce pipe blockages, food waste should ideally be ground up using in-sink disposal unit, but even then FOGs can lead to blockages.[605]	• Environmental impact is contingent on how wastewater is managed – five factors that can have serious impact on wastewater treatment are:[606] a) Total N and other nutrients – kitchen sink disposal increases the load needing treatment, as well as affecting the environment discharged into (generally a river or sea); b) Total flow – kitchen sink disposal increases household water use by an estimated 1%;	• Can lead to disconnect between people and their waste, limiting opportunities to increase waste awareness and ownership and encourage prevention of food loss and waste.[603,605]	• Potentially suitable for multi-unit dwellings with limited food waste options. • Additional loads to the wastewater network (nutrients, as well as physical/chemical properties) can result in additional costs/operational risks. e.g. capacity of piped network/WWTP, pipe blockages, treatment and management of increased water/nutrient loading at WWTP.

Process	More about the process and products	Key environmental considerations	Key social and cultural considerations	Other considerations and comments
		c) Total C – a small number of facilities in NZ have digesters and can produce methane gas; d) Total biosolids: Biosolids management is a significant cost and almost all biosolids are landfilled in NZ; and e) Increased occurrence of blockage in pipes/pumps.		
Given these considerations, what could a best-practice future state for landfilling food waste, without gas capture, look like in NZ? *Food waste to WWTPs is generally avoided, except in scenarios where alternative solutions are entirely impractical (e.g. multi-unit dwellings with highly limited space). Where food waste does go to WWTP, the plants are equipped with AD facilities to capture energy, useful by-products like struvite are collected, and the resulting biosolids are land applied in appropriate contexts and in accordance with relevant standards and/or guidelines. Ideally, biosolids safely and effectively offset the use of mineral fertilisers.*				

Annex 2: The environmental impact of capturing value – lifecycle lens

A common approach to measuring the environmental impacts of food waste treatment methods, as well as a host of other processes and products, is the use of Life Cycle Assessment (LCA). LCA is an analytical tool for the systematic and quantitative evaluation of the environmental impacts of a product or service system through all stages of its life.[607] In essence, LCAs are comparative studies, designed to compare different products performing the same function, different process alternatives or different waste-handling alternatives in a standardised manner.[608] The LCA approach follows an internationally accepted framework laid out in *ISO standards 14040* and *14044*,[609] which define the generic steps for conducting an LCA.

A fundamental step in undertaking an LCA is to define a system's boundaries, i.e. the scope of the analysis that specifies which processes and activities are included in the assessment and which are excluded.[518,608] System boundaries determine the stages of the process or product life cycle that are considered, such as the transportation of waste, the various treatment steps, and the resulting product's use. System boundaries can be drawn narrowly to focus on a specific part of the process, or broadly to encompass the entire life cycle, including elements like energy generation, waste treatment, and displacement of alternate products. The choice of system boundaries depends on the goal and scope of the LCA study, and different system boundaries can yield different results, even when the same processes are being compared.[518] Thus, a clear understanding of the system boundaries used is needed when interpreting the outcomes of LCA studies. Equally important is an understanding of the assumptions made by study authors, particularly as these are likely to vary considerably in different contexts. For example, some studies might assume that compost or digestate are not used in agricultural settings (and therefore don't displace fertilisers), while others may assume these products are direct fertiliser replacements used in a variety of contexts.[31]

LCA studies are frequently used to compare the environmental impacts of different food waste treatments. This allows researchers to model the inputs, processes, and outputs of different treatment options within the same boundaries, hypothetical or real-world. Typically, studies relating to food loss and waste have, in recent decades, compared the environmental outcomes of composting, AD, and incineration of food waste at large scales,[518] often setting these against a baseline scenario of sending food waste to landfill. In evaluating the environmental impacts of different studies, almost all studies predict the global warming potential of each option, usually expressed as kilograms of CO_2e emitted per tonne of food waste treated. In addition, a range of other impacts can be measured, including, but not limited to, eutrophication potential, acidification, water consumption, and energy demand.

Building on Bernstad and la Cour Jansen's foundational review[518] of LCAs of food waste management prior to 2011, we have synthesised peer-reviewed studies published since 2011 that compare different food waste treatment options for managing food waste in a variety of contexts (see table 14). Importantly, while individual LCA studies set out to create fair and consistent comparisons of treatment methods within their study system, comparing treatment methods across different studies can be difficult. Bernstad and la Cour Jansen highlighted that system boundaries and underlying assumptions often vary largely from study to study, leading to challenges in ensuring the comparability and validity of results.[524] For example, assumptions around the energy efficiency of a process or the displacement of mineral fertiliser can substantially alter study outcomes. As seen in table 14, as well as Bernstad and la Cour Jansen's study,[518] there is limited consistency in the environmental impact categories across studies, and author conclusions on the 'optimal' processes to treat waste are dependent on the comparisons made, the study goals, the system boundaries, and the underlying assumptions of the study. Thus, when assessing and comparing different options for treating food waste, it's important to recognise that their specific application in a particular context will play a large part in determining their effectiveness and their impacts on the environment.

Table 14: A synthesis of 15 peer-reviewed studies, published since 2011, which compare different food waste treatment options and scenarios for managing food waste in a variety of contexts. Environmental impact values for each scenario are expressed per tonne of food waste, unless otherwise stated. Abbreviations: AD = anaerobic digestion, AE = accumulated exceedance, DCB eq = dichlorobenzene equivalents, GHG = greenhouse gas, GO = garden organics (green waste), CO_2 eq = carbon dioxide equivalents, N eq = nitrogen equivalents, oil eq = oil equivalents, P eq = phosphorus equivalents, SO_2 eq = Sulphur dioxide equivalents, kg = kilogram, km = kilometre, m^2a crop eq = land use impact over time (standardised measure), m^3= meter cubed, MJ = megajoule, NH_3= ammonia, RNG = renewable natural gas, CFC-11 eq = trichlorofluoromethane equivalents, xE = exponential notation.

Type of FW, location	**Scenarios**	**System boundaries**	**Key assumptions**	**Environmental impacts**	**Optimal scenario and other comments**
Household food and green waste, New South Wales Australia[524]	**Baseline** (B) Landfill of food waste, open windrow composting of garden organics. **Scenario 1** (S1) Open windrow of food organics and garden organics combined. **Scenario 2** (S2) Open windrow compost of garden organics and separate collection and AD of food waste.	Waste collection, transport to transfer station, transfer station handling, transport to processor, processing (compost or AD), end-product.	• Compost facility >200 km from transfer stations. • Transport from transfer station via heavy rail for compost. • FOGO and GO composting modelled as producing the same outputs. • No transfer station for AD (i.e. closely located AD plant). • Digestate considered organic fertiliser.	**Global warming potential** (kg CO_2 eq) B = 797.4; S1 = 129.6; S2 = 22.49 **Water consumption** (m^3) B = 0.33; S1 = 0.08; S2 = 0.11 **Land use** (m^2a crop eq) B = 1.59; S1 = 0.46; S2 = -8.21 **Freshwater ecotoxicity** (kg 1,4-DCB eq) B = 328.1; S1 = 0.18; S2 = -0.60 **Freshwater eutrophication** (kg P eq) B = 0.0329; S1 = 0.000825; S2 = -0.0032 **Terrestrial ecotoxicity** (kg 1,4-DCB eq) B = 283.9; S1 = 39.0; S2 = -74.8 **Terrestrial acidification** (kg SO_2 eq) B = 0.17; S1 = 0.07; S2 = -0.41	• Authors considered S2, AD of food waste and composting of green waste, the optimal strategy. • Reliant on secondary data: compost data based on Danish facility; AD data based on Australian facility. • AD of food waste observed to used twelve times as much water as the food fraction of open windrow composting.
Municipal food waste, China[442]	**Scenario 1** (S1) Food waste in mixed solid waste is collected and sent to landfill with gas capture. **Scenario 2** (S2) Food waste in mixed solid waste is incinerated, with electricity generation. **Scenario 3** (S3a, S3b) AD of food waste, with solid digestate either landfilled (S3a, as is standard practice in China) or recycled as fertiliser substitute (S3b).	Collection and transport, pre-treatment, processing, electricity, and fuel compensation.	• Biogas used to generate electricity which is fed into the national grid. • Biodiesel is manufactured from oils derived from a pre-treatment step in the AD scenario.	**Global warming potential** (kg CO_2 eq) S1 = 580; S2 = 40; S3a = 140; S3b = -20 **Freshwater eutrophication** (10^{-4}kg P eq) S1 = 400; S2 = 600; S3a = 200; S3b = 50 **Terrestrial acidification** (10^{-2}kg SO_2 eq) S1 = 1,100; S2 = -200; S3a = 100; S3b = -100 **Water consumption** (kg water) S1 = 400; S2 = -1,200; S3a = 1,000; S3b = -50 **Primary energy demand PED** (MJ) S1 = 100; S2 = -4,900; S3a = -1,100; S3b = -1,300	• Authors considered S2, incineration, to be the best outcome for climate change mitigation. • Authors note that digestate management has a significant role to play in determining the of AD, as landfilling creates significant to methane emissions and dramatically increases water consumption during wastewater treatment.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
				Note, values are derived from publication figures and are therefore approximate.	
Municipal organic waste (food and food-soiled paper products), San Jose US[443]	**Scenario 1** (S1) Landfill of organic waste, with gas capture. **Scenario 2** (S2) Outdoor windrow composting of organic waste. **Scenario 3** (S3a, S3b, S3c, S3d, S3e) Dry AD of organic waste where is electricity is generated and digestate is composted (S3a), landfilled (S3b) or applied directly to land (S3c). Alternately, biogas is upgraded to RNG to replace diesel while digestate is composted (S3d), or biogas is upgraded to RNG and injecting into the pipeline to replace natural gas (S3e).	Waste collection, processing, application of residual solids to land (fertiliser displacement), energy production (fuel and electricity offset).	• Compost facility 70 km from waste collection point. • Compost is applied to cropland as a soil amendment and partial fertiliser replacement, offset calculated based on N (assuming a 1.7% N content in compost). • AD calculations based on actual plant in San Jose, where 30% of biogas is flared (due to storage limitations) and digestate is composted before land application. • Conservatively assume that N content in dried digestate is the same as food waste-derived compost (1.7%). • Because of nutrient runoff concerns, land application of digestate only occurs for half of the year, with digestate being sent to landfills during the winter rainy season.	**Global warming potential** (kg CO_2 eq) S1 = 400; S2 = -41; S3a = 9; S3b = 40; S3c = 27, S3d = -36; S3e = -2	• Authors suggest that all scenarios are likely to better than landfilling organic waste. • Authors don't provide firm conclusions on an 'optimal' scenario, instead noting the importance of assumptions in determining the outcomes. However, composting was found to have the lowest GHG footprint of all scenarios. • Authors find that NH_3 emissions may be highest from composting but note the lack of data on these air pollutants from a range of scenarios.
Retail food waste, France[452]	**Scenario 1** (S1) Redistribution to people and/or reuse of surplus for food animal feed with AD and	'Cradle to grave' including land-use. changes, i.e. the entire life cycle of surplus	• Digestate considered a source of organic fertiliser. • Bottom ashes from incineration used for road	**Global warming potential** (kg CO_2 eq) S1 = -1313; S2 = -92; S3 = -155; S4 = -2955 **Terrestrial acidification** (AE)	• Authors found S1, the redistribution and/or reuse of surplus food to people/animals was found to have substantial

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
	incineration of residual streams. **Scenario 2** (S2) AD of all food waste, including pre-treatment. **Scenario 3** (S3) Incineration of all food waste. **Scenario 4** (S4) Prevention of food waste (used as a benchmark).	food generated at retail outlets.	construction, fly ashes for backfilling of salt mines. • Primary data source expressed food waste in monetary value, and therefore needed to be converted to mass (kg) assuming certain conversion factors.	S1 = -0.61; S2 = -0.62; S3 = -0.61; S4 = -0.67 **Freshwater eutrophication** (kg N eq) S1 = -8; S2 = 2.2; S3 = 0.27; S4 = -20 **Fossil depletion** (MJ) S1 = -13,800; S2 = -2,580; S3 = -3,000; S4 = -23,000	environmental savings, second only to prevention with nevertheless of similar magnitude. • Both AD and incineration were estimated to have a net negative benefit for GWP.
Household, service, and retail food waste, Istanbul Turkey.[610]	**Baseline** (B) Landfill with gas capture. **Scenario 1** (S1) AD, with mechanical pre- and post-sorting. **Scenario 2** (S2) Incineration of food waste with mixed solid waste. **Scenario 3** (S3) Food waste discharged to sewer lines, treated at WWTPs.	Waste collection and transfer, waste conversion, chemical and energy inputs, end-product displacement, water, air and soil emissions, residual disposal.	• Solid fraction of digestate substitutes equivalent amount of mineral fertiliser. • Authors assume high energy generation efficiency for waste-to-energy practices: 22% and 60% for electrical and heat conversion efficiencies.	**Global warming potential** (kg CO_2 eq) B = 4.67E-01; S1 =3.46E-02; S2 = -1.02E-01; S3 = 4.26E-01 **Human toxicity** (kg 1,4-DCB eq) B = -1.41E-02; S1 = -8.31E-02; S2 = -1.00E-01; S3 = -3.04E-02 **Marine eutrophication** (kg N eq) B = 2.94E-02; S1 = 2.95E-02; S2 = 2.93E-02; S3 = 2.58E-02 **Marine ecotoxicity** (kg 1,4-DCB eq) B = 4.82E-02; S1 = 4.65E-02; S2 =4.60E-02; S3 = 2.22E-02 **Freshwater ecotoxicity** (kg 1,4-DCB eq) B = -5.62E-04; S1 = -3.37E-03; S2 =-3.57E-03; S3 = -9.59E-04 **Freshwater eutrophication** (kg P eq) B = -4.83E-05; S1 = -4.18E-04; S2 = -1.59E-04; S3 = 6.56E-05 **Terrestrial ecotoxicity** (kg 1,4-DCB eq) B = 1.60E-05; S1 = 1.75E-04; S2 =-1.27E-05; S3 = 1.29E-05 **Terrestrial acidification** (kg SO_2 eq) B = 7.12E-04; S1 = -7.40E-04; S2 = -8.45E-04; S3 = 4.75E-04 **Fossil depletion** (kg oil eq) B = 8.51E-02; S1 = -5.18E-02; S2 = -8.81E-02; S3 = 6.02E-02	• Authors considered S2, incineration of food waste, the optimal solution as it performed best in 6 of 9 LCA impact categories. • Authors note that a similar study provided conflicting results, finding incineration to have a worse environmental performance than landfilling (like due to low energy generation efficiency). • Energy generated from incineration (steam) adds substantial credit by substituting existing fossil-fuel sources in Turkey.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
				Note, values expressed per 1kg of food waste.	
Retail food waste, UK.[453]	**Scenario 1** (S1) Donation of all food waste from retailers. **Scenario 2** (S2) Food waste is used to produce animal feed, used to replace oat and soybean meal. **Scenario 3** (S3) Food waste is sent to an AD plant to produce biogas and digestate. **Scenario 4** (S4) Food waste is composted aerobically. **Scenario 5** (S5) Food waste is incinerated with electricity generation. **Scenario 6** (S6) Food waste is landfilled with gas capture and utilisation (6.1), with gas capture and flaring (6.2), and without gas collection (6.3).	Transport from retailer to processor, processing (incl. emissions), replacement of fertiliser, crops, and electricity.	• Limited to food waste from retailers. • In the donation scenario, assumed that all food is safely edible. • Digestate and compost are both assumed to be a direct substitute for mineral fertiliser. • Numerous other assumptions, clearly listed in Table 1 of the paper.	**Emissions** (kg CO_2 eq) S1 = -5583; S2 = -347; S3 = -314; S4 = -31; S5 = -58; S6.1 = 573, S6.2 = 795, S6.3 = 2969	• Considering only emissions, the authors concluded that S1, food rescue/donation, is the best 'disposal' option for unsold food from retailers. Where food is unfit for human consumption, conversion to animal feed, followed by AD, were considered the optimal strategies.
Household food waste, UK.[454]	**Scenario 1** (S1) In-vessel composting of food waste. **Scenario 2** (S2) Incineration of all food waste, producing both heat and electricity.	'Gate to grave', processing and product displacement but not food waste collection and transportation.	• Compost fertiliser efficiencies assumed were 20% for N, 100% for P, and 100% for K. • Digestate substitutes N, P and K fertilisers with an	**Global warming potential** (kg CO_2 eq) S1 = 10; S2 = -110; S3 = -150 **Ozone depletion** (xE-7 kg CFC-11 eq) S1 = 6; S2 = -2.1; S3 = -85 **Terrestrial acidification** (xE-4 AE) S1 = 2.5; S2 = 7.9; S3 = 6.3 **Terrestrial eutrophication** (AE) S1 = 1.4; S2 = 4.2; S3 = 4.5	• Looking at the average impact across environmental and health impacts, authors considered composting (S1) to rank best among the different technologies.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
	Scenario 3 (S3) AD of food waste.		efficiency of 34.5, 46 and 60%, respectively.	**Freshwater eutrophication** (xE-3 kg P eq) S1 = -2.8; S2 = -3.5; S3 = -2.8 **Marine eutrophication** (xE-2 kg N eq) S1 = 1.8; S2 = 6.5; S3 = 40 **Fossil depletion** (MJ) S1 = 74; S2 = -2400; S3 = -3000	• Notably, composting performed worse than AD with respect to GWP and depletion of fossil fuels as composting does not generate energy.
Retail food waste limited to five fruits and vegetables (banana, tomato, apple, orange, bell pepper), Sweden.[611]	**Scenario 1** (S1) Incineration (with energy recovery) of food waste and mixed solid waste. **Scenario 2** (S2) AD of food waste. **Scenario 3** (S3) Upcycling (food waste to chutney), with incineration of unsuitable food wastes. **Scenario 4** (S4) Donation of surplus food, with AD of unsuitable food wastes.	Waste collection and transport, processing, product displacement (energy and fertiliser).	• Biogas from AD assumed to replace petrol and diesel. • Assumed digestate would replace fertilisers on farmland, with digestate substitutes for N and P at efficiencies of 70 and 100% respectively.	**Global warming potential** (kg CO_2 eq) S1 = 0.02; S2 = -0.11; S3 = -0.61; S4 = -0.59 **Primary energy use** (MJ) S1 = 0.22; S2 = -0.38; S3 = -8.28; S4 = -6.60 *Note, values expressed as averages and per 1 kg of food waste. Values are derived from publication figures and are therefore approximate.*	• Options for re-use (donation and upcycling) were found to reduce GHG emissions and the primary energy use to a significantly higher degree than the energy recovery options (incineration and AD. • Food waste modelled was restricted to fresh fruit and vegetables, which contain high water content, making them inefficient for energy recovery options.
Municipal food waste, Australia.[612]	**Baseline** (B) Landfilling food waste. **Scenario 1** (S1) Industrial AD of food waste (AD). **Scenario 2** (S2) Pyrolysis of food waste. **Scenario 3** (S3) Integrated system, AD sequence with pyrolysis.	Inputs, processing, and materials and energies saved through recovery of useful products (e.g. digestate and grid energy).	• Digestate considered a substitute for mineral fertiliser.	**Global warming potential** (g CO_2 eq) B = 498.27; S1 = -757.16; S2 = -125.97; S3 = -721.44 **Ozone depletion** (µg CFC-11 eq) B = 0.32; S1 = -0.45; S2 = -11.82; S3 = 0.91 **Terrestrial acidification** (g SO_2 eq) B = 0.08; S1 = -1.33; S2 = 1.43; S3 = -1.00 **Freshwater eutrophication** (g P eq) B = 0.01; S1 = -0.21; S2 = 0.96; S3 = -0.21 **Marine eutrophication** (g P eq)	• S1, AD, was considered by the authors to be the most environmentally beneficial option. • The authors considered S3 to have similar benefits to S1.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
				B = 2.81; S1 = -2.88; S2 = -2.56; S3 = -2.87 **Human toxicity** (g 1,4-DCB eq) B = 3.41; S1 = -10.52; S2 = -2.32; S3 = -7.41 **Water depletion** (litres) B = 34.98; S1 = -591.56; S2 = 1293.79; S3 = -554.73 **Fossil depletion** (g oil eq) B = 1.86; S1 = -87.94; S2 = 96.97; S3 = -72.63 *Note, values for scenarios expressed per 1 kg of food waste.*	
Municipal food waste, UK.[183]	**Scenario 1** (S1) Conversion into dry pig feed. **Scenario 2** (S2) Conversion into wet pig feed. **Scenario 3** (S3) AD of food waste. **Scenario 4** (S4) Composting of food waste.	Process and product displacement (conventional animal feed, electricity production, mineral fertiliser, and compost).	• Food waste feed substitutes conventional feed 1:1 on a dry matter basis. • The compost utilisation efficiencies used are: 20% for N, 100% for P, and 100% for K, compost is applied to loamy soils, where substitutes 1:1 for synthetic fertilisers. • Dried digestate substitutes N, P and K fertilisers with an efficiency of 34.5%, 46.0% and 60.0%, respectively.	**Global warming potential** (kg CO_2 eq) S1 = 3.96E+01; S2 = 3.80E+01; S3 = 2.09E+00; S4 = 2.80E+02 **Ozone depletion** (µg CFC-11 eq) S1 = 3.08E-06; S2 = -2.95E-06; S3 = 7.34E-06; S4 = 1.87E-05 **Freshwater eutrophication** (kg P eq) S1 = -2.17E-02; S2 = -3.00E-02; S3 = 2.86E-02; S4 = 2.86E-02 **Marine eutrophication** (kg N eq) S1 = -1.38E+00; S2 = -1.77E+00; S3 = 1.91E+00; S4 = 1.93E+00 **Ecotoxicity** (CTU) S1 = -2.20E+02; S2 = -2.76E+02; S3 = 3.03E+02; S4 = 2.95E+02 **Acidification** (AE) S1 = -6.48E-01; S2 = -1.00E+00; S3 = 2.05E+00; S4 = 1.59E+00 **Fossil fuel depletion** (MJ) S1 = 4.03E+03; S2 = 1.80E+03; S3 = -1.73E+03; S4 = 3.43E+03	• Recycling of food waste as wet pig (S2) feed was considered the best scenario by authors, with composting scoring worst among impacts. • Process-specific data for FW feed taken from South Korea, as use of FW as animal is illegal in the UK. • Used a hybrid, consequential life cycle approach (e.g. if FW is used to make dry pig feed, avoided emissions of conventional feed is account for, but also knock-on emissions from composting/AD which did not take place).

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
Household food waste, New York US[613]	**Baseline** (B) Incineration of mixed solid waste, including food waste. **Scenario 1** (S1) Enclosed tunnel composting of food waste, residual waste sent to incineration. **Scenario 2** (S2) Enclosed windrow composting, residual waste sent to incineration. **Scenario 3** (S3) AD with subsequent enclosed windrow composting of digestate, residual waste sent to incineration.	Waste generation, collection and transport, processing, product displacement (energy and fertiliser).	• 70% of food waste is diverted at source from mixed solid waste (S1-S3) • Compost is used as a fertiliser replacement, although the ratio of replacement is unclear.	**Global warming potential** (kg CO_2 eq) B = 185; S1 = 204; S2 = 206; S3 = 185 **Ozone depletion** (g CFC-11 eq) B = -0.0026; S1 = -0.0026; S2 = -0.0026; S3 = -0.0026 **Terrestrial acidification** (AE) B = -10; S1 = 1.8; S2 = 0.10; S3 = -31 **Terrestrial eutrophication** (AE) B = 2.40; S1 = 2.23; S2 = 2.23; S3 = 2.09 **Freshwater eutrophication** (kg P eq) B = -0.000035; S1 = -0.0072; S2 = -0.0072; S3 = -0.0075 **Marine eutrophication** (kg N eq) B = 0.22; S1 = 0.29; S2 = 0.32; S3 = 0.28 **Fossil depletion** (MJ) B = -911; S1 = -899; S2 = -885; S3 = -949	• Authors found that S3, AD with subsequent composting, scored best on aggregate across measured impact factors. • Generally, the baseline (incineration) and tunnel composting scenarios performed better than the windrow composting scenario. • Because the whole waste stream was modelled, with food waste making up <14% of modelled waste, the relative difference between scenarios was small.
Household, service, and retail food waste, Singapore.[614]	**Baseline** (B) Incineration at centralised facility, ash disposal in landfill. **Scenario 1** (S1) Two-phase AD in a centralised facility AD. **Scenario 2** (S2) Food waste to energy biodiesel (FWEB) via hydrothermal carbonisation (HTC, producing (hydrochar) and transesterification (producing glycerol).	Food waste collection, processing, waste conversion, disposal/use of outputs (electrical energy, hydrochar, and glycerol).	• End products displace virgin materials in term of equivalent calorific value, but digestate not included as fertiliser substitute. • Construction and material requirements not included. • Collection and transport of end products not included.	**Global warming potential** (kg CO_2 eq) B = 240; S1 = -5; S2 = 135 **Acidification potential** (kg SO_2 eq) B = 0.5; S1 = 0.045; S2 = 0.1 **Eutrophication potential** (kg PO_4 eq) B = 0.08; S1 = 0.015; S2 = -0.26 **Cumulative energy demand** (MJ) B = 3,300; S1 = -150; S2 = -1,000	• Authors considered S2 optimal when FW oil content > 5%, but S1 optimal when FW oil content < 5%. • Data derived from lab-scale experiments and literature.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
Retail food waste limited to five food products (bananas, grilled chicken, lettuce, beef, and bread), Sweden.[615]	**Scenario 1** (S1) Landfill without gas capture. **Scenario 2** (S2) Incineration (with energy recovery) of food waste and mixed solid waste. **Scenario 3** (S3) Composting of food waste in outdoor windrows. **Scenario 4** (S4) AD of food. waste **Scenario 5** (S5) Conversion to animal feed. **Scenario 6** (S6) Donation of surplus food.	Waste collection and transport, processing, product displacement.	• Compost produced is used as a soil amendment for landfills and does not replace any other product. • Digestate used as a 'dilute' fertiliser replacement. • Assumed that conversion to animal feed did not produce additional GHGs, also assumed it was theoretically legal to feed animals with animal products.	**Global warming potential** (kg CO_2 eq) S1 = 1.74; S2 = -0.13; S3 = 0.04; S4 = -0.38; S5 = -0.04; S6 = -0.28 *Note, values expressed as averages and per 1 kg of food waste.*	• Authors suggested that the greatest potential for reducing GHG emissions was via donation (S6) and AD (S4). • If compost is not used to replace mineral fertiliser (as assumed in this study), the absence of nutrient recovery sees it as one of the least favourable options for managing food waste.
Household organic waste, Sweden.[616]	**Scenario 1** (S1) Incineration (with energy recovery) of food waste and mixed solid waste. **Scenario 2** (S2) Food waste is source separated and composted in decentralised compost reactors in residential areas. **Scenario 3** (S3) Food waste is source separated and anaerobically digested, with biogas upgraded and used as fuel. **Scenario 4** (S4) Food waste is source separated and anaerobically digested, with biogas not upgraded and instead used for	Collection and transportation, pre-treatment, processing, product displacement (fertiliser, fuel, and energy).	• Compost is used to substitute production of garden soil (peat and commercial fertilisers). • Digestate is used on farmland to replace commercial fertilisers.	**Global warming potential** (kg CO_2 eq) S1 = 4230.1; S2 = -4575.6; S3 = -9199.2; S4 = 2908.2 **Ozone depletion** (µg CFC-11 eq) S1 = 0.01; S2 = 0.0; S3 = 0.0; S4 = 0.0 **Acidification** (kg SO_2 eq) S1 = 3.3; S2 = 804.0; S3 = -82.6; S4 = -60.3 **Nutrient enrichment** (kg NO_3 eq) S1 = 4.3; S2 = 1561.5; S3 = 22.8; S4 = 741.9 **Ozone formation** (kg C_2H_4 eq) S1 = 0.3; S2 = 1.6; S3 = -14.0; S4 = -6.5 *Note, scenario values are **not** expressed per kilogram or tonne of food waste processed. Instead, the 'functional unit' for each scenario of this study is the total organic waste generated by a residential*	• Authors found S1, AD with use of biogas as vehicle fuel and use of digestate on sandy soils, to be the scenario with the best environmental outcomes. • Authors noted that S1, incineration, made the largest contribution to global warming among scenarios. • Both anaerobic and aerobic biological treatments increase net contribution to nutrient enrichment and acidification compared to incineration.

Type of FW, location	Scenarios	System boundaries	Key assumptions	Environmental impacts	Optimal scenario and other comments
	electricity production and thermal energy.			*area in Sweden consisting of 1,631 households. For example, for Scenario 1, 4,230.1 kg of CO_2 eq are produced per 1,631 households (i.e., the whole residential area).*	
Commercial and industrial food waste, US[617]	**Scenario 1** (S1a, S1b, S1c, S1d) Composting of food waste via windrows (S1a), aerated static pile (S1b), Gore cover system (S1c), in-vessel system (S1d) with green material (shredded branches) co-composted in all scenarios. **Scenario 2** (S2) AD of food waste, with digestate dewatered, mixed with shredded branches, and cured aerobically. **Scenario 3** (S3a, S3b, S3c, S3d) Food waste is landfilled without gas capture (S3a), with gas capture and flaring (S3b), with gas capture and energy recovery (S3c), and in a bioreactor landfill (S3d).	Transport, processing, product displacement (energy and fertiliser).	• Compost is used as a fertiliser offset or a peat offset. • Dewatered digestate is used a soil amendment, with excess water treated in a wastewater treatment plant.	**Global warming potential** (kg CO_2 eq) S1a = -150; S1b = -80; S1c = -100; S1d = -65; S2 = -400; S3a = 1150; S3b = -20; S3c = -230; S3d = -5 **Acidification** (kg NO_x) S1a = 0.04; S1b = 0.09; S1c = 0.03; S1d = 0.13; S2 = -0.59; S3a = 0.12; S3b = 0.2; S3c = -0.25; S3d = -0.21 **Acidification** (kg SO_2) S1a = -0.02; S1b = 0.17; S1c = 0.01; S1d = 0.25; S2 = -1.58; S3a = 0.03; S3b = 0.04; S3c = -1.3; S3d = -1.18 **Total energy use** (MJ) S1a = -20; S1b = 350; S1c = 10; S1d = 490; S2 = -2200; S3a = 150; S3b = 150; S3c = -2400; S3d = -2100 *Note, values are derived from publication figures and are therefore approximate.*	• Authors found S2, AD, to lead to the largest reductions in all environmental emissions and energy use, mainly due to offset emissions from avoided electricity generation. • Authors note that AD and in-vessel composting are the costliest scenarios, suggesting that more cost-effective designs for AD systems would increase their adoption. • Authors found S3c, landfill with energy recovery, to reduce GWP more than all composting scenarios.

Annex 3: Upcycling certification and consumer protection

The *Fair Trading Act* already protects New Zealand consumers against misleading and deceptive conduct.[618] This applies to environmental claims, with the Commerce Commission advising that "all traders, large and small, must make sure their environmental claims are substantiated, truthful, and not misleading to avoid breaching the *Fair Trading Act 1986*."[619] However, with definitional ambiguities associated with upcycled foods, applying the *Fair Trading Act* in the context of upcycling claims may be difficult.

Certain terms and claims relating to food products are regulated under New Zealand law. In particular, health and nutrition claims are regulated under the *Australia and New Zealand Food Standards Code* – there are some claims that can't be made (e.g. claims of therapeutic benefit) and others that must be substantiated to avoid making false or misleading claims.[153] The *Food Standards Code* doesn't contain any rules around sustainability or environmental claims, but is currently under review.[620] Similarly, the *Organic Products and Production Bill*, passed in March 2023, seeks to regulate the use of the term 'organic.'[621]

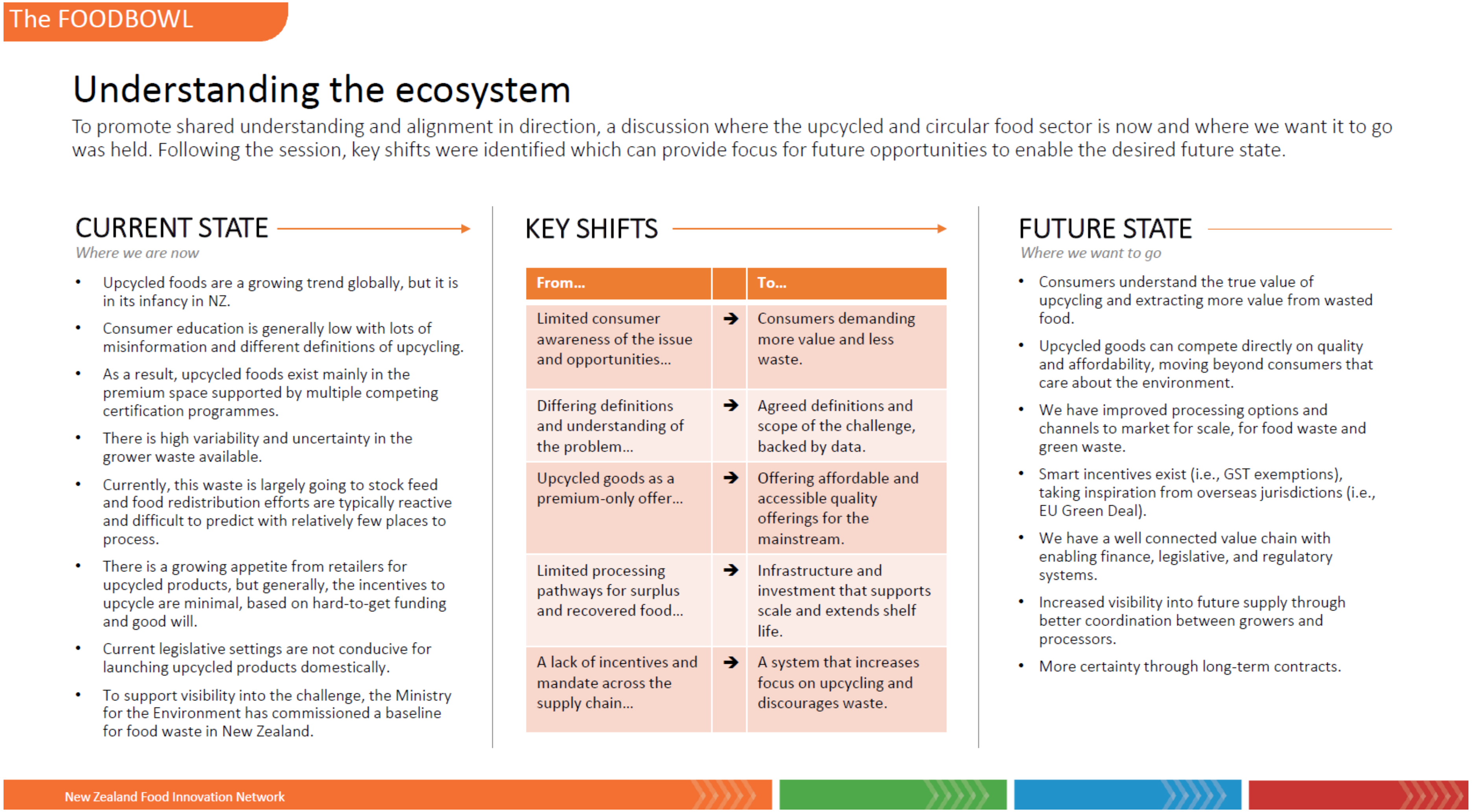
The Upcycled Food Association certification standard provides for three upcycled designations for food for sale for human consumption and a wider range of non-durable goods.[21] These are described below.

- Upcycled ingredients – Food ingredients that are composed of at least 95% upcycled inputs by weight.[123]
- Products containing upcycled ingredients – Food products that are made from at least 10% upcycled inputs by weight or meet a specified food waste tonnage diversion threshold.[123]
- Products containing minimal upcycled ingredient content – Food products that are made from less than 10% upcycled inputs by weight or fail to meet a specified food waste tonnage diversion threshold.[123]

There are annual fees associated with certification, which go towards administration of the program, maintenance of the standard, and education and outreach.[622,623] In the future, the standard could be expanded to include explicit requirements relating to proof of environmental benefit (including greenhouse gas emissions) and nutritional objectives.

Many of these requirements of the Upcycled Food Association certification standard align with those required by Verra to earn verified C credits under the standard for avoiding greenhouse gas emissions by keeping food in the human supply chain[624] (see section 3.3 in *Food rescue in 2022: Where to from here?*). With overlaps in the technical requirements of the two standards, businesses going to the effort of seeking certification through one standard could seek to be certified under both, gaining the reputational and consumer appeal benefits of the upcycled certification and the opportunity to earn further revenue in voluntary C markets. However, the complexity of complying with these standards may exceed the capacity of small businesses, and tools supporting them to gather the evidence needed to demonstrate their compliance would help. In addition, anyone seeking to engage with voluntary C markets should uphold the principles outlined in MfE's guidance,[625] detailed in *Food rescue in 2022: Where to from here?*, and offsets shouldn't be seen as a substitute for the need to achieve gross emissions reductions.[15]

Annex 4: Upcycling business kōrero hosted by FoodBowl in January 2023 – key messages



The FOODBOWL

Understanding the ecosystem

To promote shared understanding and alignment in direction, a discussion where the upcycled and circular food sector is now and where we want it to go was held. Following the session, key shifts were identified which can provide focus for future opportunities to enable the desired future state.

CURRENT STATE

Where we are now

- Upcycled foods are a growing trend globally, but it is in its infancy in NZ.
- Consumer education is generally low with lots of misinformation and different definitions of upcycling.
- As a result, upcycled foods exist mainly in the premium space supported by multiple competing certification programmes.
- There is high variability and uncertainty in the grower waste available.
- Currently, this waste is largely going to stock feed and food redistribution efforts are typically reactive and difficult to predict with relatively few places to process.
- There is a growing appetite from retailers for upcycled products, but generally, the incentives to upcycle are minimal, based on hard-to-get funding and good will.
- Current legislative settings are not conducive for launching upcycled products domestically.
- To support visibility into the challenge, the Ministry for the Environment has commissioned a baseline for food waste in New Zealand.

KEY SHIFTS

From...		To...
Limited consumer awareness of the issue and opportunities...	➔	Consumers demanding more value and less waste.
Differing definitions and understanding of the problem...	➔	Agreed definitions and scope of the challenge, backed by data.
Upcycled goods as a premium-only offer...	➔	Offering affordable and accessible quality offerings for the mainstream.
Limited processing pathways for surplus and recovered food...	➔	Infrastructure and investment that supports scale and extends shelf life.
A lack of incentives and mandate across the supply chain...	➔	A system that increases focus on upcycling and discourages waste.

FUTURE STATE

Where we want to go

- Consumers understand the true value of upcycling and extracting more value from wasted food.
- Upcycled goods can compete directly on quality and affordability, moving beyond consumers that care about the environment.
- We have improved processing options and channels to market for scale, for food waste and green waste.
- Smart incentives exist (i.e., GST exemptions), taking inspiration from overseas jurisdictions (i.e., EU Green Deal).
- We have a well connected value chain with enabling finance, legislative, and regulatory systems.
- Increased visibility into future supply through better coordination between growers and processors.
- More certainty through long-term contracts.

New Zealand Food Innovation Network

Figure 53: Summary of key messages from upcycling business kōrero hosted by FoodBowl in January 2023. Attendees reflected on the current state of the upcycling ecosystem, the desired future state, and shifts needed to get there. Abbreviations: GST = Goods and Services Tax, EU = European Union. Image credit: Marshall Bell, FoodBowl.

Annex 5: Consumer research for upcycled food

Several specialised consumer research tools can be applied to upcycled food development and marketing.

Eye tracking technology and other implicit measures can be used to study how consumers engage with the food products, including their packaging and placement in retail environments (see figure 54).[626,627] Eye tracking technology can help food product developers, marketers, and retailers understand how consumers engage with the appearance of food, its packaging, and its placement in retail contexts. Because eye movements are often unconscious, this can help researchers understand determinants of consumer choice without the distortion of conscious consideration and social desirability bias.[628] When combined with physiological and psychological reaction tests, eye tracking can help with the design food packages and optimisation of placement to maximise sales, including for upcycled food products, given that “the first taste is almost always with the eye.”[629]

Figure 54: Eye tracking and facial expression analysis at the University of Otago’s Upcycled Food Lab. In the set-up shown in the top two images, monitor-based eye tracking and facial expression analysis are being undertaken to assess the response to a student-designed upcycled muesli bar package. The bottom image is a heat map showing eye tracking results from multiple participants, demonstrating that information about the upcycling process elicited significant attention from participants. Image credit: Department of Food Science, University of Otago.

Sensory evaluation is the scientific discipline focused on the assessment of the sensory properties of food. Analytical and affective tests are used to evaluate people’s perceptions and appreciation of food (its appearance, smell, taste, flavours, texture, and consistency), supporting the development or reformulation of food products.[630–632] Consumer-led sensory evaluation during upcycled food development may increase the odds of new products succeeding, although cost can be a barrier. Aotearoa has considerable expertise in sensory evaluation, including at Massey University's Food Experience and Sensory Testing laboratory (Feast),[633] Otago University's analytical services consultancy,[634] PFR's Sensory and Consumer Science Team,[635] and FoodSouth Otago's sensory panel.[636]

Affective tests focus on how much a prospective consumer will engage with a food product, focusing in on preference, level of liking, and emotional engagement. Affective tests are usually undertaken using representative group of consumers who reflect the target market for the food product. Consumers may be asked to state which food sample they like the most, rank food samples from best to worst, or give a food sample a score (e.g. from extremely unacceptable to extremely acceptable or using a pictorial[637] or emoji[638] scale). As well as giving responses to foods overall, they may be asked to focus on a specific characteristic (e.g. which food has the best texture?). [630–632]

Annex 6: Mitigating risk in producing animal feed

Potential mitigants for some risks associated with using food loss and waste in animal feed are summarised in table 15. This table is non-exhaustive but covers key treatments that could be considered acceptable in Aotearoa. These techniques may not be suitable mitigants for all risks under these classes (e.g. while best practice heat treatment can mitigate most food safety/biosecurity risks, it cannot mitigate the risk of prion transmission, as prions are highly resistant, heat-tolerant disease-causing proteins – see annex 7). Toxicity is not included in this table as what constitutes a toxin varies widely between animals, and toxicity risks are best mitigated through avoiding feeding animals with foodstuffs containing compounds in concentrations that are known to be toxic to them. Other proposed techniques don't sufficiently inactivate risk pathogens in meat-based feeds (in the case of freeze-drying, chilling, high-pressure processing), or risks nutrient loss (irradiation).[185]

Table 15: Techniques that can be used to improve the palatability, digestibility/nutrition, and/or microbiological food safety/biosecurity of food system by-products and post-consumer food waste being used for animal feed. Abbreviations: N = nitrogen, P = phosphate, NH_3 = ammonia.

Technique	Challenges that this technique addresses	Technique details	Examples
Algal cultivation	Palatability. Digestibility/nutrition. Food safety/biosecurity.	Algae is grown using food waste (especially liquid-based waste) as a nutrient source. Algae is then fed to animals.[639] Can also use digestate from AD as algal growth medium.[640]	Microalgae and microbes co-cultivated in dairy wastewater can decrease N and P levels below wastewater discharge limits and the algae can be used in a variety of ways, incl. as animal feed.[639]
Blending	Palatability. Digestibility/nutrition.	Different feed materials are combined into a composite feed that achieves dietary balance. Less palatable ingredients can be combined with more palatable ones.[195]	Malt sprouts have a bitter flavour but this can be masked by blending with other feeds.[195] Rice bran by-products are high in unsaturated fatty acids so should be mixed with other feed ingredients to avoid body fat softening.[195]
Chemical treatment	Palatability. Digestibility/nutrition. Food safety/biosecurity.	Chemicals are used to break down food waste. Chemical treatment also has antimicrobial effects, and the chemicals themselves may add	NH_3 can be added to roughages, helping to break down molecules (e.g. cellulose), and killing/arresting bacteria and fungi.[641] Rawhide animal treats (i.e. skin by-products)

Technique	Challenges that this technique addresses	Technique details	Examples
		further nutritive value.[185,641]	can be rendered microbiologically safe by chemical treatment with pH of 13 or higher for at least 8 hours.
Drying	Palatability. Digestibility/nutrition. Food safety/biosecurity.	Many food system by-products and post-consumer food wastes have a high moisture content (70–90%). If they aren't going to be used right away, drying can reduce the risk of spoilage.[195,642] Drying also mitigates the risk of reduced total dry matter consumption by animals which can occur if the water content of feed is too high.[195]	Tomato pomace can be fed to animals directly but is commonly sundried or ensiled with low-moisture feeds like maize stovers.[195]
Enzymatic treatment	Palatability. Digestibility/nutrition.	Enzymes are added to food waste to make nutrients more readily available and/or breakdown anti-nutritional factors.[195,643]	Enzyme-assisted fermentation of fruit pomace can enhance nutrient availability for poultry and pigs.[644] Adding phytase to by-product and surplus-based feed makes P more accessible and digestible.[643,645]
Fermentation, ensiling	Digestibility/nutrition. Food safety/biosecurity.	Plant-based food system by-products are 'pickled' (e.g. in siloes, bales) to make nutrients more readily available and reduce the risk of spoilage.[189,195,646,647]	Two food waste streams (non-spec apples and cowpea stover) were ensiled in a case study in Portugal, producing a stable silage.[648]
Gradual introduction	Palatability. Digestibility/nutrition.	New feeds, including food waste-based feeds, are introduced incrementally to an animal's diet,	Agriculture Victoria recommends a gradual introduction of grain- or pellet-based feeds to sheep and cattle,

Technique	Challenges that this technique addresses	Technique details	Examples
		increasing acceptance of the new food and giving gut microbes time to adjust to enhance digestibility.[190,195]	supplementing with gradually reducing volumes of hay.[649]
Heat treatment (e.g. rendering, pasteurisation, retorting, extrusion cooking, baking)	Digestibility/nutrition. Food safety/biosecurity.	Food waste is heated to kill or inactivate microbes and stabilise the product.[185,189,195] Heat treatment can also improve digestibility (e.g. by inhibiting anti-nutritional factors).[195]	Dry pet food is made by mixing ingredients into a dough and then baking at around 200 °C for 7-15 minutes, which thermally inactivates pathogens and reduces the moisture content of the food to prevent spoilage.[185]
Insect bioconversion	Palatability. Digestibility/nutrition. Food safety/biosecurity.	Food waste is fed to insects and the insect larvae are used as a protein- and lipid-rich animal feed.[227,228]	FlyFarm is a commercial bioconversion company that feeds homogenous vegetal by-products to black soldier fly larvae. The larvae are used as an animal feed ingredient.[650]
Selective breeding	Palatability. Digestibility/nutrition.	Animals can be selectively bred for more efficient feed utilisation, including utilisation of food waste-based feeds, although this needs to be balanced against selection for other desired phenotypes.[651,652]	Feed efficiency is a selectable trait in beef cattle genetic improvement programmes.[651]

Annex 7: Infection and biosecurity risks in animal feed

Some types of waste would pose infection and biosecurity risks were they to be used in animal feed. There are several pig-specific diseases that are currently absent from Aotearoa but, if introduced and allowed to spread, would cause pig illnesses and deaths, and substantial economic damage. Chief amongst these are two viral diseases: African Swine Flu and Porcine Reproductive and Respiratory Syndrome.[194] Foot and Mouth Disease affects cows and ungulates (animals with two toes) in addition to pigs.[653]

Existing regulations are aimed at these risks, with strict biosecurity controls in place to minimise the risk of these diseases entering the country. For example, pork products are subject to Import Health Standards, which include requirements for meat from countries with Porcine Reproductive and Respiratory Syndrome to be either treated or in consumer-ready cuts. Even with such biosecurity regulations at the border, there are additional limitations on feeding meat to various animals. Table 16 describes these regulations and the diseases they are designed to prevent.

Table 16: Examples of diseases that can be transmitted via feeding food waste to animals.

Animal infected	Relevant law	Disease risks (through food transmission)	How to feed waste safely
Cows	*Biosecurity (Ruminant Protein) Regulations 1999*: Feeding of ruminant protein to ruminant animals prohibited.[553]	Bovine Spongiform Encephalopathy ('mad cow disease').[654]	No safe method for feeding ruminant protein to ruminant animals.
Dogs	The whole of NZ is under a Controlled Area Notice prohibiting feeding dogs untreated offal, under the *Biosecurity Act 1993*.[655]	Hydatids cysts.[655]	Offal must be boiled for thirty minutes at 100 °C or frozen to -10 °C for ten days. Additionally, preventive deworming is advised.
Pigs	*Biosecurity (Meat and Food Waste for Pigs) Regulations 2005*: illegal to feed untreated meat, or food in contact with untreated meat, to a pig.[552]	Porcine Reproductive and Respiratory Syndrome.[656] African Swine Fever.[657] Foot and mouth disease.[658]	Any meat or feed in contact with meat must be boiled for one hour at 100 °C.

Table 16 outlines approved methods for treating feed that has been in contact with meat. Other promising techniques for treatment in the future include fermentation[659] and insect bioconversion[226] but more work will be needed to establish that these techniques are safe.

The problem with prions

Prions are infectious proteins that cause uniformly fatal neurodegenerative diseases in animals and humans.[660,661] Prion diseases occur when a normal protein, cellular prion protein (PrP^C), is folded incorrectly to give scrapie prion protein (PrP^{Sc}), which forms pathological aggregates in the brain and other tissues, especially in the nervous system. Many animals have PrP^{C} and are therefore theoretically susceptible to prion diseases, which can emerge spontaneously, be inherited, or be acquired, predominantly through the food chain, other infected animals, the environment, or infected medical equipment.[660] There is no cure or vaccine for prion diseases, and it is very difficult to inactivate a prion – they are extremely resistant to degradation so standard methods for inactivation or killing infectious agents don't work (for example, boiling meat at 100 °C for an hour is sufficient to prevent Porcine Reproductive Respiratory Syndrome, but temperatures in excess of 480 °C for many hours would be needed to render prions safe[662]).[663] Incubation times can be long, and diagnosis is difficult – vets and doctors must rely on clinical signs, with definitive diagnosis only possible post-mortem.[660]

Sheep, cattle, and deer (all of which are ruminant animals) are the main food animals with which prion diseases are associated,[660] although no ruminant prion diseases have ever been detected in Aotearoa.[664–666] Prion diseases spread most readily between animals of the same species, but there is no hard species barrier.[660] In sheep, prion disease is known as scrapie, and has been reported for hundreds of years.[660] Prion disease in cervids (e.g. deer) is known as chronic wasting disease (CWD), and has been reported predominantly in North America.[660] Prion disease in cattle is known as bovine spongiform encephalopathy (BSE), with the first diagnosis occurring in 1986 before the disease spread to over 179,000 cattle in the UK as the result of feeding healthy cattle on meat and bone meal made from infected cattle.[660] Most notably, the BSE outbreak triggered 750,000 animals to be slaughtered, and these cattle entered the human food chain, causing the eventual onset of over 200 cases of a prion disease known as variant Creutzfeldt-Jakob Disease (vCJD) in humans.[660,661]

The difficulty of mitigating prion risks through control measures underpin Aotearoa's blanket ban in the inclusion of ruminant protein in animal feed intended for ruminants.[654] A small selection of ruminant proteins and products are excluded from this ban, such as dairy products, because there is no evidence of BSE transmitting through milk.[667]

Annex 8: Animal diets in New Zealand

Farmed animals

Aotearoa has a large population of commercially farmed animals (see table 17). Sheep are the most populous, with five sheep for every human.[668] We also have large populations of dairy and beef cattle (almost six million and four million respectively).[668] We also farm pigs (over 600,000 raised per year),[194] deer (with a population of 776,000)[668] and poultry (121 million meat birds raised per year[669] and 3.5 million laying hens raised per year).[670] Livestock numbers are declining, with decreases for all livestock animals except dairy cows between 2002-2020.[671]

Beef cattle, dairy cattle, sheep, and deer predominantly eat pastural diets, with pastures (including hay and silage) comprising 90, 82, 96, and 94% of their dietary composition, respectively.[651,672–675] The remainder of their diets are made up of purpose-grown feed crops (e.g. maize, barley, fodder beet) and, in some instances, by-products and waste from the human food system, particularly imported palm kernel expeller for dairy cattle feed.[191,673] Meanwhile, pigs and poultry eat feeds comprising purpose-grown grains and cereals, soybean meal, and other meals (which are generally food system by-products) and, particularly for pigs, surplus foods from the human supply chain including bread, dairy, and vegetables.[191,192,676]

Table 17: Main commercially farmed animals in Aotearoa and what they eat.

Animal	**Number born/raised throughout year and total population as available** [p]	**Main feed components** (excluding vitamin and mineral supplements)	**Additional comments**
Beef cattle and calves	960,000 calves born to beef cows (year to June 2022).[668] Total beef cattle population of 3.8 million as at June 2022.[668]	90% pasture (including hay and silage), supplemented with cereal grains and roughages.[651]	Beef cattle are most densely farmed in the Northland region (52.2/km^2 of farmland).[671]
Dairy cattle and calves	4.2 million calves born to dairy cows (year to June 2022).[668] Total dairy cattle population of 5.9 million as at June 2022.[668]	82% pasture (including hay and silage, down from 96% in 1990/91), with increasing proportions of the diet containing imported palm kernel expeller, crops (e.g. fodder beet), and harvested supplements (e.g. maize silage).[673]	Dairy cattle are most densely farmed in the Taranaki region (122.8/km^2 of farmland).[671]
Deer and fawns	284,000 fawns born and alive at 4 months (year to June 2022).[668] Total deer population of 776,000 as at June 2022.[668]	93-94% pasture (with a preference for clover, chicory, etc. over grasses), supplemented with silage, crops, and barley.[672,674,675]	Deer are most densely farmed in the Southland region (13.1/km^2 of farmland).[671]

[p] Some of this data comes from the 2022 agricultural production census, funded by the Ministry for Primary Industries and conducted by Stats NZ every five years.[668] A low initial response rate of 67% and subsequent follow up means that data is still being finalised, so these figures, which cover the financial year to 30 June 2022, are provisional.

Animal	Number born/raised throughout year and total population as available [p]	Main feed components (excluding vitamin and mineral supplements)	Additional comments
Pigs	632,000 slaughtered at licenced facilities in 2021.[194] Total pig population of 262,000 as at June 2022.[668]	Mixture of grains, proteins (incl. dairy by-products, soybean meal, meat and bone meal, and fishmeal), as well as by-products and surplus from the human food supply chain such as bread, dairy, and vegetables.[192]	66% of pigs are farmed in the South Island,[194] predominantly in the Canterbury region.[677]
Poultry (for eggs)	3.5 million laying hens raised throughout 2022.[670]	Feed predominantly made from wheat, maize, corn, and soybean meal or bone meal.[676]	Poultry farming for eggs is concentrated in Canterbury, followed by Northland, Auckland, Manawatū-Whanganui, and Waikato.[678]
Poultry (for meat)	121 million birds raised throughout 2021.[669]	Unknown.	Poultry farming for meat is concentrated in Waikato, followed by Auckland, Canterbury, and Taranaki.[678]
Sheep and lambs	22 million lambs born (year to June 2022).[668] Total sheep population of 25 million as at June 2022.[668]	95-96% pasture, predominantly supplemented with baleage, swedes, kale, and leafy turnip.[675]	Sheep are most densely farmed in the Manawatū-Whanganui region (328.8/km^2 of farmland).[671]

Aquaculture

Aquaculture is a small but high-value industry in Aotearoa. Of the three main species farmed here (see table 18), only king salmon require feeding – Pacific oysters and greenshell mussels filter feed from the water column. Typical salmon feed contains fish protein and fish oil, cereals and grains, vegetable protein, and by-products from land-based animal farming.[679]

Table 18: Main aquaculture species farmed in Aotearoa and what they eat.

Animal	**Greenweight[q] tonnage harvested/yr** (3 significant figures)	**Main feed components** (excluding vitamin and mineral supplements)	**Additional comments**
King salmon *(Oncorhynchus tschawytscha)*	14,200 tonnes (2019).[680]	Feed made from fish protein and fish oil from foraged wild fish and by-products from human food production, vegetable and poultry oil, cereals and grains, vegetable protein, land-animal by-products.[679]	Farmed in Marlborough (63%), Southland (23%), and Canterbury (14%).[681]
Pacific oysters *(Crassostrea gigas)*	1,800 tonnes (2019).[680]	No feed – oysters filter phytoplankton from the water.	Predominantly farmed in upper North Island.[681]
Greenshell mussels *(Perna canaliculus)*	97,500 tonnes (2019).[680]	No feed – mussels filter phytoplankton from the water.	Predominantly farmed in Marlborough (65%) and Coromandel (23%).[681]

Companion animals

Aotearoa is also home to over 4.35 million companion animals, with 64% of New Zealand households having at least one pet[682] (see table 19). The diets of companion animals vary widely given the range of species represented, from the pasture-dominated diets of horses[683] to the animal-based protein diets of cats.[684]

Table 19: Main companion animals in New Zealand and what they eat.

Animal	**Estimated number at point in time** (3 significant figures)	**Main feed components** (excluding vitamin and mineral supplements)	**Additional comments**
Birds	560,000 (2020)[682]	Varies by species – e.g. domestic chickens eat food scraps and commercial layer chickens eat pellets[685]; some birds need fruit- and nectar-based diets[686]; others need seed-based feeds, fruit, and vegetables.[687]	6% household penetration, average of 5.2/home.[682]
Cats	1,220,000 (2020)[682]	High protein, moderate fat, low carbohydrate diet, predominantly from	41% household penetration, average of 1.7/home.[682]

[q] Greenweight = unprocessed weight.

Animal	**Estimated number at point in time** (3 significant figures)	**Main feed components** (excluding vitamin and mineral supplements)	Additional comments
		animal sources (cats are obligate carnivores).[684]	
Dogs	851,000 (2020)[682]	At least 10% protein, 5.5% fat, and up to 50% carbohydrates, including animal-based ingredients (dogs are omnivores).[688]	34% household penetration, average of 1.4/home.[682]
Fish	1,370,000 (2020)[682]	Varies by species – fish can be carnivores, omnivores (most aquarium fish), or herbivores; feed can come in the form of processed flakes, pellets, granules, or wafers, as well as whole krill, worms, insects, etc.[689,690]	9% household penetration, average of 8.1/home.[682]
Horses/ponies	72,000 (2020)[682]	Pasture-based diets (grass and hay) are ideal, with supplementary feed only where pasture quality is poor or horses are using extra energy or need to gain condition.[683]	1.6% household penetration, average of 2.5/home.[682]
Rabbits	121,000 (2020)[682]	Plant-based diet high in fibre (rabbits are herbivores); hay and grass should comprise 85% of the diet, with vegetables (10%) and pellets (5%) making up the rest.[691]	2.8% household penetration, average of 2.4/home.[682]
Other small mammals[r]	101,000 (2020)[682]	Varies by species – e.g. guinea pigs need high-fibre plant-based diets while rats and mice eat seed- and grain-rich diets and may also eat small invertebrates.[692]	1.8% household penetration, average of 3.2/home.[682]
Reptiles	60,000 (2020)[682]	Varies by species – generally a mixture of invertebrates (e.g. worms, insects) and vegetables/greens.[693,694]	1.3% household penetration, average of 2.6/home.[682]

[r] E.g. rat, mouse, guinea pig.

Annex 9: Summary of microbial, chemical, and allergenic risks from insects as food and feed

Table 20: Summary of microbiological, chemical, and allergenic risks from the use of waste-fed farmed insects as animal feed and human food. This table has predominantly been populated using information from the European Food Safety Authority (2015)[226] and Gold et al. (2018).[247] Abbreviations: BPA = bisphenol A, PCB = polychlorinated biphenyl.

		How could this get into an insect farm?	Risk in animal feed and human food
Microbiological	Bacteria	Insects may carry insect-infecting pathogens or pathogens may be introduced through feedstock or during processing, handling, and storage.	Vertebrate-infecting pathogenic bacteria and viruses introduced through the feedstock could be taken up by insects during feeding or carried on the outside of their bodies. In this case, insects could be passive vectors of these bacteria and viruses. Pre-treatment or tight control of the feedstock and processing of insects (e.g. heat treatment) can mitigate this risk. While some insect species are known to be active vectors of viral diseases affecting humans and animals (e.g. mosquitoes as active carriers of dengue fever virus), none of the insect species commonly raised for feed or food are known to be active viral disease vectors.
	Viruses		
	Parasites		Insects can harbour parasites and transfer them to organisms that eat them. There are several documented cases of human infections arising from insect consumption, but only for wild harvested insects, not farmed ones. A properly managed closed farm environment would lack all the hosts needed for parasites to complete their lifecycle, mitigating this risk. Insect processing before consumption can further reduce potential parasitic risks.
	Fungi		Insect-infecting pathogenic fungi can infect immunocompromised individuals. Insects can also be carriers of fungi and yeasts with potential hazards to humans and animals. However, fungal risks can readily be mitigated through hygiene measures throughout the production chain.
	Prions (see annex 7)	Insects don't have the protein which forms the infectious particle of prion diseases, so the only way prions could be introduced is through the feedstock.	Insects can be mechanical vectors for prions introduced through the feedstock (e.g. a lab study showed that *Sarcophaga* carnaria, a meat-eating fly, can spread scrapie if raised on infected hamster organs and subsequently fed to uninfected hamsters). Apart from ultra-high heat, which is often impractical, the only way to effectively mitigate this risk is to avoiding raising insects on potentially prion-containing feedstock and/or to only allow insects raised on potentially prion-containing feedstock to be fed to animals that aren't known to experience prion diseases or to animals of different species to the potential prion source (given prion diseases are usually less infectious to individuals of another species).
Chemical	Heavy metals and arsenic	Heavy metals and arsenic could be introduced through contaminated feedstock.	Heavy metals and arsenic can be taken up by insects from feedstock, and some may bioaccumulate (esp. cadmium), although this depends on the production method, substrate, stage of harvest, insect species, and metal in question. The risk of heavy metals and arsenic being taken up by insects is best managed through feedstock control.

		How could this get into an insect farm?	Risk in animal feed and human food
	Insect toxins	Insects can produce toxins or accumulate them from feedstock, an adaptation that many insects have evolved to for self-defence.	For the main insects farmed for animal feed or human food, there are no indications that they excrete reactive, irritating, or toxic substances at the life stage of consumption. However, not all insect toxins are excreted: some are only toxic after ingestion. Toxicological tests of whole insects or insect proteins are lacking, so we don't know if there is a 'toxic dose' of certain insects.
	Mycotoxins	Poorly stored feedstock can harbour mycotoxin-producing fungi. Fungi infecting insects can also produce mycotoxins.	As with heavy metals and arsenic, the accumulation of mycotoxins produced by fungi in the insect gut and/or feedstock likely varies depending on the production method, substrate, stage of harvest, and insect species, and the mycotoxin in question. Mycotoxins don't accumulate in black soldier fly larvae, based on a limited number of studies.
	Pharmaceuticals and hormones[s]	Pharmaceuticals and hormones can be introduced through feedstock containing material of animals treated with veterinary drugs or raised using hormones, or from human biosolids. In addition, insects (and farming equipment and enclosures) may also be treated with biocides and antibiotics during husbandry.	Residues of veterinary drugs introduced through the substrate can accumulate in insects, as can veterinary drugs and antimicrobials used during insect production. Limited available studies demonstrate that selected pharmaceuticals and veterinary medicines don't accumulate or exist below the limits of detection. The possible presence of pharmaceuticals and hormones in insects can be mitigated by testing insects for drugs and hormones as with other animal products intended for feed and food.
	Other	Other contaminants such as pesticide residues, dioxins, polyaromatic hydrocarbons, and packaging contaminants could be introduced through the feedstock.	Pesticide residues can be present on feedstock but accumulation in insects has been found to be negligible, based on limited available studies. The same is true to dioxins, dioxin-like PCBs, and polyaromatic hydrocarbons. There is a lack of data on the transfer of packaging-related chemicals (e.g. inks, BPA, etc.) to insects raised on feedstock containing packaging.
Allergenic	Various (glyco)proteins	Some of the proteins that make up the bodies of insects could have allergenic properties, either serving as 'new' allergens or being equivalent to allergens known from other food types.	Human allergies to insects from bites/stings are well known, and inhalation and contact allergies have also been reported. In addition, consumption-based allergic reactions have been reported, incl. anaphylactic shock. As well as being a source of 'new' allergens, some insects for human food have proteins that are similar to allergens known from other contexts or products (e.g. based on protein similarities, allergies to dust mites and shrimp may predict allergies to consumed insects, allergies to crustaceans may predict allergies to crickets). In addition, chitin (part of the exoskeleton of insects) is not an allergen itself but can modulate the immune system and have consequences for the expression of allergic reactions to other allergens. Like humans, animals can have allergies. However, to our knowledge there are currently no documented allergic reactions in animals fed on insects.

[s] NB: Growth promoting hormones are used widely in animal husbandry in some countries but are not generally used in New Zealand livestock.

Annex 10: Digestate and compost use and regulation – international insights

Table 21: Highlighting the regulations which dictate the legal status and/or quality criteria for compost and digestate in multiple countries. Note, for many countries listed below an estimate of the number of 'biogas' plants is provided, a number which typically includes AD facilities that process manure, food waste, agricultural residues, and other organic waste streams, wastewater treatment plants that process sewage sludge, and landfills that capture biogas from degrading organic waste. Where available, data highlighting the volumes and end uses of digestate and compost is provided.

Country	Standards and regulations	Regulatory context	Production and use
Australia	*Compost Standard AS4454*[695]	There are no national processing guidelines that cover the use of digestate.[695] Some guidance is emerging at state level, e.g. in Victoria.[696]	As of December 2016, there were an estimated 242 biogas plants operating in Australia, the majority of which were landfill and wastewater plants. Agricultural AD plants primarily digest pig, cattle, and poultry manure.[697] There is little information regarding the end-fate of digestate produced in Australia, although the lack of regulation around digestate suggests it goes to waste destinations (wastewater treatment plants and landfill) rather than being used in agricultural settings.[698] Approximately 7.5 million tonnes of organic waste is 'recycled' in Australia annually, of which 40% is turned into composted soil conditioners and 11% becomes composted mulches.[699] A variety of compost-based products are produced commercially in Australia from household collection of green wastes, including soil conditioners, mulches, garden soils, top dressing soils, and potting mixes.[700]
Canada	*Federal Fertilizer Act*	Both compost and digestate are regulated as fertilisers in Canada. A specific section (T-4-120) of this act addresses composts.[701] Additionally, the Canadian Biogas Association has created a *Digestate Management Guide*[702] while the Compost Council of Canada has created the Compost Quality Alliance certification system.[703]	The Canadian Biogas Association lists some 300 operational biogas plants across Canada, most of which are part of wastewater treatment facilities and landfill gas capture systems. Some 50 plants digest agricultural and industrial sources of organic waste.[704] Canada's AD sector produces over 1.2 million tonnes of digestate annually, with direct application to land being the most common use as a liquid fertiliser.[702] However, we did not find data quantifying the end destinations of digestate in Canada. Canadian households diverted 2.3 million tonnes of organic waste from landfill in 2018, although it is unclear how much of this waste was composted. However, indications are that Canadians regularly send their food waste to compost; 76% of households composted their kitchen or yard waste in 2019.[705] Primary markets for compost in Canada include landscapers, commercial nurseries, home gardeners, and a few farmers, while some municipalities sell or give compost to their residents.[703]
China	*NY/T 2065-2011* Technical specification for biogas fertilizer application[706] *NY/T 525-2021* Organic Fertilizer	*NY/T 2065-2011* set standards for process conditions, chemical properties, and pollutants for producing biogas fertiliser (digestate) from biogas digesters. It is applicable to digestate produced by household	China's biogas approach is notably different to other countries listed in this table, as they have focused on AD at local scales. As of 2014, there were anaerobic digesters in 41.93 million households, as well as 257,000 small-scale plants, and 103,500 medium-scale plants (which, for reference, can generate 0.5 m^3 of biogas per day).[538] As such, the vast majority of China's digestate output come from households, with little coming from agriculture or industry (although the agricultural share is increasing in recent

Country	Standards and regulations	Regulatory context	Production and use
	A range of waste-sorting laws[t]	biogas fermentation. For commercialised organic fertilisers (including digestate and compost from larger scale facilities), the Organic Fertilizer standard applies. The use of organic fertilisers is on the rise in China, a trend driven by the Chinese government's initiative to partly substitute chemical fertilisers with organic ones as of 2015.[707] By 2025, the Chinese Ministry of Agriculture and Rural Affairs plans to increase the use of organic fertilisers by >5% (relative to the 2016-2020 period), cutting back on chemical fertilisers in the process.[708]	years).[538] Digesters across the country produce an estimated 71 million tonnes of digestate each year, which is typically applied directly to land in rural areas and sometimes mixed with other nutrients in commercial settings.[538] Digestate produced from larger-scale facilities is typically split into liquid and solid fractions, with the latter predominantly going to landfills.[442] As of 2020, China sent roughly 5% of its municipal solid waste to compost treatment plants. The amount of compost produced in China is unclear, although a 2007 estimate by the Ministry of Agriculture suggested that some 1,580 'organic fertiliser factories' produced 9.87 million tonnes of organic fertiliser in 2006.[709] This estimate includes, but is not limited to, the production of compost.
EU	*EU fertiliser regulation (EU 2019/1009)*[710] Additionally, a variety of other EU directives[u] regulate environmental pollution in agricultural settings, which can be of relevance to compost/digestate application to land.[361] At a national level, individual countries implement additional regulations and guidelines. Examples from Austria, Germany, Ireland, Italy, and the Netherlands are listed below.	The recently enforced Fertiliser Regulation widened the scope of fertilisers to include organic fertilisers such as digestate and compost. The Regulation lays down common rules for safety, quality, and labelling requirements for fertilising products, and introduces limits for known toxic contaminants for the first time.[710]	There are roughly 18,000 biogas plants across Europe.[711] Biogas plants within the 27 members states of the EU produce an estimate 176 million tonnes of digestate annually, a figure which includes agricultural digestate (120 million tonnes), mixed municipal solid waste digestate (46 million tonnes), and digestate from source-separated biowaste (7 million tonnes), agro-food industry (1.7 million tonnes), and sewage sludge (1.7 million tonnes).[712] The vast majority of digestate is used directly as a fertiliser.[712] Commercial composters from the 27 members states of the EU produce an estimated 17.6 million tonnes of compost annually, a figure which includes compost produced from sewage sludge (approx. 800,000 tonnes).[414,712] The vast majority of compost (approx. 14 million tonnes) is derived from green waste and separately collected biowaste. It is estimated that the majority (approx. 85%) of compost is used as a fertiliser or soil improver in agriculture, gardening, horticulture and landscaping.[712]

[t] See Table 1 in Cui et al. (2023) for an extensive list of laws and policies relating to waste sorting in China that influence the production of compost.
[u] These directives include the Nitrates Directive, IPPC Directive, the NEC Directive, the Water Framework Directive, and the Guidance document on ammonia emissions from agricultural sources. Kovačić et al. (2020) explore these directives and their implications in detail in their review of digestate management in Europe.

Country	Standards and regulations	Regulatory context	Production and use
Austria	*Fertilizer Law*, 1994[713] *Fertilizer Regulation*, 2004[713] *Compost Ordinance Regulation No. 292 of 2001*[714]	Austria has *Compost Ordinance Regulation No. 292 of 2001* (currently under revision) under the umbrella of the waste management law, which defines input materials, quality criteria, etc., to produce compost as a product. Digestate has no legal end-of-waste ordinance, and instead falls under fertiliser regulations, which has standards, as well as guidelines from the Ministry of Agriculture.[714]	Austria produces approx. 1.5 million tonnes of digestate[713] from approx. 444 biogas plants[711]. There is little data available to elucidate the end-fate of this digestate, although its regulation as a fertiliser means it can be applied to land as a 'biogas slurry'.[715] There is inconsistent evidence regarding the volumes of compost produced in Austria. The European Compost Network (ECN) estimated in 2019 that 402 compost plants in the country process 1.25 million tonnes of organic waste.[715] A separate market analysis in the same year suggested that Austria produces 300,000 tonnes of compost annually.[712] ECN data suggest that compost use is dictated by its grade; with higher grades (A+ and A) being used for hobby gardening, plantations, and agriculture, while all grades (A+, A, B) are used in landscape gardening and maintenance.[715] How much compost goes to which market is unclear.
Germany	*2013 Ordinance on the Recovery of Bio-waste on Land Used for Agricultural, Silvicultural and Horticultural Purposes (Biowaste Ordinance – BioAbfV)*[716] *German Fertiliser Ordinance* *German Quality Assurance for Compost* (Bundesgütegemeinschaft Kompost, BGK)	The *Bio-waste Ordinance* defines the legal status of biowaste and garden waste, but where compost and digestate meet BGK standards they are no longer considered 'waste' but rather a product.[714] However, where compost is applied to soils, the *German Fertiliser Ordinance* sets specific regulations. The BGK operates a voluntary quality assurance certification for both compost and digestate.	There are 10,846 biogas plants in Germany[711] which produce an estimated 87 million of tonnes of digestate annually.[712] Germany's digestate output accounts for almost half of the EU's total digestate production. Approximately 97% of digestate produced is used in agricultural settings, with the rest being used in landscaping and for other purposes like landfill cover.[717] Some 171 AD facilities produce BGK-certified digestate.[717] Commercial compost production in Germany is estimated at 4.3 million tonnes per year.[712] Compost produced is largely used in agricultural settings (59%), but also to create soil products (19%), for landscaping (8%) and for hobby gardening (7%), among other uses (7%).[712]
Ireland	Statutory Instrument 248/1978[714] - Marketing of fertilisers and liming materials not covered under EU regulations	*Irish Fertiliser Regulation S.I. 248 of 19787* is under review, with a view to updating to provide end-of-waste criteria for the domestic market for compost and digestate.[714] This review is in alignment with Ireland's updated 2020 waste policy *A Waste Action Plan for a Circular Economy*.[718]	There are 29 biogas plants in Ireland[711] which produce an estimated 400,000 tonnes of digestate annually[712], of which 123,000 tonnes were from source-separated materials[714]. The primary end market for source-separated digestate is grasslands/pasture (72% of digestate produced).[714] Commercial composting facilities in Ireland produce approx. 100,000 tonnes of compost annually[712], of which 84,000 tonnes are from source-separated materials.[714] The primary market for compost derived from brown bin material (green and food wastes from households) is tillage.[714] Compost is seldom used in grassland, although the are a number of higher value markets developing in garden centres and landscaping.[714] Landscaping is also the primary market for composts derived from garden material and sewage sludge.[714]

Country	Standards and regulations	Regulatory context	Production and use
Italy	*Fertiliser Legislative Decree 75/2010*[714] Ministerial Decree 2016 for the production and use of agronomy of digestate[719] CIC Quality Assurance Scheme	Compost and digestate must be registered under national fertiliser regulations as an organic fertiliser or soil improver before it can be used. The Fertiliser Regulation covers compost. For digestate from waste feedstocks it must be composted to receive 'product' status (i.e. no longer considered a waste stream). For digestate from farm biogas plants, there are no (national) quality standards; since 2016, there have only been rules for its storage and application.[714] According to the Ministerial Decree of 2016, digestate produced from food waste is (still) considered as a waste product, requiring an aerobic step in order to turn it into compost, which can be marketed freely. However, the Decree reclassified digestate from on-farm AD plants as a 'sub-product' rather than a waste product.	There are approx. 1,600 biogas plants in Italy,[711,720] which produce an estimated 30 million tonnes annually.[712] Some 47 of Italy's AD plants treat mainly food waste or biowaste, while the vast majority (1,466) are on-farm plants that treat animal manure and forestry-agricultural by-products[720]. AD plants treating food and green waste in Italy separate the digestate into solid and liquid fractions. According to the World Biogas Association, the solid fraction is typically composted to produce a soil improver, while the liquid fraction is either recirculated in the plant or sent to a wastewater treatment plant. By contrast, digestate slurries produced in on-farm biogas plants is generally directly applied to farmland as a fertiliser.[720] Commercial compost production in Italy produces an estimated 2.2 million tonnes of compost annually.[712] Two-thirds of compost production takes place at composting plants, while the remaining third occurs at biogas facilities.[721] Half of all compost produced is certified under the voluntary label 'Compost Qualità CIC'. About 75% of compost produced in Italy is used in agriculture or horticulture, while the remaining 25% is sold for gardening or landscaping applications.[722]
Netherlands	*The Manure and Fertilisers Act 2016*[714] *The Dutch National Waste Management Plan (LAP)*	Compost and digestate must be registered under national fertiliser regulations as an organic fertiliser or soil improver before it can be used. Once organic waste has been converted to compost and has been tested to comply with the fertiliser regulation, it falls under the scope of that regulation (if it does not comply, it falls under waste legislation).[714] Under fertiliser regulations, the feedstocks used in AD dictate their land application. Digestate derived	There are some 260-270 biogas plants in the Netherlands,[711,723] of which 11 digest 'biowaste' (food waste from various sources), while the majority treat agricultural feedstocks (mostly manure) and wastewater.[724] AD plants across the Netherlands produce an estimate 2.9 million tonnes of digestate, the majority of which is used in agriculture as a fertiliser.[712] Commercial compost production in the Netherlands produces an estimated 1.4 million tonnes of compost annually.[712] The majority of compost derived from household biowaste goes to agriculture (77%) and to potting soil substrates (15%).[725]

Country	Standards and regulations	Regulatory context	Production and use
		from household biowaste, or food waste, must be composted (and is then designated as a compost product). Digestate derived from at least 50% manure (and a maximum of 50% of other organic residues) can be used directly on land and is classified as animal manure.[714]	
Norway	*Regulations for Organic Fertilisers, FOR-2003-07-04-951* (under revision)[714,726]	In Norway, compost and digestate must be registered under the national fertiliser regulations as organic fertiliser or soil improver before it can be used. Once registered, compost/ digestate is a product and has ceased to be waste, i.e. it is given de facto end-of-waste status.[714]	Estimates for the number of biogas plants in Norway vary widely, from 40 – 123 plants.[711,727] The disparity in estimates appears to be driven by the scale at which the plants operate, and whether to count small-scale plants. Only 17 plants are considered to produce enough biogas and biomethane to influence markets and be captured by Norwegian statistics.[723] Of these 17 plants, the main feedstocks are sewage sludge (50%) and industrial solid waste containing mainly food waste (33%), with other smaller percentages for manure (2%) and other type of feedstocks (15%).[723] We did not find information on the total volume of digestate produced in Norway, nor digestate end markets. There are approximately 40 commercial-scale composting plants in Norway, which treat food, sludge, and garden waste.[727] An estimated 228,000 tonnes of household biowaste (including garden waste) was sent to composting in 2016.[727] We did not find information on the total volume of compost produced in Norway, nor compost end markets.
Sweden	*SJVFS 2004:62 (manure regulations)* *SNFS 1994:2 (metals regulations)* *Certifierad återvinning (SPCR 120, SPCR 152)*	The use of digestate and compost as fertilisers or soil amendments is not regulated by specific fertiliser-targeted legislation in Sweden[728]. Instead, the regulation of the land application of these products falls under legislation for manure and sewage sludge, which capture nutrient loading and metals application respectively.[728] Additionally, there is a quality assurance scheme *Certifierad återvinning (Certified Re-use)* to certify the quality of digestate *(SPCR 120)* and compost *(SPCR 152)*.	There are an estimated 282 biogas plants in Sweden.[711] In 2021, Sweden produced 1.7 million tonnes of digestate from source-separated waste,[729] although the amount of digestate produced from agricultural sources like manure is unclear.[729] Of the 1.7 million tonnes, 408,000 tonnes of digestate were from municipal food and garden waste.[729] Of digestate produced from source-separated waste, some 99.8% is used in agricultural land, with 37% approved for use in organic production.[729] Commercial compost production in Sweden produces approx. 311,000 tonnes of compost annually, as per a 2019 estimate.[712,729] In 2015, there were an estimated 40 commercial composters in Sweden.[728] As of 2015, just one composting plant produced compost to the standard specified by *SPCR 152*. Commercial-scale composting of food waste is increasingly uncommon in Sweden, with just 8,300 tonnes of municipal food waste going to composting plants in 2021.[729] However, Swedish authorities estimate a current home-composting capacity of 48,000 tonnes.[730]

Country	Standards and regulations	Regulatory context	Production and use
Switzerland	*Regulation on the Marketing of Fertilisers, 2001*[714]	Compost and digestate must be registered under national fertiliser regulations as an organic fertiliser or soil improver before it can be used. The fertiliser law thus defines when compost/digestate is no longer a waste and is a product instead.	In 2021, there were 418 active biogas plants in Switzerland, which primarily process sewage sludge (4 million tonnes), agricultural residues such as manure (1 million tonnes), organic municipal solid waste (734,000 tonnes), and industrial wastes (250,000 tonnes).[723] AD plants in Switzerland produce an estimated 1.7 million cubic metres of digestate, that includes 628,100 of whole, non-separated digestate, 360,000 of separated liquid digestate, and 156 of separated solid digestate.[723] In 2021, 341,785 cubic meters of compost was produced from digestate, with an additional 206,000 cubic meters where composted and blended with earth.[723] Most digestate produced in Switzerland is used directly as a biofertiliser in agricultural settings, with a small amount specifically used in horticulture.[723] Recent data on composting statistics in Switzerland is limited. As of 2013, there were approximately 260 composting plants in the country, which processed roughly 600,000 tonnes of biogenic waste annually. The majority of compost produced goes to agriculture (approx. 250,000 tonnes), with a further 120,00 tonnes used in horticulture.[731]
Japan	*Food Recycling Act, 2001* *Food Loss Act, 2019* *Water Pollution Prevention Act 1970* (last amended in 2016) *Fertiliser Regulation Act 1950* (last amended in 2019)	Japan's *Food Recycling Act*, introduced in 2001, promotes reducing and recycling food wastes into fertiliser and feed, and obligates businesses that promote large amounts of food waste to take measures to reduce and recycle the waste and report their food waste situation to the government.[732] There are no special restrictions on digestate as a fertiliser in Japan, although digestate discharged to public sewers or rivers must meet wastewater standards set out by the *Water Pollution Prevention Act*.[733] *The Fertiliser Regulation Act* regulates the quality and safe application of fertilisers in Japan, including 'special fertilisers' like compost. It is unclear if digestate is included as a special fertiliser.	As of 2019, there are more than 200 biogas plants operating in Japan, most of which are either situated within wastewater treatment plants or on farms. A few centralised digesters process food waste from municipalities, although data on the exact number of these facilities is unavailable.[734] Feedstocks are dominated by sewage sludge and manure, but the proportion of industrial waste and food scraps is increasing.[734] We did not find data on total volume of digestate produced in Japan. Of 170 registered food waste recycling plants in Japan, 108 are composting facilities.[734] As of 2019, 90% of livestock manure in Japan was composted.[734] We did not find data on the total volume of compost and its exact end markets in Japan.
New Zealand	*NZS 4454:2005 Composts, soil conditioners and mulches*.[735]	Standards for compost production in NZ are voluntary. Currently, there are	NZ has some 33 facilities which produce biogas, the most common of which are associated with landfill gas capture (14) and waste water treatment plants (13).[63] Of

Country	Standards and regulations	Regulatory context	Production and use
	There are national guidelines under development,[74] and work is ongoing to create a digestate accreditation scheme.[736]	no standards which specifically apply to digestate. There are guidelines on the safe application of biosolids to land,[737] which are relevant to land spreading of digestate and compost. These guidelines are set to be superseded by a new set of guidelines,[74] which are under discussion, on the beneficial use of organic materials on land. Additionally, the Bioenergy Association of New Zealand has developed its own guidelines for the production and use of digestate as a biofertiliser.[434] Currently, there are no specific national regulations for digestate use and digestate is managed as a waste product.[430]	the remaining facilities named in an industry stocktake, two AD facilities process manure, two of which process industrial effluents, and processes municipal organic waste (Ecogas).[63,430] The total volume of digestate produced by these plants currently is unclear but estimates suggest some 192,000 wet tonnes of digestate are produced at wastewater treatment plants annually.[430] According to industry estimates, some 68% of digestate solids produced at wastewater treatment plants are used for landfill cover, quarry infilling, agricultural land or forestry.[430] BECA estimate that there is potential to produce some six million tonnes of digestate annually in NZ, if the country made use of all the available agricultural feedstocks (dairy manure, pig manure, poultry manure, crop residues, and source-segregated food waste). Given the absence of a regulatory framework, digestate is currently seldom applied to land in NZ and is typically sent to wastewater treatment plants.[430] Trials are ongoing at Ecogas,[450] with plans to apply digestate to farmland in accordance with N limits set by NZ's synthetic fertiliser cap.[410] Currently, decisions on the dispersal of digestate to land lie with regional councils, who determine if it's a permitted, controlled, or discretionary activity (and hence whether a resource consent is required). The annual amount of compost produced in NZ is unclear. A recent national stocktake[63] suggests that NZ produces approx. 4 million tonnes of organic waste each year, 10% of which is made up of 'putrescibles', a category which includes food waste. Some 62 large-scale facilities process organic waste, of which 25 are windrow-composting operators, nine are in-vessel composters, seven are vermicomposters, and five are aerated-windrow composting operators. Additionally, there are numerous smaller-scale composters operating within communities, which process about 5% of the overall food waste recovered. There is little data to show how compost is used in NZ and where it goes proportionally, but anecdotal evidence suggests it is primarily used in urban gardens, in landscaping, on farms, and as cover fill for landfills.[738]
South Korea	*Fertiliser Control Act* Ministry of Environment (MoE) Guidelines	The purpose of the *Fertiliser Control Act* is to promote agricultural productivity and protect the agricultural environment by regulating the quality of fertiliser, including 'by-product' fertilisers derived from human excrement, food waste, and agricultural outputs. The Act enforces legal standards imposed by the Minister of Agriculture and Forestry that dictate product quality, contaminant loading, and the	As of 2014, South Korea had 82 biogas plants. Of these 38 are AD plants which process sewage sludge, 16 which process bio-waste, and seven which process agricultural feedstocks. An additional 21 plants are biogas plants located at landfills. The end fate of digestate depends on feedstocks. Dewatered digestate produced from sewage sludge is either sent to landfill or incinerated, while the liquid component is sent to wastewater treatment plants. Dewatered digestate from biowaste is either landfilled, incinerated, or sent for composting, while the liquid component is either sent to wastewater treatment plants or used as a liquid fertiliser in agricultural settings. Digestate slurry produced from agricultural residues like manure is used as a liquid fertiliser.[740] We did not find data on the total volume of digestate produced in South Korea.

Country	Standards and regulations	Regulatory context	Production and use
		content proportions of fertilisers. Guidelines from MoE aid in standardised food treatment approaches and the quality of outputs.[739]	South Korea has an excellent reputation for composting and converting their food waste[530,741,742], with 250 food waste treatment plants nationwide, of which approx. 80 are composting facilities[739]. We did not find nationwide data on compost production, although data available from the country's capital, Seoul, suggests it is a commonly used process. Of the 3,000 tonnes of food waste produced daily in Seoul in 2017, 30% was sent for composting (with 60% going to animal feed and 10% to AD). The majority of compost produced is used in farmland.[739]
UK	Quality protocol: anaerobic digestate[743] Quality protocol: compost[744] *BSI PAS 110*[441] *BSI PAS 100*	Quality protocols for compost and digestate are within the framework of government protocols for converting waste into non-waste products. Importantly, protocols are not mandatory, rather an avenue to produce high quality products from waste materials to promote greater resource recovery. Where quality controls are met, both compost and digestate are considered 'fully recovered' and are not classified as waste. Where quality protocols are not met, digestate and compost are considered to be waste and waste management controls[745] apply to their handling, transport, and application. PAS110 is a set of standards which provide the baseline quality specification for digestate, to ensure its safe and reliable use. PAS110 is used as part of the Biofertiliser Certification Scheme[746], a private and independent scheme to assess and certify digestate quality. Similarly, PAS100 provides standards for compost, and is part of the Compost Certification Scheme[747].	The UK has over 600 operational AD plants.[446] Energy crops (30%) and food waste (29%) are the most common feedstocks used in these AD plants,[748] with operational capacity for 3.2 million tonnes of food waste annually.[749] Close to two million tonnes of digestate accredited under the Biofertiliser Certification Scheme (BCS) are produced in the UK every year,[441] although estimates of total digestate production (approx. 7.5 million tonnes in 2018) indicate that the majority of digestate is unaccredited and is handled under waste management controls.[749] BCS-accredited digestate is used as renewable fertilisers in agriculture, field-grown horticulture, forestry and land restoration.[441] Unaccredited digestate is largely applied to non-horticulture agricultural land, with a small amount used as cover fill in landfills.[750] Commercial compost production in the UK is estimated at 2.8 million tonnes per year[712], with some 272 permitted composting sites registered in 2019.[749] The operational capacity of the composting industry was estimated to be 6.8 million tonnes in 2018, with an estimated 2.7 million tonnes of compost produced in 2018. In 2019, there were 137 PAS100 certified composters, which produced approx. 1.6 million tonnes of certified compost.[750] The majority of compost produced (70%) is reported to go to agriculture and field horticulture, while 11% went to horticulture and growing media, and a further 11% to landscaping.[750]

Country	Standards and regulations	Regulatory context	Production and use
US	EPA guidelines on composting (but typically managed on a state-by-state basis) NRCS Nutrient Management code 590 Biogas Council's Digestate Standard Testing and Certification Program – voluntary standard[751]	NRCS Nutrient Management code 590 regulates the application of manure, digester effluent (digestate), fertilisers and other sources of nutrients.[752] Additionally, individual state laws govern inputs to soils.	The US has more than 2,300 biogas plants producing biogas in all 50 states: 475 digesters on farms, 1,269 water resource recovery facilities using an anaerobic digester, 97 stand-alone systems that digest food waste, and 549 landfill gas projects.[753] The US EPA states that digestate can be directly land applied to as a fertiliser and be further processed to make products like bedding for livestock.[754] While there is qualitative evidence that digestate (in particular manure-derived digestate) is applied to land as a fertiliser in the US,[755] we did not find data quantifying the amount or end destinations of digestate. US landfilled or incinerated >50 million tonnes of compostable waste in 2015. While there isn't a recent estimate of US's commercial compost production, compost production is undertaken at city level. For example, the state of San Francisco composts approx. 250,000 tonnes of organic material each year.[756]

Annex 11: New Zealand’s energy profile and the wider applications of energy-from-waste technologies

To transition away from fossil fuel use, Aotearoa will need to make use of more renewable energy sources such as biomass. This could include energy from food waste. Waste to energy based on fossil hydrocarbon feedstocks, such as waste plastics, are not considered or discussed in this section.

What does Aotearoa’s energy profile look like, and is there room for energy from waste?

The most recent MBIE annual reporting on energy use in New Zealand[426] is useful to understand our current energy needs and the likely demand for energy from deploying FLW in EfW processes. One of the key messages of that report is that Aotearoa is not self-sufficient for energy, and in fact our energy self-sufficiency has been trending down. Another key message is that although our electricity needs are largely met by renewables, only about 30% of our total energy consumption is supplied by renewables. Figure 55 shows renewable vs non-renewable energy use by sector, with transport being the largest non-renewable category of energy use.

Transitioning transport and some industries to electricity will enable us to use renewable sources of energy instead of fossil fuels. However, some industrial uses will not easily be able to transition to renewables, as they rely on high heat that is most easily achieved by burning coal.[426] Moreover, as we successfully transition other energy demands to electricity, this will require more sources of renewable electricity.

The MBIE report also highlighted that the high proportion of electricity generated by renewables in 2022 was because hydro lakes were full; in contrast, when lakes were lower in 2021, a lower proportion of electricity was generated by renewables and New Zealand was a net importer of coal as the Huntly plant had to compensate.[426] This reflects what is known as the 'dry year problem'. Much government effort is going to identify additional ways to secure renewable energy,[757] to buffer the 'dry year' problem and to meet anticipated future demand.

EfW processes using biomass may also provide a renewable alternative to virgin natural gas (see section 4.4, Anaerobic digestion) albeit at small scale in the medium term.[758]

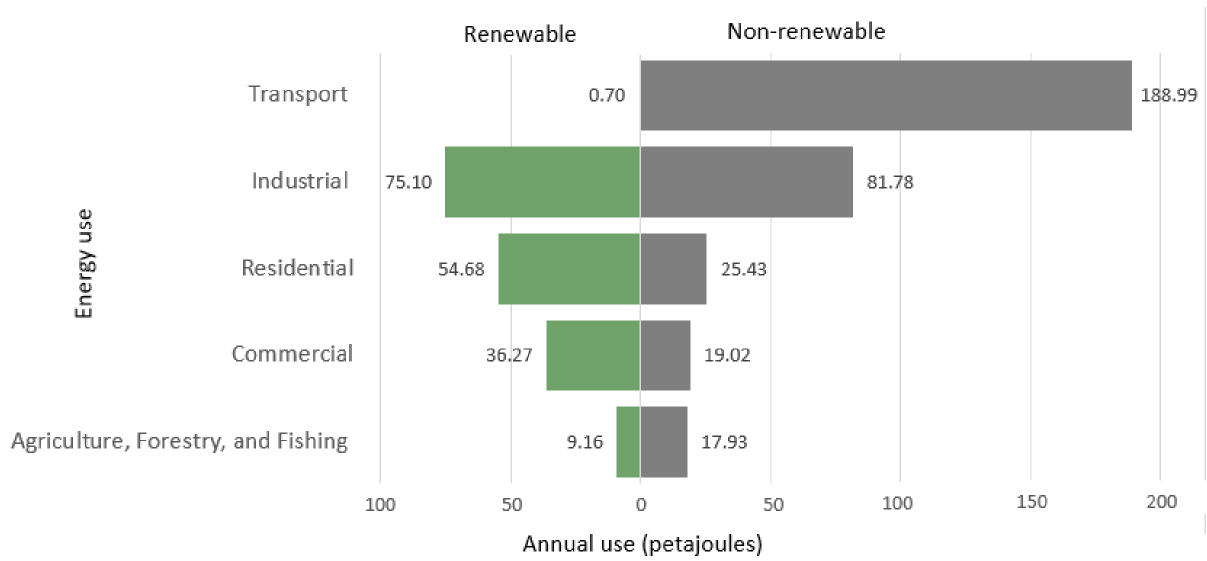


Figure 55: Renewable and non-renewable energy use in New Zealand by sector in 2022. Figure adapted from MBIE[426,759]

Figure 55 shows that there remains considerable scope for more sources of renewable energy, particularly in the transport and industrial sectors. Whether EfW – and specifically EfW using food waste as an input – offers suitable solutions is a separate question.

Waste-to-energy globally and in Aotearoa

Figure 56 and figure 57 provide an overview of trends in EfW contribution to energy and electricity generation worldwide. In 1990, biofuels and waste[v] were the source of 36 million terajoules of energy and this increased steadily to 57 million terajoules in 2020. Despite this large increase, the proportion of all energy produced from these sources declined over the same period as supply from other sources, notably natural gas and coal, increased more dramatically.

[v] This category includes industrial non-renewable waste combusted directly to produce heat/and or power; municipal renewable and non-renewable waste combusted directly to produce heat and/or power; plant matter used directly as fuel or converted into other forms before combustion and comprising materials generated by industrial processes or provided by forestry and agriculture (including manure); biogases which arise from anaerobic digestion of biomass or gasification of solid biomass (including biomass in wastes); biofuels; charcoal; and non-specified primary biofuels and waste.

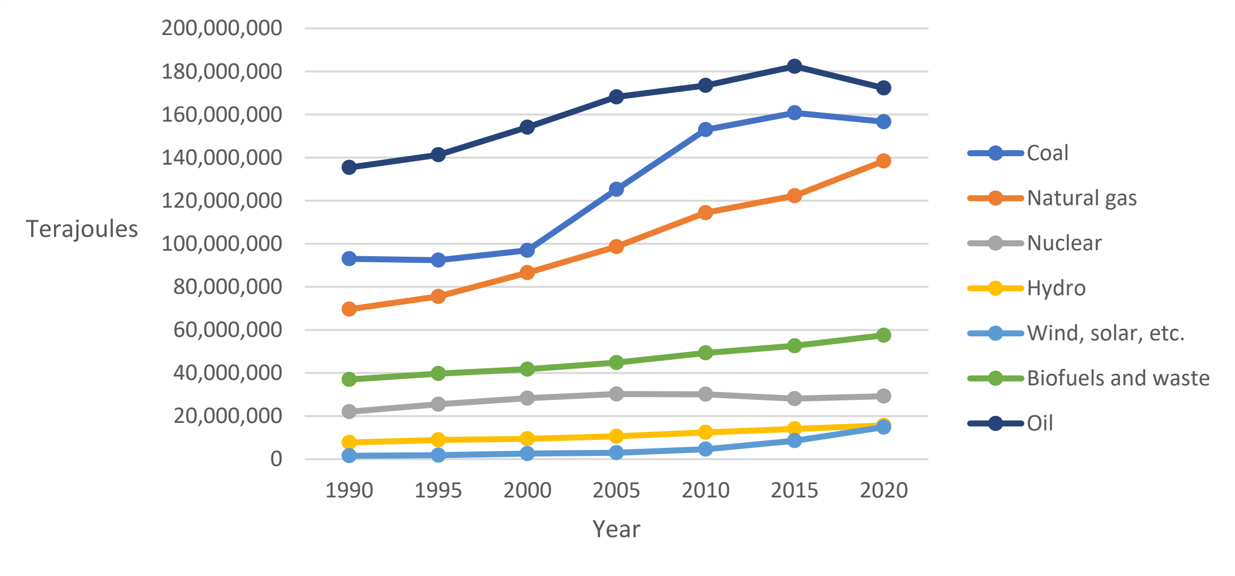


Figure 56: Trends in total energy supply globally by source, 1990-2020 Data source: International Energy Agency.[760]

Figure 57 shows trends in the global amount of electricity generated by different types of biofuels and waste. Electricity generated globally by industrial waste in 1990 was approximately 7,700-gigawatt hour (GWh) and by 2020 this had risen to approximately 37,000 GWh. Municipal waste followed a similar trajectory, rising from about 8,000 GWh in 1990 to about 38,000 GWh in 2020. The increase for biogas was greater, from approximately 4,000 GWh to about 90,000 GWh in 2020, with the fastest increase from 2005 to 2015. Data was first recorded for liquid biofuels in 1980 in 2005, at about 2,000 GWh, and electricity from this source had risen to about 10,000 GWh by 2020.[760]

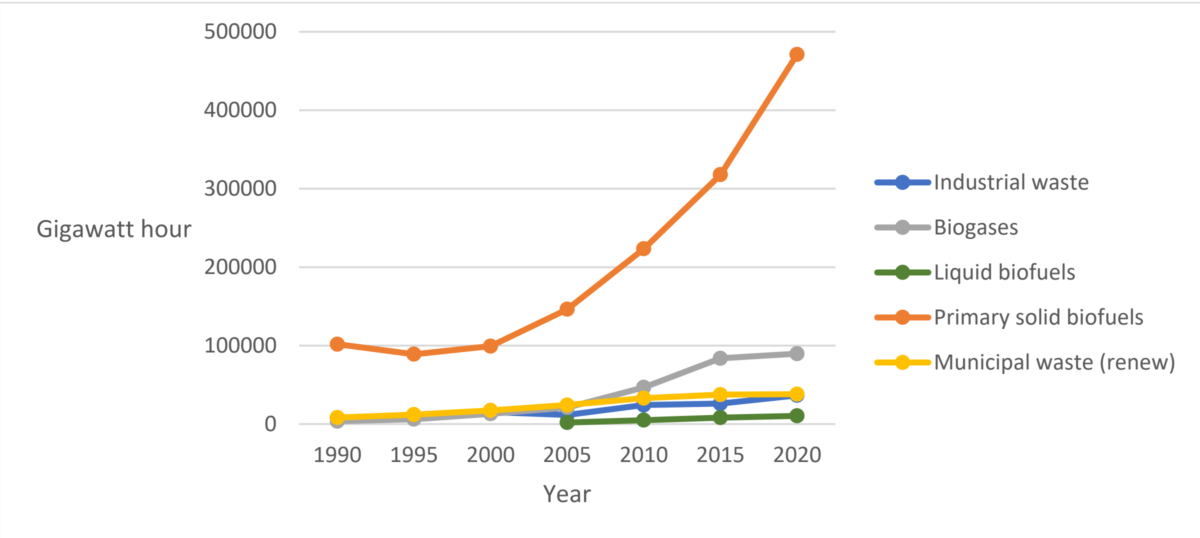


Figure 57: Trends in global electricity generation from biofuels and waste[v] (including (left) and excluding (right) primary solid biofuels) by source, 1990-2020. Data source: International Energy Agency.[760]

In Aotearoa, EfW currently accounts for a small amount of energy consumed, and this is primarily from biomass rather than technologies that may be more suited to using food loss and waste as inputs (see figure 58).

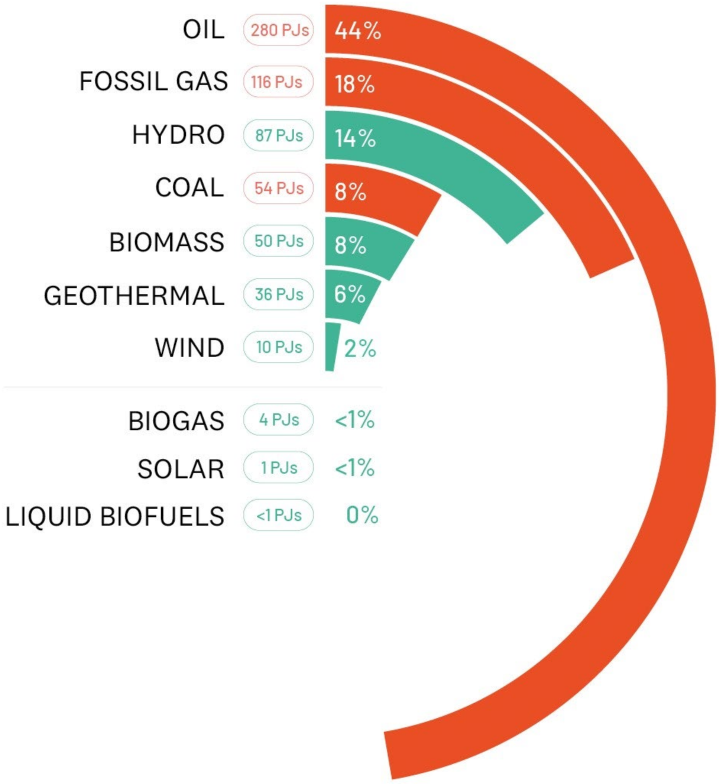


Figure 58: Primary energy consumption in New Zealand in 2021. Abbreviations: PJ = petajoules. Image credit: Energy Efficiency and Conservation Authority.[761]

But EfW facilities are coming online in Aotearoa. Ecogas has been given a 20-year contract to process all of Auckland's household food waste (see case study 15) using AD. Other AD facilities (as of 2019) are shown in figure 59; none apart from the Ecogas facility in Reparoa use food waste streams.

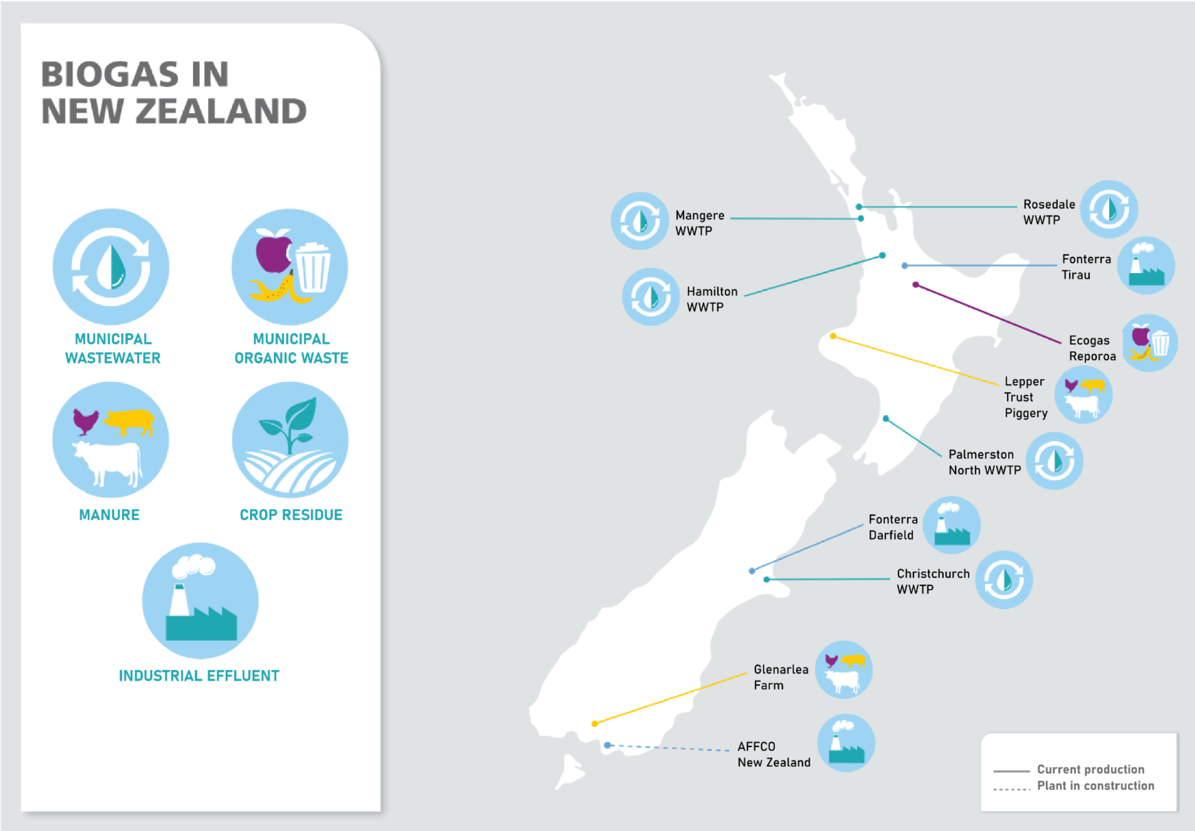


Figure 59: Biogas from AD in NZ. Figure from BECA,[430] amended to reflect that Ecogas is operational as of 2023.

Further context on anaerobic digestion

Internationally, AD is well-established and widely practiced approach to treating and capturing value from FLW feedstocks[31,762], often in concert with digestion of other waste materials, such as manure from livestock.[724,734,763] Broadly, there are four types of AD facilities that process, or co-process, FLW[31]: industry-dedicated stand-alone digesters, which are typically located at food processing facilities where the feedstock is well-controlled and characterised; multi-source stand-alone digesters (sometimes called 'merchant digesters'), which process food waste and other feedstocks from sources across their region; digestion systems at wastewater treatment plants, which process wastewater solids that can include food from household sinks or drains at food-processing facilities; and digestion systems on farms, which process manure and agricultural by-products like crop residuals.

The key output of AD is biogas, but AD is not the only way to generate biogas. Beyond facilities which generate biogas from food streams, Aotearoa has about 30 facilities that produce biogas, Importantly, landfills with gas capture are distinct from AD facilities, although they are commonly cited together as both produce biogas from waste streams.[430] While methane produced in landfills happens under anaerobic conditions (see section 5), landfills are fundamentally different from AD facilities in their design, operation, and scope, and do not generate methane from food-based feedstocks as efficiently as purpose built AD facilities.

Another important output of AD is digestate, which may have applications as a fertiliser. The total volume of digestate produced in New Zealand is currently unclear but estimates suggest some 192,000 wet tonnes of digestate are produced at wastewater treatment plants annually.[430] According to industry estimates, 68% of digestate solids produced at wastewater treatment plants are used for landfill cover, quarry infilling, agricultural land or forestry.[430] BECA estimate that there is potential to produce six million tonnes of digestate annually in Aotearoa, if the country made use of all the available agricultural feedstocks (dairy manure, pig manure, poultry manure, crop residues, and source-segregated food waste, see section 4.4).

Further context on incineration

We include incineration here as it's a commonly used approach for energy recovery from municipal solid waste internationally (see figure 60), of which food waste is often a significant fraction.[428,764] As with landfilling, the nutrients in food waste are lost when it is incinerated. Incineration also produces fly ash and flue gas, which must be cleaned before discharge, and the residues from cleaning must be dealt with, generally as hazardous waste.

The use of incinerators for municipal social waste is used globally and with China, EU (see figure 60), Japan and US having the largest capacities.[765] The use of incinerators in EfW is complex and highly-context specific, with population density and the ability to displace fossil energy generation important considerations; in New Zealand we have low population density and thus limited ability to generate the required amount of waste, as well as relatively low fossil energy generation. Swedish municipalities offer kerbside food waste collection[730] and separate waste streams management, even though they have a high reliance on incinerators (see figure 60). Malaysia, where landfill has been the dominant waste management strategy for a highly co-mingled waste (with a large fraction being food waste),[766] is working towards an integrated waste management strategy that includes the use of incinerators.[767]

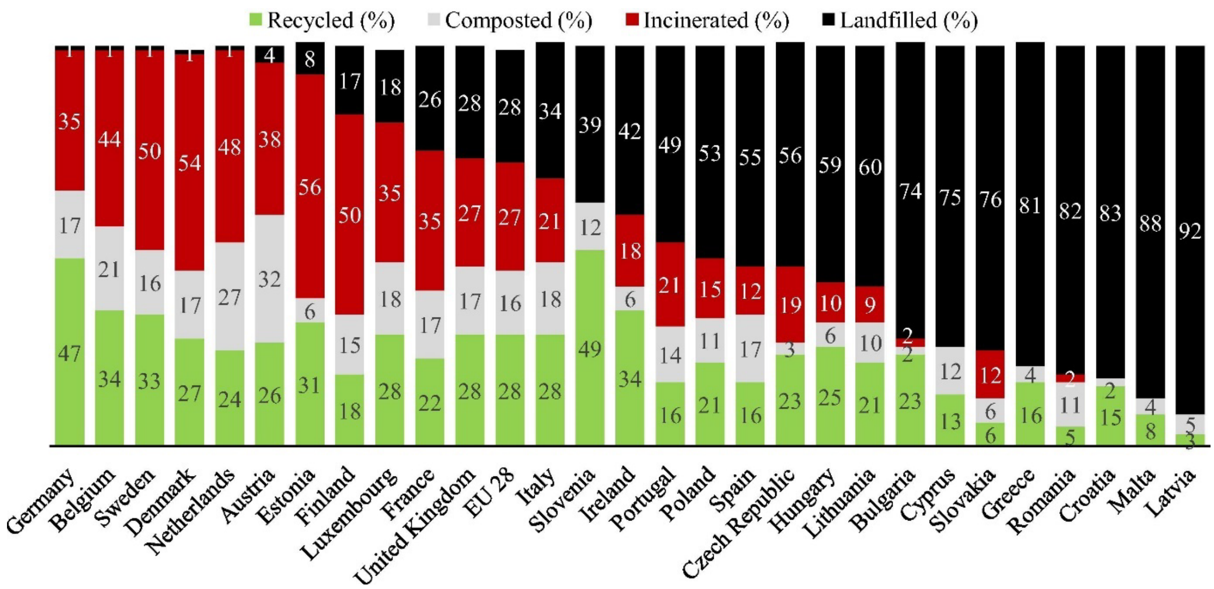


Figure 60: Municipal solid waste disposal methods in the EU 28 in 2014. EU 28 is the average across all 28 countries. Image credit: Cucchiella, D'adamo, and Gastaldi.[765]

Emissions generated from incineration of municipal solid waste are dominated by CO_2, with proportionally less methane and nitrous oxide and other substances like dioxins and furans. Furthermore, the residues produced from incineration have limited usefulness and are generally sent to landfills.[314] Alternative approaches, such as using fly ash in cement[768] and bottom ash in road construction,[769] can be complex and present environmental trade-offs.[768,770] Air pollution controls have evolved over time to include electrostatic precipitators and filters catalysts as part of the flue gas produced to reduce dioxin emissions.

Further context on pyrolysis and gasification

Instead of reducing food waste to ash and heat energy (as is the case with incineration), pyrolysis and gasification of biomass like agricultural residues, forestry waste, or other organic materials produce biochar,[474] a solid, carbon-rich product that can store C for a long period of time and potentially improve soils.[475,771] In addition, syngas (produced by both pyrolysis and gasification) and bio-oil (produced by pyrolysis) can be used as energy sources or raw materials for manufacture of useful chemicals. Pyrolysis and gasification are well-established processes for some feedstocks[576] but have only recently started to be used for organic waste, especially mixed food waste. Here we focus on the use of these processes for organic material processing only.

The main products are typically gaseous (syngas, primarily hydrogen and carbon monoxide, but also CO_2, methane, and other minor gases), liquid products (bio-oils including acids and alcohols), and solid products (carbon-rich char, as well as ash, tars, other residues). The resulting biochar and syngas both offer economic and environmental advantages including the potential to displace fossil derived fuel sources. The composition and properties of the feedstock must be understood to evaluate the environmental impact of these processes.

Pyrolysis plants have been built in Canada, US, Netherlands, Germany, Finland, Spain, Australia, and South Africa with some plants reaching capacities of several 1,000 kilograms per hour. Gasification is not as widely used but is being adopted in the US, Norway, and China.[772] The use of these processes for organic material processing in Aotearoa is largely limited to demonstration and pilot scale operations.[319] Large-scale pyrolysis or gasification technologies in areas outside of big cities present challenges[495] such as the need for consistent levels of feedstock for energy generation and the emissions associated with needing to transport waste from other regional councils.

Biochar, bio-oil, and syngas have many uses, and the benefits of these need to be balanced against the loss of nutrients in the food waste, so pyrolysis and gasification sit towards the bottom of the food waste hierarchy. MfE has produced a useful waste to energy guide for Aotearoa,[314] which deals with these topics and other key considerations such as the risk that EfW investments will undermine resource recovery efforts and source prevention of waste. In a wider context, pyrolysis can help 'close the loop'[773] for some difficult-to-manage organic waste streams beyond food waste.

Annex 12: Managing food waste within the household

Table 22: An overview of the main options for managing food waste within the household.[3]

	Composting	Worm farming	Bokashi
You'll need...	Composting bin, pile, box, etc. Medium to large amount of space Food scraps (30%) and brown carbon-rich matter (70%, e.g. dry leaves, wood chips, toilet-roll tubes)	Worm bin Tiger worms Medium amount of space Cool, sheltered spot Food scraps (70%) and brown carbon-rich matter (30%)	Airtight bokashi container system Small amount of space (inside is fine) Bokashi 'sprinkle' Food scraps (no brown carbon-rich matter needed)
Key benefits	Produces compost to spread on gardens Great if you have lots of garden waste Can take relatively large volumes of food scraps	Produces 'worm tea' and castings to fertilise plants Don't need to aerate (the worms do the work!)	Bokashi liquid can be used to clean drains, fertilise plants, etc Bokashi 'pickle' can add nutrients to soil or compost Can handle a wide range of food scraps (including meat and dairy)
Considerations	Need to keep aerated (e.g. by turning) to prevent rotting Best not to include meat, fish, dairy, or cooked food	Best not to include meat, fish, dairy, or cooked food Also need to exclude spicy or acidic foods Need to build capacity gradually	Need somewhere to bury or compost bokashi 'pickle' Need two bokashi bins, so that full bin can stay closed to 'mature'

Abbreviations

°C	Degrees Celsius
AD	Anaerobic Digestion
ASF	African Swine Fever
BAM	Beneficial Anaerobic Microbes
BOD	Biological Oxygen Demand
BPA	Bioresource Processing Alliance
BSE	Bovine Spongiform Encephalopathy
C	Carbon
CAGR	Compound Annual Growth Rate
CCFL	Codex Alimentarius Committee On Food Labelling
CO_2	Carbon Dioxide
CO_2e	CO_2 Equivalent
CRC	Cooperative Research Centre
CWD	Chronic Wasting Disease
DAF	Dissolved Air Flotation
DOC	Department of Conservation
ECM	Extracellular Matrix
ECN	European Compost Network
EECA	Energy Efficiency & Conservation Authority
EFSA	European Food Safety Authority
EfW	Energy-from-Waste
ERP	Emissions Reduction Plan
EU	European Union
FIET	Food Industry Enabling Technologies
FLW	Food Loss and Waste
FOGO	Food Organics and Garden Organics
FOGs	Fats, Oils, and Grease
FSANZ	Food Standards Australia New Zealand
FW	Food Waste
GHG	Greenhouse Gas
GO	Garden Organics
GWh	Gigawatt Hour
GWP	Global Warming Potential
HPP	High Pressure Processing
ICI	Industrial, Commercial, And Institutional
IPCC	Intergovernmental Panel on Climate Change

IRD	Inland Revenue Department
ITP	Industry Transformation Plan or Equivalent
K	Potassium
LCA	Life Cycle Analysis
LOAF	Logistically Optimised Animal Feed
MBIE	Ministry of Business, Innovation and Employment | Hīkina Whakatutuki
MfE	Ministry for the Environment | Manatū Mō Te Taiao
MoE	Ministry of Education | Te Tāhuhu o te Mātauranga
MoH	Ministry of Health | Manatū Hauora
MPI	Ministry for Primary Industries | Manatū Ahu Matua
MSD	Ministry of Social Development
N	Nitrogen
NCEA	National Certificate of Educational Achievement
NH_3	Ammonia
NZ	New Zealand
NZFIN	New Zealand Food Innovation Network
NZFMA	New Zealand Food Manufacturers Association
NZFN	New Zealand Food Network
NZS	New Zealand Standard
NZTE	New Zealand Trade and Enterprise
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
PAHs	Polyaromatic Hydrocarbons
PCDD/Fs	Polychlorinated dibenzo-*p*-dioxins and Polychlorinated dibenzo-*p*-furans (also called dioxins)
PEF	Pulsed Electric Fields
PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
PFR	Plant and Food Research
pH	Potential of Hydrogen
PJ	Petajoules
PM	Particulate Matter
POPs	Persistent Organic Pollutants
PrP^{C}	Cellular Prion Protein
PrP^{Sc}	Scrapie Prion Protein
PRRS	Porcine Reproductive and Respiratory Syndrome
RNG	Renewable Natural Gas
SDG	Sustainable Development Goals
SFFF	Sustainable Food and Fibre Futures

SME	Small and Medium Enterprise
SPICE	Static Pile Inoculated Compost Extension
TA	Territorial Authority
TPK	Te Puni Kōkiri	Ministry of Māori Development
UHT	Ultra-High Temperature
UK	United Kingdom
US	United States
US EPA	United States Environmental Protection Agency
vCJD	Creutzfeldt-Jakob Disease
WAS	Waste-Activated Solids (also called dairy biosolids)
WMF	Waste Minimisation Fund
WtE	Waste-to-energy (aka energy-from-waste, EfW)
WTO	World Trade Organisation
WWTP	Wastewater treatment plant

Glossary

Acidification	A decrease in the pH of a substance over time, making it more acidic.
Adsorb	When small particles like atoms and molecules stick to the surface of a material, they have been adsorbed. This is different from absorption, where a liquid is soaked up, like water into a sponge.
Aotearoa New Zealand	The terms Aotearoa New Zealand, Aotearoa, and New Zealand are used interchangeably in this report.
Biochar	The carbon-rich product which occurs when plant-derived biomass (such as wood, manure, or crop residues) is heated in a closed container with little or no available oxygen.
Biodegradable plastic	Plastics, typically polycaprolactone (PCL), polylactic acid (PLA), and polyurethane (PU), which can be degraded by biological processes.
Biodegradable product	The meaning of biodegradable is very broad, but generally means a product will break down naturally with the help of microbes, producing water, CO_2 (and methane if oxygen isn't present), and biomass.
Bioeconomy	Aspects of the economy that use biological resources, including food systems.
Bioresource	Naturally occurring, bio-based materials and processes, which are renewable and sustainable.
Biosolids	Treated sewage sludges and the product of the wastewater treatment process. They primarily comprise water and organic materials, but may also contain traces of synthetic organic compounds, metals, and other contaminants.
Bokashi 'sprinkle'	A mix of microbes, water, sugar, and carbon-rich material (also called bran) which is used to maintain a healthy environment for bokashi microbes.
By-product	In the context of food, a by-product is something that is generated during production, processing, manufacturing, or preparing that isn't the targeted food product. For example, a by-product of processing grapes to wine is grape marc, the skins, seeds and stems left over after pressing grapes.
Carbon dioxide equivalent (CO_2e *or* CO_2 eq)	A metric used to compare the emissions from various greenhouse gases based on their global warming potential (GWP). It is calculated by converting amounts of greenhouse gases to the equivalent amount of CO_2 with the same global warming potential.
Carbon sequestration	The removal of CO_2 from the atmosphere (where it contributes to global warming) and storage through natural or artificial processes.
Cellular agriculture	An emerging field which involves technologies to produce biologically equivalent agricultural products from cell cultures.[249] Animal-derived cells can be grown in laboratory environments to produce cultured meat or microbes can be utilised to produce proteins via precision fermentation, including dairy products or components.

Circular economy	A sustainable approach to resource use where waste and pollution are viewed as design flaws, products and materials are kept in use as long as possible, and nutrients and energy are captured at the end of a product's life to regenerate natural systems.
Class 1 landfill	Municipal solid waste landfills.
Compostable product	Certified products which are expected to break down in large-scale, community-level, and/or home compost systems.
Digestibility	The degree to which food can be broken down and nutrients absorbed when the food is consumed.
Embodied emissions	The greenhouse gas emissions associated with a material or product throughout its lifecycle.
End-of-life emissions	Greenhouse gas emissions that occur during the end-of-life treatment of a product. For food waste, a wide range of end-of-life options are available (e.g., landfill, composting, anaerobic digestion), all of which have different emissions profiles.
Energy recovery	Capturing the energy held in food waste so that it can be used to generate heat or electricity, or as a fuel or natural gas equivalent.
Ensiling	Preparing or storing plant-based animal feed under conditions that allow feed fermentation, producing silage.
Enteric fermentation	Part of the digestive process in ruminant animals, whereby microbes in the digestive tract breakdown food, producing methane as a by-product.
Environmental indicators	Metrics which provide information on the state of the environment. Stats NZ | Tatauranga Aotearoa collects data for, and publishes indicators on, New Zealand's air, marine environment, fresh water, atmosphere and climate, land, and biodiversity.
Eutrophication	An increased concentration of nutrients in water bodies. This in turn leads to increased microbial activity and "algal blooms" which deplete the water of oxygen.
Food	In this project, food is intended to capture both food and beverages. Unless specified, we are referring to food intended for human consumption.
Food-competing feedstuffs	Animal feed that could be directly eaten by humans.
Food loss	Food that has been discarded before it can be sold.
Food recovery hierarchy	A framework for thinking about solutions to food waste, prioritising interventions according to which types of solutions are likely to deliver the most environmental and social good. The food recovery hierarchy is a modified version of the waste management hierarchy, specific to food. There are many different versions of the food recovery hierarchy. Also known as the food waste hierarchy.
Food rescue	The process by which surplus food is captured for human consumption.

Food security	All people at all times, having physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy lifestyle.
Food supply chain	The whole food value chain, from farm to fork. The main stages of the supply chain are production, processing and manufacturing, retail, and consumption, including through the food service industry and in households. Handling, storage, transport, and distribution occurs throughout the food supply chain.
Food system	Food system and food supply chain are used interchangeably throughout this project. Food system is intended to capture the reality that the food supply chain isn't inherently linear but rather is made up of a network of interconnected organisations, entities, and individuals.
Food loss and waste	For the purposes of this project, food loss and waste is defined broadly and inclusively. Any food or drink that isn't utilised according to its original purpose, as well as by-products and the non-edible components of food are included. We give regard to the variable understandings of food and food waste. The entire food supply chain is in scope.
Frass	Insect excrement.
Global warming potential (GWP)	An index allowing comparisons to be made between GHGs. GWP takes into account how much energy the gas absorbs and the gas's lifetime. CO_2 is used as a reference (and has a GWP value of 1), with GWP for a given gas expressed as a multiple of the emissions from the same mass of CO_2 over a specified period of time. (See also CO_2e).
Grape marc	The solid residue left behind when grapes are processed during wine making. Grape marc contains skins, stalks, and moisture, as well as organic acids and polyphenols (including tannins), sugar residues, and alcohol.
Leachate	Water that has moved through a solid (such as the contents of a landfill or compost bin) and carried some material with it. If not managed, leachate can seep into the ground, introducing contaminants or excessive concentrations of certain nutrients.
Life cycle assessment	An analytical tool for evaluating the environmental impacts of a product or service through all stages of its life, not just at the end of its life. These should incorporate averted environmental harms not only from disposal or alternative waste management approaches, but also from producing more food instead of fully capturing value from existing food.
Material recovery	The use of inedible components of food at risk of going to waste to produce useful materials, such as fibre-based packaging.
Methanogenic	A process, object, or living thing that generates methane.
Nutraceuticals	Products derived from food sources with (real or claimed) health benefits.
Nutrient recovery	Capturing nutrients from food waste so that they can be used in agricultural systems, gardens, and to regenerate natural environments.

Organic	Being or coming from living plants and animals (e.g., food waste, manure, sewage sludge, crop residues).
Palatability	Acceptability or agreeability to the palate.
Palm kernel expeller	A by-product of palm oil production, used in Aotearoa as a feed supplement for dairy cows.
Per-and polyfluoroalkyl substances (PFAS)	Chemicals which are used to make coatings in products like food packaging that resist heat, oil, stains, grease, and water.
Rendering	A process that coverts waste animal tissue to value-added, more stable materials (e.g. processing raw fat to lard).
Stover	The leaves and stalks of grain crops that are commonly left in a field after harvest.
Surplus food	Quality, safe, edible food that exceeds the need or demands of a population and is at risk of being wasted if it isn't used. It is distinct from food that is spoiled, damaged, contaminated, past its use-by date, or otherwise no longer fit for human consumption.
Thermal pasteurisation	A relatively mild heat treatment in which a liquid is heated to less than 100°C to kill or inactivate microbes.
Upcycling	Keeping food at risk of going to waste in the human food supply chain by creating new food products from by-products or unmarketable foods such as stale bread, offcuts, or damaged produce.
Valorisation	Adding value to or capturing value from food which otherwise would have gone to waste (e.g. landfill) or would not have been used to its full potential. Valorisation can be achieved through technical solutions (e.g., processing by-products into edible foods) or a reimagining of food at risk of going to waste (e.g., expanding the cosmetic standard specifications from fresh produce).
Vermicast	Worm excrement.
Vermicomposting	The technical name for worm farming.
Wānanga	A forum for open discussion and education.
Windrow	A long line or row of heaped material.

References

1. Office of the Prime Minister's Chief Science Advisor. (2022). Food waste: A global and local problem. https://doi.org/10.17608/k6.OPMCSA.20164736
2. Office of the Prime Minister's Chief Science Advisor. (2022). Food rescue in 2022: Where to from here? https://doi.org/10.17608/k6.OPMCSA.21218243
3. What can I do with my food waste? Office of the Prime Minister's Chief Science Advisor. Retrieved 2 November 2023 from https://www.pmcsa.ac.nz/topics/food-rescue-food-waste/what-can-i-do-with-my-food-waste/
4. World Wildlife Fund. (2021). Driven to waste: Global food loss on farms. Report summary. https://www.worldwildlife.org/publications/driven-to-waste-the-global-impact-of-food-loss-and-waste-on-farms
5. Reducing food waste. Ministry for the Environment | Manatū Mō Te Taiao. Retrieved 31 August 2023 from https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/reducing-food-waste/
6. Yates, S. (2018). New Zealand food waste audits. Sunshine Yates Consulting. https://lovefoodhatewaste.co.nz/wp-content/uploads/2019/02/Final-New-Zealand-Food-Waste-Audits-2018.pdf
7. Thorsen, M., Mirosa, M., & Skeaff, S. (2021). A quantitative and qualitative study of food loss in glasshouse-grown tomatoes. Horticulturae, 8(1), 39. https://doi.org/10.3390/horticulturae8010039
8. Thrive Consulting (Prepared for Central Otago District Council). (2021). Understanding fruit loss in Central Otago. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/services/economic-development/documents/Understanding%20Fruit%20Loss%20in%20Central%20Otago%20report%20final.pdf
9. Jones, J., McLaren, S., Seraj, M., & Jones, J. R. (2020). Options for Repurposing Grape Marc in Marlborough, New Zealand. In Chemeca 2020: Renew, Sustain, Disrupt, Advance (pp. 110–117). Engineers Association. https://search.informit.org/doi/abs/10.3316/informit.478569252422061
10. Prest, A. (2018). Food residue to value-add: An examination of food by-product and waste, and the associated opportunities for value-add products in New Zealand. Sustainability Systems.
11. WasteMINZ. (2018). What is known about food waste in New Zealand. https://lovefoodhatewaste.co.nz/wp-content/uploads/2020/09/What-is-known-about-food-waste-in-New-Zealand.pdf
12. Ministry for the Environment | Manatū Mō Te Taiao. (2023). Food loss and waste definition for Aotearoa New Zealand. https://environment.govt.nz/assets/publications/Waste/Food-loss-and-waste-definition-for-Aotearoa-New-Zealand.pdf
13. Food loss and waste reduction. United Nations. Retrieved 2 November 2023 from https://www.un.org/en/observances/end-food-waste-day
14. Fabi, C., & English, A. (2018). SDG 12.3.1: Global Food Loss Index. Food and Agricultural Organisation of the United Nations.
15. Ministry for the Environment | Manatū Mō Te Taiao. (2022). Te hau mārohi ki anamata, Towards a productive, sustainable and inclusive economy: Aotearoa New Zealand's first Emissions Reduction Plan. https://environment.govt.nz/assets/publications/Aotearoa-New-Zealands-first-emissions-reduction-plan.pdf
16. Office of the Prime Minister's Chief Science Advisor. (2022). Household food waste: Diversion to where? (Draft—Not fully peer reviewed). https://bpb-ap-se2.wpmucdn.com/

blogs.auckland.ac.nz/dist/f/688/files/2022/12/Household-food-waste_Diversion-to-where_DRAFT.pdf
17. Teigiserova, D. A., Hamelin, L., & Thomsen, M. (2020). Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy. Science of the Total Environment, 706, 136033. https://doi.org/10.1016/j.scitotenv.2019.136033
18. Moshtaghian, H., Bolton, K., & Rousta, K. (2021). Challenges for upcycled foods: Definition, inclusion in the food waste management hierarchy and public acceptability. Foods, 10(11), 2874. https://doi.org/10.3390/foods10112874
19. Papargyropoulou, E., Lozano, R., K. Steinberger, J., Wright, N., & Ujang, Z. B. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. Journal of Cleaner Production, 76, 106–115. https://doi.org/10.1016/j.jclepro.2014.04.020
20. Food Standards Australia New Zealand (FSANZ). Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 1 June 2022 from https://www.mpi.govt.nz/food-business/food-safety-codes-standards/australia-new-zealand-co-operation/food-standards-australia-new-zealand-fsanz/
21. Upcycled Food Association. (2022). Upcycled Certified Standard: Version 2. https://static1.squarespace.com/static/606ce580b6b9b6777f470253/t/630f5c59408cbc03108c5f76/1661951066332/Upcycled+Certified+Standard_V2.pdf
22. Fundraising and community events food safety rules. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 18 December 2023 from https://www.mpi.govt.nz/food-business/starting-a-food-business/exemptions-from-the-food-act/fundraising-and-community-event-food-safety-rules/
23. Food recovery hierarchy. United States Environmental Protection Agency. Retrieved 26 May 2022 from https://19january2017snapshot.epa.gov/sustainable-management-food/food-recovery-hierarchy_.html
24. European Commission. (2020). Brief on food waste in the European Union. https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste/food-waste-measurement_en
25. Hierarchy to reduce food waste & build community. Brenda Platt, Institute for Local Self-Reliance. Retrieved 1 November 2022 from https://ilsr.org/food-waste-hierarchy/
26. Environment, Food and Rural Affairs Committee. (2017). Food waste in England. UK House of Commons. https://publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/429/42902.htm
27. Ministry for the Environment | Manatū Mō Te Taiao. (2023). Te rautaki para | Waste strategy. https://environment.govt.nz/assets/publications/Te-rautaki-para-Waste-strategy.pdf
28. Zero Waste Europe. (2019, January 23). Food Systems: A 'recipe' for food waste prevention [Press release]. https://zerowasteeurope.eu/press-release/policy-briefing-food-systems/
29. Government of Canada. (2019). Taking stock: Reducing food loss and waste in Canada. https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/food-loss-waste/taking-stock.html
30. Commonwealth of Australia. (2017). National food waste strategy: Halving Australia's food waste by 2030. https://www.agriculture.gov.au/sites/default/files/documents/national-food-waste-strategy.pdf
31. Kenny, S., Stephenson, J., Stern, A., Beecher, J., Morelli, B., Henderson, A., Chiang, E., Beck, A., Cashman, S., Wrexley, E., McGaughy, K., & Martell, A. (2023). From field to bin: The environmental impacts of U.S. food waste management pathways (EPA/600/R-23/065).

United States Environmental Protection Agency. https://www.epa.gov/land-research/field-bin-environmental-impacts-us-food-waste-management-pathways
32. Food and drink waste hierarchy: Deal with surplus and waste. Department for Environment, Food and Rural Affairs, Government of the United Kingdom. Retrieved 8 November 2023 from https://www.gov.uk/government/publications/food-and-drink-waste-hierarchy-deal-with-surplus-and-waste/food-and-drink-waste-hierarchy-deal-with-surplus-and-waste
33. Electricity. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. Retrieved 1 November 2023 from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/energy-in-new-zealand-2023/electricity/
34. New Zealand energy strategy. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. Retrieved 16 November 2023 from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand/new-zealand-energy-strategy/
35. Boerner, L. K. (2019, June 15). Industrial ammonia production emits more CO2 than any other chemical-making reaction. Chemists want to change that. Chemical & Engineering News. https://cen.acs.org/environment/green-chemistry/Industrial-ammonia-production-emits-CO2/97/i24
36. Hutchings, J. (2020). Māori soil sovereignty: Advocating for the rights of our ancestral soils. In J. Hutchings & J. Smith (Eds.), Te Mahi Oneone Hua Parakore: A Māori soil sovereignty and wellbeing handbook (pp. 45–59). Freerange Press.
37. Brownlie, W. J., Sutton, M. A., Heal, K. V., Reay, D. S., & Spears, B. M. (Eds.). (2022). Our phosphorus future: Towards global phosphorus sustainability. UK Centre for Ecology & Hydrology. https://doi.org/10.13140/RG.2.2.17834.08645
38. Dhillon, J. S., Eickhoff, E. M., Mullen, R. W., & Raun, W. R. (2019). World potassium use efficiency in cereal crops. Agronomy Journal, 111(2), 889–896. https://doi.org/10.2134/agronj2018.07.0462
39. Kibblewhite, M. G., Ritz, K., & Swift, M. J. (2007). Soil health in agricultural systems. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492), 685–701. https://doi.org/10.1098/rstb.2007.2178
40. Singh, B. (2018). Are nitrogen fertilizers deleterious to soil health? Agronomy, 8(4), 48. https://doi.org/10.3390/agronomy8040048
41. Tripathi, S., Srivastava, P., Devi, R. S., & Bhadouria, R. (2020). Chapter 2—Influence of synthetic fertilizers and pesticides on soil health and soil microbiology. In M. N. V. Prasad (Ed.), Agrochemicals Detection, Treatment and Remediation (pp. 25–54). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-103017-2.00002-7
42. Chrysargyris, A., Höfte, M., Tzortzakis, N., Petropoulos, S. A., & Di Gioia, F. (2022). Editorial: Micronutrients: The borderline between their beneficial role and toxicity in plants. Frontiers in Plant Science, 13, 840624. https://doi.org/10.3389/fpls.2022.840624
43. Email correspondence with Auckland Council. (2023). [Personal communication].
44. New Zealand Infrastructure Commission | Te Waihanga. (2021). Sector state of play: Resource recovery and waste. https://media.umbraco.io/te-waihanga-30-year-strategy/4zih23ph/sector-state-of-play-resource-recovery-and-waste.pdf
45. Diprose, G., Dombroski, K., Sharp, E., Yates, A., Peryman, B., & Barnes, M. (2023). Emerging transitions in organic waste infrastructure in Aotearoa New Zealand. New Zealand Geographer, 79(1), 15–26. https://doi.org/10.1111/nzg.12348
46. Prince, L. (2021). Expanding organic waste collections and composting in Aotearoa. Greenpeace Aotearoa. https://www.greenpeace.org/static/planet4-aotearoa-

stateless/2021/09/0e47a063-expanding-organic-waste-collections-and-composting-in-aotearoa.pdf
47. Blumhardt, H., & Prince, L. (2022). From lines to circles: Reshaping waste policy. Policy Quarterly, 18(2). https://doi.org/10.26686/pq.v18i2.7577
48. Waste Minimisation Fund. Ministry for the Environment | Manatū mō te Taiao. Retrieved 28 October 2022 from https://environment.govt.nz/what-you-can-do/funding/waste-minimisation-fund/
49. Mourad, M. (2016). Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France. Journal of Cleaner Production, 126, 461–477. https://doi.org/10.1016/j.jclepro.2016.03.084
50. Keep Britain Tidy. (2023). Shifting the public's focus from recycling to waste prevention: How do we move people up the waste hierarchy? https://c-6.net/virtualdocs/kbt_waste-campaign-report/
51. van Doorn, J., & Kurz, T. (2021). The warm glow of recycling can make us more wasteful. Journal of Environmental Psychology, 77. https://doi.org/10.1016/j.jenvp.2021.101672
52. Grant Thornton (Prepared for Ministry for the Environment | Manatū Mo Te Taiao). (2020). Report on waste disposal levy investment options. https://environment.govt.nz/assets/publications/waste-levy-investment-options.pdf
53. Department of Environment and Science. (2021). Energy from waste guideline. Queensland Government. https://www.qld.gov.au/__data/assets/pdf_file/0018/227241/waste-strategy-guideline-energy-from-waste.pdf
54. Condamine, P. (2020). France's law for fighting food waste: Food waste prevention legislation. Zero Food Waste Aotearoa. https://zerowasteeurope.eu/wp-content/uploads/2020/11/zwe_11_2020_factsheet_france_en.pdf
55. Leipold, S., Weldner, K., & Hohl, M. (2021). Do we need a 'circular society'? Competing narratives of the circular economy in the French food sector. Ecological Economics, 187. https://doi.org/10.1016/j.ecolecon.2021.107086
56. Circular economy introduction. Ellen Macarthur Foundation. Retrieved 10 October 2023 from https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview
57. Food and the circular economy. Ellen Macarthur Foundation. Retrieved 21 August 2023 from https://emf-digital.shorthandstories.com/food-and-the-circular-economy/
58. Ministry for the Environment | Manatū Mō Te Taiao. (2021). Te kawe i te haepapa para | Taking responsibility for our waste: Proposals for a new waste strategy; Issues and options for new waste legislation. https://consult.environment.govt.nz/waste/taking-responsibility-for-our-waste/supporting_documents/wastestrategyandlegislationconsultationdocument.pdf
59. Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., & Schösler, H. (2016). Transition towards Circular Economy in the Food System. Sustainability, 8(1), 69. https://doi.org/10.3390/su8010069
60. Te Takarangi. Project: Moonshot. Retrieved 1 November 2023 from https://www.projectmoonshot.city/our-origins
61. Shareef, J. (2020, October 8). An indigenous Māori view of doughnut economics. Resilience. https://www.resilience.org/stories/2020-10-08/an-indigenous-maori-view-of-doughnut-economics/
62. Para Kore. Para Kore. Retrieved 1 November 2022 from https://www.parakore.maori.nz/
63. Wilson, D., & Lewis, A. (2023). Waste and resource recovery infrastructure and services stocktake. Eunomia Research and Consulting Ltd (Prepared for Ministry for the Environment | Manatū Mō Te Taiao). https://environment.govt.nz/assets/publications/

Waste/Waste-and-resource-recovery-infrastructure-and-services-stocktake-Project-summary-report.pdf

64. Goodman-Smith, F., Mirosa, M., & Skeaff, S. (2020). A mixed-methods study of retail food waste in New Zealand. Food Policy, 92, 101845. https://doi.org/10.1016/j.foodpol.2020.101845
65. Levine, A. J., & Chung, D. (2023, August 5). The other greenhouse gas. Reuters. https://www.reuters.com/graphics/FOOD-WASTE/METHANE/gdpzwqwqovw/
66. New project: NZ food waste baseline. University of Otago and Food Waste Innovation. Retrieved 2 November 2023 from https://foodwaste-otago.org/news/new-project-nz-food-waste-baseline
67. ISO/WD 20001 Food loss and waste management system. International Organization for Stadardization. Retrieved 3 November 2023 from https://www.iso.org/standard/85052.html
68. International Standards Organisation (ISO) Annual Meeting. University of Otago and Food Waste Innovation. Retrieved 3 November 2023 from https://foodwaste-otago.org/news/international-organisation-of-standardization-annual-meeting
69. Clarke, W. P. (2018). The uptake of anaerobic digestion for the organic fraction of municipal solid waste – push versus pull factors. Bioresource Technology, 249, 1040–1043. https://doi.org/10.1016/j.biortech.2017.10.086
70. Gilbert, J., & Ricci-Jürgensen, M. (2023). A practitioners' guide to preventing and managing contaminants in organic waste recycling. ISWA.
71. United States Environmental Protection Agency. (2021). Emerging issues in food waste management: Persistent chemical contaminants. https://www.epa.gov/system/files/documents/2021-08/emerging-issues-in-food-waste-management-persistent-chemical-contaminants.pdf
72. United States Environmental Protection Agency. (2021). Emerging Issues in food waste management: Plastic contamination. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=352658&Lab=OSAPE
73. United States Environmental Protection Agency. (2021). Emerging issues in food waste management: Plastic and persistent chemical contaminants. https://www.epa.gov/system/files/documents/2021-08/emergining-issues-in-food-waste-persistent-chemicals-and-plastic-contamination.pdf
74. Guidelines for beneficial use of organic materials on land. Water New Zealand. Retrieved 28 November 2022 from https://www.waternz.org.nz/Article?Action=View&Article_id=1212
75. Whelan, C. (2023, November 30). Coca-Cola produces $3 billion worth of pure cocaine per year. NZ Herald. https://www.nzherald.co.nz/lifestyle/coca-cola-produces-3-billion-worth-of-pure-cocaine-per-year/E4ASXQXKGBFRBAHTGK5AXX57D4/
76. Tracing the journey from waste to whey protein. New Zealand Milk Products. Retrieved 30 November 2023 from https://www.nzmp.com/global/en/news/journey-from-waste-to-whey.html
77. Aotearoa composters network. Retrieved 21 December 2023 from https://www.aotearoacompostersnetwork.org/
78. Martin, M. (2023, May 5). Ecogas—Turning Auckland's food waste into gold. Stuff. https://www.stuff.co.nz/environment/climate-news/300858851/ecogas--turning-aucklands-food-waste-into-gold
79. Stop Food Waste Australia. Retrieved 13 September 2022 from https://www.stopfoodwaste.com.au/

80. Susan Bell & Associates. (2023). Reducing food loss and waste: A roadmap for philanthropy. Food and Land Use Coalition, ReFED, and Waste & Resources Action Programme. https://refed.org/uploads/reducing-food-loss-and-waste-a-roadmap-for-philanthropy.pdf
81. Living Compost Hubs. Retrieved 30 November 2023 from http://livingcomposthubs.org.nz
82. Schneider, F., & Lebersorger, S. (2016). Austria—Country report on national food waste policy. https://www.eu-fusions.org/phocadownload/country-report/AUSTRIA%20%2023.02.16.pdf
83. Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. (2015). What harmonised regulatory framework do we need in order to substantially support the implementation of separate collection and recycling of biowaste in Europe? https://www.compostnetwork.info/wordpress/wp-content/uploads/Position-of-Austria-on-Biowaste.pdf
84. Landells, E., Anjum, N., Pearson, D. H., Karunasena, G. G., & Oakden, S. (2022). Out of sight, out of mind: Using post-kerbside organics treatment systems to engage Australian communities with pro-environmental household food waste behaviours. Sustainability, 14(14), 8699. https://doi.org/10.3390/su14148699
85. Aschemann-Witzel, J., Asioli, D., Banovic, M., Perito, M. A., Peschel, A. O., & Stancu, V. (2023). Defining upcycled food: The dual role of upcycling in reducing food loss and waste. Trends in Food Science & Technology, 132, 132–137. https://doi.org/10.1016/j.tifs.2023.01.001
86. Balkan, E., Broad Leib, E., Coari, A., DePuy, M., Deutsch, J., Golison, M., Gray, B., Kolberg, A., McBride, M., Nguyen, J., Robertson, K., Spratt, O., & Zanolli, A. (2020). Defining upcycled foods. Upcycled Food Association. https://chlpi.org/wp-content/uploads/2013/12/Upcycled-Food_Definition.pdf
87. Thorsen, M., Skeaff, S., Goodman-Smith, F., Thong, B., Bremer, P., & Mirosa, M. (2022). Upcycled foods: A nudge toward nutrition. Frontiers in Nutrition, 9. https://doi.org/10.3389/fnut.2022.1071829
88. Shirvell, B. (2019, December 19). The upcycled food industry is worth $46.7 billion; here are 11 products you can try at home. Forbes. https://www.forbes.com/sites/bridgetshirvell/2019/12/19/the-upcycled-food-industry-is-worth-467b-here-are-11-products-you-can-try-at-home/?sh=c85092c340d9
89. Products from Food Waste Market. Future Market Insights. Retrieved 30 November 2023 from https://www.futuremarketinsights.com/reports/products-from-food-waste-market
90. Citizen. Citizen Collective. Retrieved 16 December 2022 from https://citizen.co.nz/
91. Dunedin Craft Distillers. Dunedin Craft Distillers. Retrieved 16 December 2022 from https://www.dunedincraftdistillers.nz/
92. Wild Heart Burger. Burgerfuel. Retrieved 22 July 2022 from https://burgerfuel.com/nz/wildheart
93. Upcycled Grain Project savingthe planet one snack at a time. Dish. Retrieved 17 January 2024 from https://dish.co.nz/news-reviews/food-news/upcycled-grain-project-saving-the-planet-one-snack-at-a-time/
94. Heagney, G. (2022, August 31). Is it ice cream? Kinda—Frozen cauliflower dessert comes to life. Stuff. https://www.stuff.co.nz/life-style/food-drink/300675166/is-it-ice-cream-kinda--frozen-cauliflower-dessert-comes-to-life
95. Introducing Spiced Orange Syrup—Everybody Eats collab. Six Barrel Soda. Retrieved 28 September 2023 from https://www.sixbarrelsoda.co/blogs/blog/introducing-spiced-orange-syrup-everybody-eats-collab
96. Getting the best from our food. The Development Kitchen. Retrieved 28 September 2023 from https://www.devkitchen.co.nz

97. Little beauties. Little Beauties. Retrieved 16 December 2022 from https://www.littlebeauties.kiwi/
98. Leong, S. Y., Treadwell, M., Liu, T., Hochberg, M., Sack, M., Mueller, G., Sigler, J., Silcock, P., & Oey, I. (2020). Influence of Pulsed Electric Fields processing at high-intensity electric field strength on the relationship between anthocyanins composition and colour intensity of Merlot (Vitis vinifera L.) musts during cold maceration. Innovative Food Science & Emerging Technologies, 59, 102243. https://doi.org/10.1016/j.ifset.2019.102243
99. Oey, I., Faridnia, F., Leong, S. Y., Burritt, D. J., & Liu, T. (2016). Determination of Pulsed Electric Fields effects on the structure of potato tubers. In D. Miklavcic (Ed.), Handbook of Electroporation (pp. 1–19). Springer International Publishing. https://doi.org/10.1007/978-3-319-26779-1_151-1
100. Food Industry Enabling Technologies. (2020, July 9). FIET Pulsed Electric Fields. Vimeo. https://vimeo.com/436694637
101. Gholamibozanjani, G., Leong, S. Y., Oey, I., Bremer, P., Silcock, P., & Farid, M. (2021). Heat and mass transfer modeling to predict temperature distribution during potato frying after pre-treatment with Pulsed Electric Field. Foods, 10(8), 1679. https://doi.org/10.3390/foods10081679
102. Leong, S. Y., Roberts, R., Hu, Z., Bremer, P., Silcock, P., Toepfl, S., & Oey, I. (2022). Texture and in vitro starch digestion kinetics of French fries produced from potatoes (Solanum tuberosum L.) pre-treated with pulsed electric fields. Applied Food Research, 2(2), 100194. https://doi.org/10.1016/j.afres.2022.100194
103. McCain | Pulsed Electric Field. Energy Efficiency and Conservation Authority. Retrieved 16 December 2022 from https://www.eeca.govt.nz/insights/case-studies-and-articles/mccain-pulsed-electric-field/
104. Abduh, S. B. M., Leong, S. Y., Zhao, C., Baldwin, S., Burritt, D. J., Agyei, D., & Oey, I. (2021). Kinetics of colour development during frying of potato pre-treated with Pulsed Electric Fields and blanching: Effect of cultivar. Foods, 10(10), 2307. https://doi.org/10.3390/foods10102307
105. Fitzgerald, J. A. (2023). Biochemical and metabolic defence responses to Candidatus Liberibacter solanacearum in potato tubers and the implications for PEF treatment [PhD thesis, Department of Food Science, University of Otago]. http://hdl.handle.net/10523/14762
106. Arcena, M. R., Leong, S. Y., Then, S., Hochberg, M., Sack, M., Mueller, G., Sigler, J., Kebede, B., Silcock, P., & Oey, I. (2021). The effect of pulsed electric fields pre-treatment on the volatile and phenolic profiles of Merlot grape musts at different winemaking stages and the sensory characteristics of the finished wines. Innovative Food Science & Emerging Technologies, 70, 102698. https://doi.org/10.1016/j.ifset.2021.102698
107. Leong, S. Y., Burritt, D. J., & Oey, I. (2016). Effect of combining Pulsed Electric Fields with maceration time on Merlot grapes in protecting Caco-2 cells from oxidative stress. Food and Bioprocess Technology, 9(1), 147–160. https://doi.org/10.1007/s11947-015-1604-y
108. Shahidi, F. (2009). Nutraceuticals and functional foods: Whole versus processed foods. Trends in Food Science & Technology, 20(9), 376–387. https://doi.org/10.1016/j.tifs.2008.08.004
109. Bioresource Processing Alliance. Bioresource Processing Alliance. Retrieved 14 January 2022 from https://bioresourceprocessing.co.nz/
110. About Sustainable Food and Fibre Futures. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 31 May 2022 from https://www.mpi.govt.nz/funding-rural-support/sustainable-food-fibre-futures/about-sustainable-food-and-fibre-futures/
111. Email correspondence with Francesca Goodman-Smith. (2023). [Personal communication].

112. Birn, J. (2022). Upcycling of food in Denmark—Upgrading of food and use of side streams. Technology Institute. https://onethird.dk/wp-content/uploads/2022/12/Upcycling-i-Danmark.pdf
113. Vriesekoop, F., Russell, C., Tziboula-Clarke, A., Jan, C., Bois, M., Farley, S., & McNamara, A. (2022). The iconisation of yeast spreads—Love them or hate them. Beverages, 8(1). https://doi.org/10.3390/beverages8010016
114. Upcycled Foods, Inc. Retrieved 15 December 2023 from https://upcycledfoods.com/
115. Ajila, C. M., Aalami, M., Leelavathi, K., & Rao, P. (2010). Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. Innovative Food Science & Emerging Technologies, 11(1), 219–224. https://doi.org/10.1016/j.ifset.2009.10.004
116. Strati, I. F., & Oreopoulou, V. (2014). Recovery of carotenoids from tomato processing by-products – a review. Food Research International, 65, 311–321. https://doi.org/10.1016/j.foodres.2014.09.032
117. Goodman-Smith, F., Bhatt, S., Moore, R., Mirosa, M., Ye, H., Deutsch, J., & Suri, R. (2021). Retail potential for upcycled foods: Evidence from New Zealand. Sustainability, 13(5), 2624. https://doi.org/10.3390/su13052624
118. Thorsen, M., Mirosa, M., Skeaff, S., Goodman-Smith, F., & Bremer, P. (2023). Upcycled food: How does it support the three pillars of sustainability? Trends in Food Science & Technology, 143, 104269. https://doi.org/10.1016/j.tifs.2023.104269
119. Sustainability the key ingredient in new muffins served at H3 venues. H3. Retrieved 7 June 2023 from https://h3group.co.nz/news/sustainability-the-key-ingredient-in-new-muffins-served-at-h3-venues/
120. Brookes, E. (2020, December 2). Could upcycled food be the answer to reducing food waste? Stuff. https://www.stuff.co.nz/life-style/food-wine/123572635/could-upcycled-food-be-the-answer-to-reducing-food-waste
121. Standards map. International Trade Centre. Retrieved 10 February 2023 from https://www.standardsmap.org/en/home
122. The Fairtrade marks. Fairtrade International,. Retrieved 11 January 2023 from https://www.fairtrade.net/about/fairtrade-marks
123. Upcycled Certified overview. Upcycled Food Association. Retrieved 11 January 2023 from https://www.upcycledfood.org/overview-1
124. Where Food Comes From. Where Food Comes From. Retrieved 20 January 2023 from https://www.wherefoodcomesfrom.com/
125. The Peter Mitchell Churchill Fellowship. Winston Churchill Trust. Retrieved 20 January 2023 from https://www.churchilltrust.com.au/project/the-peter-mitchell-churchill-fellowship-to-motivate-australian-businesses-to-innovate-and-become-world-leaders-in-the-upcycled-food-sector/
126. Codex Alimentarius Commission. (2023). Discussion paper on sustainability labelling claims. Food and Agricultural Organization of the United Nations and World Health Organization. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/pt/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-714-47%252Ffl47_12e.pdf
127. Asioli, D., & Grasso, S. (2021). Do consumers value food products containing upcycled ingredients? The effect of nutritional and environmental information. Food Quality and Preference, 91, 104194. https://doi.org/10.1016/j.foodqual.2021.104194
128. Coderoni, S., & Perito, M. A. (2021). Approaches for reducing wastes in the agricultural sector. An analysis of Millennials' willingness to buy food with upcycled ingredients. Waste Management, 126, 283–290. https://doi.org/10.1016/j.wasman.2021.03.018

129. The Upcycled Foods Definition Task Force. (2020). Defining upcycled foods: A definition for use across industry, government, and academia (p. 20). https://chlpi.org/wp-content/uploads/2013/12/Upcycled-Food_Definition.pdf
130. Food Act 2014. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 19 December 2023 from https://www.mpi.govt.nz/food-business/running-a-food-business/food-act-2014/
131. Ministry for Primary Industries | Manatū Ahu Matua. (2017). An Overview of the Animal Products Act 1999. https://www.mpi.govt.nz/dmsdocument/15991-Guidance-Document-An-Overview-of-the-Animal-Products-Act-1999#:~:text=The%20Animal%20Products%20Act%201999%20(APA)%20is%20New%20Zealand's%20legal,New%20Zealand%20animal%20product%20standards.
132. Aschemann-Witzel, J., & Stangherlin, I. D. C. (2021). Upcycled by-product use in agri-food systems from a consumer perspective: A review of what we know, and what is missing. Technological Forecasting and Social Change, 168, 120749. https://doi.org/10.1016/j.techfore.2021.120749
133. Aschemann-Witzel, J., Asioli, D., Banovic, M., Perito, M. A., & Peschel, A. O. (2023). Consumer understanding of upcycled foods – Exploring consumer-created associations and concept explanations across five countries. Food Quality and Preference, 112, 105033. https://doi.org/10.1016/j.foodqual.2023.105033
134. Moshtaghian, H., Bolton, K., & Rousta, K. (2023). Upcycled food choice motives and their association with hesitancy towards consumption of this type of food: A Swedish study. British Food Journal, 126(1). https://doi.org/10.1108/BFJ-09-2022-0757
135. Bhatt, S., Ye, H., Deutsch, J., Ayaz, H., & Suri, R. (2020). Consumers' willingness to pay for upcycled foods. Food Quality and Preference, 86, 104035. https://doi.org/10.1016/j.foodqual.2020.104035
136. Grasso, S., Fu, R., Goodman-Smith, F., Lalor, F., & Crofton, E. (2023). Consumer attitudes to upcycled foods in US and China. Journal of Cleaner Production, 388, 135919. https://doi.org/10.1016/j.jclepro.2023.135919
137. Thorsen, M., Nyhof, F., Goodman-Smith, F., Deutsch, J., & Mirosa, M. (2022). Accessing supermarket shelves: Retail category managers advice to upcycled food manufacturers. Journal of Food Products Marketing, 28(4), 179–192. https://doi.org/10.1080/10454446.2022.2072695
138. Goodisson, M. (2022). Understanding the opportunities of Central Otago fruit loss and waste with local processors and growers [Honour's dissertation, Department of Food Science, University of Otago]. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/sitecollectiondocuments/reports/other-reports/Otago%20university%20Workstream%201%20Local%20processing.pdf
139. Appetite for Change Ltd. (2022). Value plus project—Validating demand for Central Otago fruit value streams. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/sitecollectiondocuments/reports/other-reports/Appetite%20for%20change%20workstream%203%20Value%20Plus%20project%20Dec%202022%20final.pdf
140. What a load of rubbish. CiRCLR Ltd. Retrieved 7 June 2023 from https://circlr.nz/
141. Dennis, P. (2022, December 1). "Tesco Tinder" helps suppliers to cut costs and reduce waste. Circular. https://www.circularonline.co.uk/news/tesco-tinder-helps-suppliers-to-cut-costs-and-reduce-waste/
142. Central Otago fruit loss: The unrealised potential. Central Otago District Council. Retrieved 16 February 2023 from https://www.codc.govt.nz/services/economic-development/fruit-loss

143. Lister, C. (2022). Understanding the composition and potential health claims for Central Otago fruit waste. Plant and Food Research. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/sitecollectiondocuments/reports/other-reports/Plant%20and%20Food%20Workstream%202%20%20Understanding%20the%20compositio n%20and%20potential%20health%20FINAL%20UPDATED.pdf
144. Massarotto, C., Huffman, L., & George, S. (2022). New consumer products made from apples, cherries, apricots, peaches and nectarines. Plant and Food Research. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/sitecollectiondocuments/reports/other-reports/Plant%20and%20food%20Workstream%202%20-%20New%20consumer%20products%20Final%20Updated.pdf
145. Developing New Zealand's food & beverage industry. New Zealand Food Innovation Network. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/
146. Sustainable is Attainable. Venture Timaru. Retrieved 1 June 2022 from https://www.vtdevelopment.co.nz/news/media-releases/sustainable-is-attainable
147. Sustainable is Attainable in Hawke's Bay. Hastings District Council. Retrieved 23 June 2022 from https://www.hastingsdc.govt.nz/home/article/2285/sustainable-is-attainable-in-hawkes-bay?t=featured&s=1
148. Regulation of novel foods. Food Standards Australia New Zealand. Retrieved 22 February 2023 from https://www.foodstandards.govt.nz/industry/novel/Pages/default.aspx
149. Fight Food Waste Cooperative Research Centre. (2023). Project summary: Nutraceutical extraction from Australian wine industry waste. https://endfoodwaste.com.au/wp-content/uploads/2023/11/Project-Summary_GSE-project.pdf
150. Sampano Pty Ltd. (2019). Nutraceutical industry: A roadmap for building the value chain for the nutraceutical industry in Australia. https://sampano.com.au/nutraceutical-road-map
151. Coriolis (Prepared for Ministry of Business, Innovation & Employment | Hīkina Whakatutuki). (2019). Regional growth opportunities in food and beverage processing employment in New Zealand. https://www.mbie.govt.nz/dmsdocument/7249-regional-growth-opportunities-in-food-and-beverage-processing-employment-in-new-zealand
152. Burton-Freeman, B., & Sesso, H. D. (2014). Whole food versus supplement: Comparing the clinical evidence of tomato intake and lycopene supplementation on cardiovascular risk factors. Advance in Nutrition, 5(5), 457–485. https://doi.org/10.3945/an.114.005231
153. Health and nutrition content claims for food and drink. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 11 January 2023 from https://www.mpi.govt.nz/food-business/labelling-composition-food-drinks/health-and-nutrition-content-claims-for-food-and-drink/
154. Friedman, M. (2015). Chemistry and anticarcinogenic mechanisms of glycoalkaloids produced by eggplants, potatoes, and tomatoes. Journal of Agricultural and Food Chemistry, 63(13), 3323–3337. https://doi.org/10.1021/acs.jafc.5b00818
155. Belščak-Cvitanović, A., Durgo, K., Huđek, A., Bačun-Družina, V., & Komes, D. (2018). Overview of polyphenols and their properties. In C. M. Galanakis (Ed.), Polyphenols: Properties, Recovery, and Applications (pp. 3–44). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-813572-3.00001-4
156. Fu, Y., Shi, J., Xie, S.-Y., Zhang, T.-Y., Soladoye, O. P., & Aluko, R. E. (2020). Red beetroot betalains: Perspectives on extraction, processing, and potential health benefits. Journal of Agricultural and Food Chemistry, 68(42), 11595–11611. https://doi.org/10.1021/acs.jafc.0c04241

157. Li, P., Xia, J., Nie, Z., & Shan, Y. (2016). Pectic oligosaccharides hydrolyzed from orange peel by fungal multi-enzyme complexes and their prebiotic and antibacterial potentials. LWT - Food Science and Technology, 69, 203–210. https://doi.org/10.1016/j.lwt.2016.01.042
158. Santibáñez, L., Henríquez, C., Corro-Tejeda, R., Bernal, S., Armijo, B., & Salazar, O. (2021). Xylooligosaccharides from lignocellulosic biomass: A comprehensive review. Carbohydrate Polymers, 251, 117118. https://doi.org/10.1016/j.carbpol.2020.117118
159. Hot topics – Folic acid. (2022). Office of the Prime Minister's Chief Science Advisor. https://bpb-ap-se2.wpmucdn.com/blogs.auckland.ac.nz/dist/f/688/files/2020/01/Folic-acid_23-Feb-2022_v2-1.pdf
160. Nippert, M. (2023, November 2). Ārepa hype deflates as regulator says health claims are 'unsubstantiated.' NZ Herald. https://www.nzherald.co.nz/business/arepa-hype-deflates-as-regulator-says-health-claims-are-unsubstantiated/TV3QTBD6ABGGJDHNXIYMXIZX7A/
161. New Zealand Food Innovation network celebrating 10 years. (2022). New Zealand Food Innovation Network. https://foodinnovationnetwork.co.nz/images/NZFIN_celebrating-10-years-LR.pdf
162. Ministry for Primary Industries | Manatū Ahu Matua. (2022). Food and beverage draft Industry Transformation Plan. https://www.mpi.govt.nz/dmsdocument/54505-Food-and-Beverage-Draft-Industry-Transformation-Plan
163. The FoodBowl. New Zealand Food Innovation Network,. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/locations/foodbowl
164. FoodWaikato. New Zealand Food Innovation Network,. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/locations/foodwaikato
165. NZFIN navigator. New Zealand Food Innovation Network. Retrieved 17 January 2024 from https://foodinnovationnetwork.co.nz/lower-north-island/
166. FoodPilot. New Zealand Food Innovation Network. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/locations/foodpilot
167. Public clinics & services: FoodPilot. Massey University. Retrieved 11 January 2023 from https://www.massey.ac.nz/about/clinics-and-services-for-the-public/foodpilot/
168. FoodSouth. New Zealand Food Innovation Network. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/locations/foodsouth
169. FoodSouth Otago. New Zealand Food Innovation Network. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/foodsouth-otago/
170. The Apple Press. The Apple Press. Retrieved 11 January 2023 from https://theapplepress.co.nz/
171. Waste not want not—The Apple Press. New Zealand Food Innovation Network. Retrieved 17 January 2024 from https://foodinnovationnetwork.co.nz/waste-not-want-not-the-apple-press/
172. Sanford Ltd—Adding value and reducing waste. New Zealand Food Innovation Network. Retrieved 11 January 2023 from https://foodinnovationnetwork.co.nz/projects/sanford-ltd-adding-value-and-reducing-waste
173. Food pilot plant. Queensland Government Department of Agriculture and Fisheries. Retrieved 11 January 2023 from https://www.daf.qld.gov.au/business-priorities/agriculture/rde/food-pilot-plant
174. Amicarelli, V., Lagioia, G., & Bux, C. (2021). Global warming potential of food waste through the life cycle assessment: An analytical review. Environmental Impact Assessment Review, 91, 106677. https://doi.org/10.1016/j.eiar.2021.106677
175. Shukla, P. R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., & Malley, J.

(2022). Climate change 2022: Mitigation of climate change. Working Group III contribution to the sixth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

176. Parfitt, J., Brockhaus, A., & Croker, T. (2021). Driven to waste: The global impact of food loss and waste on farms. World Wildlife Fund. https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/6yoepbekgh_wwf_uk__driven_to_waste___the_global_impact_of_food_loss_and_waste_on_farms.pdf?_ga=2.255444360.1241850679.1706054523-2087138012.1704672246

177. Food and Agriculture Organization of the United Nations. (2015). Food wastage footprint and climate change. https://www.fao.org/3/bb144e/bb144e.pdf

178. Kidd, B., Mackay, S., Vandevijvere, S., & Swinburn, B. (2021). Cost and greenhouse gas emissions of current, healthy, flexitarian and vegan diets in Aotearoa (New Zealand). BMJ Nutrition, Prevention & Health, 4(1), 275–284. https://doi.org/10.1136/bmjnph-2021-000262

179. Less meat is nearly always better than sustainable meat, to reduce your carbon footprint. Hannah Ritchie, Our World in Data. Retrieved 26 May 2022 from https://ourworldindata.org/less-meat-or-sustainable-meat

180. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Malin, J., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Sibanda, L. M., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

181. Kuempel, C. D., Frazier, M., Verstaen, J., Rayner, P.-E., Blanchard, J. L., Cottrell, R. S., Froehlich, H. E., Gephart, J. A., Jacobsen, N. S., McIntyre, P. B., Metian, M., Moran, D., Nash, K. L., Többen, J., Williams, D. R., & Halpern, B. S. (2023). Environmental footprints of farmed chicken and salmon bridge the land and sea. Current Biology, 33(5), 990-997.e4. https://doi.org/10.1016/j.cub.2023.01.037

182. Sandström, V., Chrysafi, A., Lamminen, M., Troell, M., Jalava, M., Piipponen, J., Siebert, S., van Hal, O., Virkki, V., & Kummu, M. (2022). Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. Nature Food, 3(9), 729–740. https://doi.org/10.1038/s43016-022-00589-6

183. Salemdeeb, R., zu Ermgassen, E. K. H. J., Kim, M. H., Balmford, A., & Al-Tabbaa, A. (2017). Environmental and health impacts of using food waste as animal feed: A comparative analysis of food waste management options. Journal of Cleaner Production, 140, 871–880. https://doi.org/10.1016/j.jclepro.2016.05.049

184. Coriolis (Prepared for Ministry of Business, Innovation & Employment | Hīkina Whakatutuki). (2023). Thirty opportunities: Emerging and future platforms in New Zealand's bioeconomy (Final Stage II report). Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. https://www.coriolisresearch.com/reports/coriolis-bio-stage-02-platforms-101r

185. Ministry for Primary Industries | Manatū Ahu Matua. (2021). Technical review of animal feed processing methods: Processing parameters for retorting, extrusion-cooking, baking and chemical treatment in the production of animal feed from animal-derived raw material. https://www.mpi.govt.nz/dmsdocument/44350-Technical-Review-of-Animal-Feed-Processing-Methods-Processing-parameters-for-retorting-extrusion-cooking-baking-and-chemical-treatment-in-the-production-of-animal-feed-from-animal-derived-raw-material

186. New Zealand Feed Manufacturers Association. (2023). Annual feed production statistics for the year ending December 2022. https://www.nzfma.org.nz/media/annual-feed-statistics-year-end-2022/
187. WasteMINZ. (2018). Love Food Hate Waste campaign evaluation. https://lovefoodhatewaste.co.nz/wp-content/uploads/2019/02/FINAL-WasteMINZ-National-Food-Waste-Prevention-Study-2018.pdf
188. Butt, T. (2021). General public attitudes to composting and compostable packaging—Survey report (p. 45). UMR (Prepared for Ministry for the Environment | Manatū Mō Te Taiao). https://environment.govt.nz/assets/publications/General-public-attitudes-to-composting-and-home-compostable-packaging-Survey-report.pdf
189. Rajeh, C., Saoud, I. P., Kharroubi, S., Naalbandian, S., & Abiad, M. G. (2021). Food loss and food waste recovery as animal feed: A systematic review. Journal of Material Cycles and Waste Management, 23(1), 1–17. https://doi.org/10.1007/s10163-020-01102-6
190. Kyriazakis, I., & Whittemore, C. (2006). Diet formulation. In I. Kyriazakis & C. Whittemore (Eds.), Whittemore's Science and Practice of Pig Production (pp. 438–471). https://doi.org/10.1002/9780470995624.ch14
191. New Zealand Feed Manufacturers Association. (2022). Annual feed production statistics for the year ending December 2021. https://www.nzfma.org.nz/wp-content/uploads/2022/05/Annual-Stat-2021-full-report-completed.pdf
192. Nutrition and health. NZ Pork. Retrieved 13 February 2023 from https://www.nzpork.co.nz/farmers/pig-nutrition-and-health
193. Cobb, S. R., Pharo, H., Stone, M., Grosnendaal, H., & Zagmutt, F. J. (2015). Quantitative risk assessment of the likeihood of introducing porcine reproductive and respiratory syndrome virus into New Zealand through the importation of pig meat. Revue Scientifique et Technique (International Office of Epizootics), 34(3), 961–975. https://doi.org/10.20506/rst.34.3.2409
194. NZ Pork. (2021). New Zealand Pork Industry Board annual report 2021. https://uploads-ssl.webflow.com/5f87a6eb2f34a3a32b6165cf/620d936aaa52c45e66e719ba_NZPork%20Annual%20Report%20Final.pdf
195. Čolović, D., Rakita, S., Banjac, V., Đuragić, O., & Čabarkapa, I. (2019). Plant food by-products as feed: Characteristics, possibilities, environmental benefits, and negative sides. Food Reviews International, 35(4), 363–389. https://doi.org/10.1080/87559129.2019.1573431
196. Muhlack, R. A., Potumarthi, R., & Jeffery, D. W. (2018). Sustainable wineries through waste valorisation: A review of grape marc utilisation for value-added products. Waste Management, 72, 99–118. https://doi.org/10.1016/j.wasman.2017.11.011
197. Jones, J., McLaren, S., Chen, Q., & Seraj, M. (2020). Repurposing grape marc. Massey University. https://www.marlborough.govt.nz/repository/libraries/id:1w1mps0ir17q9sgxanf9/hierarchy/Documents/Services/Recycling%20and%20Resource%20Recovery/Milestone_Report_Template_MDC_Grape_Marc_Milestone_3_%28Year_1%29.pdf
198. Thompson-Morrison, H., Robinson, B., & Gaw, S. (2022, December 23). Palm kernel product imported for use on dairy farms may actually be harmful to cows. The Conversation. https://theconversation.com/palm-kernel-product-imported-for-use-on-dairy-farms-may-actually-be-harmful-to-cows-196569
199. Thompson-Morrison, H., Moltchanova, E., Gaw, S., & Robinson, B. (2022). Elemental composition of palm kernel expeller used as supplementary stock fodder. Sustainability, 14(23). https://doi.org/10.3390/su142315752

200. The Mirage. (2021, July 14). New Kiwi research to turn biowaste into economic boost. https://www.miragenews.com/new-kiwi-research-to-turn-biowaste-into-595256/
201. Jayanegara, A., Leiber, F., & Kreuzer, M. (2012). Meta-analysis of the relationship between dietary tannin level and methane formation in ruminants from in vivo and in vitro experiments. Journal of Animal Physiology and Animal Nutrition, 96(3), 365–375. https://doi.org/10.1111/j.1439-0396.2011.01172.x
202. Moate, P. J., Williams, S. R. O., Torok, V. A., Hannah, M. C., Ribaux, B. E., Tavendale, M. H., Eckard, R. J., Jacobs, J. L., Auldist, M. J., & Wales, W. J. (2014). Grape marc reduces methane emissions when fed to dairy cows. Journal of Dairy Science, 97(8), 5073–5087. https://doi.org/10.3168/jds.2013-7588
203. Suescun-Ospina, S. T., Vera, N., Astudillo, R., Yunda, C., Williams, P., Allende, R., & Ávila-Stagno, J. (2022). Effects of País grape marc inclusion in high and low forage diets: Ruminal fermentation, methane production and volatile fatty acids. Italian Journal of Animal Science, 21(1), 924–933. https://doi.org/10.1080/1828051X.2022.2076620
204. Lamy, E., Rawel, H., Schweigert, F. J., Capela, E. S. F., Ferreira, A., Costa, A. R., Antunes, C., Almeida, A. M., Coelho, A. V., & Sales-Baptista, E. (2011). The effect of tannins on Mediterranean ruminant ingestive behavior: The role of the oral cavity. Molecules, 16(4), 2766–2784. https://doi.org/10.3390/molecules16042766
205. Caetano, M., Wilkes, M. J., Pitchford, W. S., Lee, S. J., & Hynd, P. I. (2019). Effect of ensiled crimped grape marc on energy intake, performance and gas emissions of beef cattle. Animal Feed Science and Technology, 247, 166–172. https://doi.org/10.1016/j.anifeedsci.2018.10.007
206. Bustamante, M. A., Moral, R., Paredes, C., Pérez-Espinosa, A., Moreno-Caselles, J., & Pérez-Murcia, M. D. (2008). Agrochemical characterisation of the solid by-products and residues from the winery and distillery industry. Waste Management, 28(2), 372–380. https://doi.org/10.1016/j.wasman.2007.01.013
207. Paradelo, R., Moldes, A. B., & Barral, M. T. (2013). Evolution of organic matter during the mesophilic composting of lignocellulosic winery wastes. Journal of Environmental Management, 116, 18–26. https://doi.org/10.1016/j.jenvman.2012.12.001
208. González-Centeno, M. R., Rosselló, C., Simal, S., Garau, M. C., López, F., & Femenia, A. (2010). Physico-chemical properties of cell wall materials obtained from ten grape varieties and their byproducts: Grape pomaces and stems. LWT - Food Science and Technology, 43(10), 1580–1586. https://doi.org/10.1016/j.lwt.2010.06.024
209. McKendry, P. (2002). Energy production from biomass (part 2): Conversion technologies. Bioresource Technology, 83(1), 47–54. https://doi.org/10.1016/S0960-8524(01)00119-5
210. Alvarez-Casas, M., Pájaro, M., Lores, M., & Garcia-Jares, C. (2016). Characterization of grape marcs from native and foreign white varieties grown in northwestern Spain by their polyphenolic composition and antioxidant activity. European Food Research and Technology, 242(5), 655–665. https://doi.org/10.1007/s00217-015-2573-0
211. Zhang, K., Wang, M., Wang, D., & Gao, C. (2009). The energy-saving production of tartaric acid using ion exchange resin-filling bipolar membrane electrodialysis. Journal of Membrane Science, 341(1), 246–251. https://doi.org/10.1016/j.memsci.2009.06.010
212. Kontogiannopoulos, K. N., Patsios, S. I., & Karabelas, A. J. (2016). Tartaric acid recovery from winery lees using cation exchange resin: Optimization by Response Surface Methodology. Separation and Purification Technology, 165, 32–41. https://doi.org/10.1016/j.seppur.2016.03.040

213. Shurson, G. C., Dierenfeld, E. S., & Dou, Z. (2023). Rules are meant to be broken – Rethinking the regulations on the use of food waste as animal feed. Resources, Conservation and Recycling, 199, 107273. https://doi.org/10.1016/j.resconrec.2023.107273
214. Meeting with Marco Morgestern. (2022). [Personal communication].
215. Te Roto o Wairewa | Lake Forsyth. Land Air Water Aotearoa. Retrieved 9 March 2023 from https://www.lawa.org.nz/explore-data/canterbury-region/lakes/te-roto-o-wairewa-lake-forsyth/
216. Email correspondence and meeting with Matiu Prebble. (2022). [Personal communication].
217. Bigwood, K. V. (1948). Eeling. National Library. https://natlib.govt.nz/records/22688859. https://natlib.govt.nz/records/22688859
218. Schallenberg, M., & Schallenberg, L. A. (2013). Lake Forsyth/Wairewa: A literature review. Environment Canterbury Regional Council. https://api.ecan.govt.nz/TrimPublicAPI/documents/download/1972863
219. Wairewa—Lake Forsyth. Christchurch City Council. Retrieved 9 March 2023 from https://my.christchurchcitylibraries.com/ti-kouka-whenua/wairewa/
220. Waters, S., Webster-Brown, J. G., & Hawes, I. (2021). The release of legacy phosphorus from deforestation-derived sediments in shallow, coastal lake Forsyth/Te Roto o Wairewa. New Zealand Journal of Marine and Freshwater Research, 55(3), 446–465. https://doi.org/10.1080/00288330.2020.1804408
221. Freshwater feature: Managing Te Roto o Wairewa. NIWA | Taihoro Nukurangi. Retrieved 9 March 2023 from https://niwa.co.nz/freshwater/freshwater-update/no06-2004/freshwater-feature-managing-te-roto-o-wairewa
222. Health New Zealand. (2023, February 1). Algal bloom in Te Roto O Wairewa-Lake Forsyth (Press release). Scoop. https://www.scoop.co.nz/stories/AK2302/S00008/algal-bloom-in-te-roto-o-wairewa-lake-forsyth.htm
223. NZ Herald. (2007, October 8). Research proves Lake Forsyth toxins. https://www.nzherald.co.nz/nz/research-proves-lake-forsyth-toxins/7BNABOFVHF7P7TI6ZHYF5WXFAY/
224. Perch. NIWA | Taihoro Nukurangi. Retrieved 9 March 2023 from https://niwa.co.nz/freshwater/nzffd/NIWA-fish-atlas/fish-species/perch
225. Closs, G., Ludgate, B., & Goldsmith, R. (2001). Controlling European perch (Perca fluviatilis): Lessons from an experimental removal. University of Otago | Te Whare Wānanga or Otāgo. https://www.doc.govt.nz/globalassets/documents/science-and-technical/pf05closs.pdf
226. European Food Safety Authority Scientific Committee. (2015). Risk profile related to production and consumption of insects as food and feed. European Food Safety Authority Journal, 13(10). https://doi.org/10.2903/j.efsa.2015.4257
227. Fowles, T. M., & Nansen, C. (2020). Insect-based bioconversion: Value from food waste. In E. Närvänen, N. Mesiranta, M. Mattila, & A. Heikkinen (Eds.), Food waste management: Solving the wicked problem (pp. 321–346). Springer International Publishing. https://doi.org/10.1007/978-3-030-20561-4_12
228. Ojha, S., Bußler, S., & Schlüter, O. K. (2020). Food waste valorisation and circular economy concepts in insect production and processing. Waste Management, 118, 600–609. https://doi.org/10.1016/j.wasman.2020.09.010
229. Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology, 197, 1–33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

230. Houben, D., Daoulas, G., Faucon, M.-P., & Dulaurent, A.-M. (2020). Potential use of mealworm frass as a fertilizer: Impact on crop growth and soil properties. Scientific Reports, 10(1), 4659. https://doi.org/10.1038/s41598-020-61765-x
231. Poveda, J. (2021). Insect frass in the development of sustainable agriculture. A review. Agronomy for Sustainable Development, 41(1), 5. https://doi.org/10.1007/s13593-020-00656-x
232. Southey, F. (2023, December 4). Upcycling food waste into alt protein: On-site insect farming developed for manufacturers and retailers. FeedNavigator. https://www.feednavigator.com/Article/2023/12/01/flybox-on-site-insect-farming-developed-for-food-manufacturers-and-retailers
233. Good Grub Agritech TM. Retrieved 19 July 2023 from https://www.goodgrub.co.nz
234. NZ Herald. (2023, July 19). Insects key weapon against food wastage. https://www.nzherald.co.nz/brand-insight/insects-key-weapon-against-food-wastage/DIXAGQRAENDZXLNKGKJPWUG44E/
235. Fact sheet on insect frass. (2021). International Platform of Insects for Food and Feed. https://ipiff.org/wp-content/uploads/2021/11/Nov-29-2021-IPIFF-fact-sheet-on-insect-frass-final.pdf
236. Hyde, C. (2022). Grubs up: Multiple enactments of insects as food in Aotearoa/New Zealand. New Zealand Sociology, 37(2), 94–106. https://www.saanz.net/wp-content/uploads/2022/11/8_Hyde_Grubs-Up_final_372_94-106.pdf.
237. Payne, P., Ryan, A., & Finlay-Smits, S. (2023). Insects as mini-livestock: New Zealand's public attitudes toward consuming insects. Kōtuitui: New Zealand Journal of Social Sciences Online, 18(3), 310–326. https://doi.org/10.1080/1177083X.2022.2156357
238. New South Wales Environment Protection Authority. (2021). Emissions impacts of protein production. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4167-emissions-impacts-protein-production.pdf
239. Mertenat, A., Diener, S., & Zurbrügg, C. (2019). Black Soldier Fly biowaste treatment – Assessment of global warming potential. Waste Management, 84, 173–181. https://doi.org/10.1016/j.wasman.2018.11.040
240. Salomone, R., Saija, G., Mondello, G., Giannetto, A., Fasulo, S., & Savastano, D. (2017). Environmental impact of food waste bioconversion by insects: Application of life cycle assessment to process using Hermetia illucens. Journal of Cleaner Production, 140, 890–905. https://doi.org/10.1016/j.jclepro.2016.06.154
241. Smetana, S., Schmitt, E., & Mathys, A. (2019). Sustainable use of Hermetia illucens insect biomass for feed and food: Attributional and consequential life cycle assessment. Resources, Conservation and Recycling, 144, 285–296. https://doi.org/10.1016/j.resconrec.2019.01.042
242. Smetana, S., Palanisamy, M., Mathys, A., & Heinz, V. (2016). Sustainability of insect use for feed and food: Life Cycle Assessment perspective. Journal of Cleaner Production, 137, 741–751. https://doi.org/10.1016/j.jclepro.2016.07.148
243. Fantom, L. (2022, December 20). Insect farms are scaling up—And crossing the atlantic—In a play for sustainable protein. Civil Eats. https://civileats.com/2022/12/20/insect-farms-scaling-up-sustainable-protein-innovafeed-adm-cargill-protix-black-soldier-fly-livestock-aquaculture/
244. Insect Bioconversion – Reforming the Food System. Fera. Retrieved 30 November 2023 from https://www.fera.co.uk/insect-bioconversion-reforming-the-food-system
245. Facchini, E., Shrestha, K., van den Boer, E., Junes, P., Sader, G., Peeters, K., & Schmitt, E. (2022). Long-Term Artificial Selection for Increased Larval Body Weight of Hermetia illucens in

Industrial Settings. Frontiers in Genetics, 13. https://www.frontiersin.org/articles/10.3389/fgene.2022.865490
246. Queensland Alliance for Agriculture and Food Innovation. (2022). The insects revolutionising food security. University of Queensland. https://qaafi.uq.edu.au/article/2022/08/insects-revolutionising-food-security
247. Gold, M., Tomberlin, J. K., Diener, S., Zurbrügg, C., & Mathys, A. (2018). Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Management Research, 82, 302–318. https://doi.org/10.1016/j.wasman.2018.10.022
248. Sogari, G., Amato, M., Biasato, I., Chiesa, S., & Gasco, L. (2019). The potential role of insects as feed: A multi-perspective review. Animals, 9(4). https://doi.org/10.3390/ani9040119
249. Seah, J. S. H., Singh, S., Tan, L. P., & Choudhury, D. (2022). Scaffolds for the manufacture of cultured meat. Critical Reviews in Biotechnology, 42(2), 311–323. https://doi.org/10.1080/07388551.2021.1931803
250. 40 cellular agriculture companies pioneering a sustainable future. Erin Baright, Vevolution. Retrieved 7 March 2023 from https://www.vevolution.com/articles/40-cellular-agriculture-companies-pioneering-a-sustainable-future
251. Cellular agriculture. Olivia Ogilvie, Office of the Prime Minister’s Chief Science Advisor. Retrieved 7 March 2023 from https://www.pmcsa.ac.nz/topics/cellular-agriculture/
252. Kumar, A., Sood, A., & Han, S. S. (2023). Technological and structural aspects of scaffold manufacturing for cultured meat: Recent advances, challenges, and opportunities. Critical Reviews in Food Science and Nutrition, 63(5), 585–612. https://doi.org/10.1080/10408398.2022.2132206
253. Singh, S., Yap, W. S., Ge, X. Y., Min, V. L. X., & Choudhury, D. (2022). Cultured meat production fuelled by fermentation. Trends in Food Science & Technology, 120, 48–58. https://doi.org/10.1016/j.tifs.2021.12.028
254. Andreassen, R. C., Rønning, S. B., Solberg, N. T., Grønlien, K. G., Kristoffersen, K. A., Høst, V., Kolset, S. O., & Pedersen, M. E. (2022). Production of food-grade microcarriers based on by-products from the food industry to facilitate the expansion of bovine skeletal muscle satellite cells for cultured meat production. Biomaterials, 286, 21602. https://doi.org/10.1016/j.biomaterials.2022.121602
255. Jones, J. D., Rebello, A. S., & Gaudette, G. R. (2021). Decellularized spinach: An edible scaffold for laboratory-grown meat. Food Bioscience, 41, 100986. https://doi.org/10.1016/j.fbio.2021.100986
256. Thyden, R., Perreault, L. R., Jones, J. D., Notman, H., Varieur, B. M., Patmanidis, A. A., Dominko, T., & Gaudette, G. R. (2022). An edible, decellularized plant derived cell carrier for lab grown meat. Applied Sciences, 12(10), 5155. https://doi.org/10.3390/app12105155
257. Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., & Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: A mass flow analysis. Resources, Conservation and Recycling, 149, 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011
258. Updates to the FLW Standard (v1.1 published April 2021): Food Loss and Waste Protocol. Retrieved 9 November 2023 from https://flwprotocol.org/updates-to-the-flw-standard-v1-1-published-april-2021/
259. Environmental trend: 5 new materials made from food waste. Trend-Monitor. Retrieved 13 November 2023 from https://trend-monitor.co.uk/environmental-trend-materials-made-from-food-waste/

260. Beef + Lamb New Zealand. (2022). Compendium of New Zealand farm facts 2022. https://beeflambnz.com/sites/default/files/2023-06/Compendium-22.pdf
261. Circular economy and bioeconomy strategy. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. Retrieved 15 December 2023 from https://www.mbie.govt.nz/business-and-employment/economic-development/circular-economy-and-bioeconomy-strategy/
262. Limeneh, D. Y., Tesfaye, T., Ayele, M., Husien, N. M., Ferede, E., Haile, A., Mengie, W., Abuhay, A., Gelebo, G. G., Gibril, M., & Kong, F. (2022). A comprehensive review on utilization of slaughterhouse by-product: Current status and prospect. Sustainability, 14(11), 6469. https://doi.org/10.3390/su14116469
263. The little-known world of beef and sheep byproducts and co-products. Shawn Moodie, Beef + Lamb NZ. Retrieved 13 November 2023 from https://www.beeflambnz.co.nz/news/2021/7/16/the-little-known-world-of-beef-and-sheep-co-products
264. Meat Industry Association. Retrieved 21 December 2023 from https://www.mia.co.nz/
265. Surgical Gut Suture Plain. Johnson&Johnson MedTech. Retrieved 4 December 2023 from https://www.jnjmedtech.com/en-US/product/surgical-gut-suture-plain
266. Surgical aortic pericardial valves. Edwards. Retrieved 4 December 2023 from https://www.edwards.com/healthcare-professionals/products-services/surgical-heart/aortic-pericardial
267. MedSafe. Heparin Sodium: New Zealand data sheet. Retrieved 4 December 2023 from https://www.medsafe.govt.nz/profs/datasheet/h/HeparinsodiumPfizerinj.pdf
268. Intact Fish Skin for Tissue Regeneration. Retrieved 4 December 2023 from https://www.kerecis.com/
269. Fenwick, R., Harper, J., Hobman, P., Huffman, L., Kirkpatrick, K., MacGibbon, J., Marshall, K., Matthews, M., Wilson, A., & Woodhams, D. (2014). Whey to go—Whey protein concentrate: A New Zealand success story (J. MacGibbon, Ed.). Ngaio Press.
270. Hamilton, R. (n.d.). The manufacture of ethanol from whey. Bioenergy Association. https://www.bioenergy.org.nz/documents/resource/Reports/Manufacture-of-Ethanol-from-Whey-3H.pdf
271. Fonterra. Academic Accelerator. Retrieved 15 December 2023 from https://academic-accelerator.com/encyclopedia/fonterra
272. Hembry, O. (2008, February 29). Pharmaceuticals latest target for dairy giant. NZ Herald. https://www.nzherald.co.nz/business/pharmaceuticals-latest-target-for-dairy-giant/OETFOSSRL6PZM32MOMWP7ABWZE/
273. Excipients in medicines. Healthify. Retrieved 23 November 2023 from https://healthify.nz/medicines-a-z/e/excipients-in-medicines/
274. Rawson, E. (2014, June 6). Making bovine gold. Stuff. https://www.stuff.co.nz/business/unlimited/innovation/10124112/Making-bovine-gold
275. Southern Lights Biomaterials and Collagen Solutions merge. Collagen Solutions. Retrieved 13 November 2023 from https://www.collagensolutions.com/southern-lights-biomaterials-and-collagen-solutions-merge/
276. Collamex. Waitaki Biosciences. Retrieved 13 November 2023 from https://www.waitakibio.com/products/brands/collamex/
277. Gelita NZ. Ltd. Gelita. Retrieved 5 January 2024 from https://www.gelita.com/en/new-zealand
278. Aroa Biosurgery. Aroa Biosurgery. Retrieved 13 November 2023 from https://aroa.com/
279. Sharma, A., Sharma, D., & Zhao, F. (2023). Updates on Recent Clinical Assessment of Commercial Chronic Wound Care Products. Advanced Healthcare Materials, 12(25), 2300556. https://doi.org/10.1002/adhm.202300556

280. Myriad Morcells: Morcellized bioscaffold. AROA Biosurgery Limited. Retrieved 22 January 2024 from https://aroa.com/wp-content/uploads/2023/08/MKT.1654.03_Myriad-Morcells-US-Sell-Sheet_v1_WEB.pdf
281. NZ Herald. (n.d.). Blood-based plastic a green bonus. https://www.nzherald.co.nz/business/blood-based-plastic-a-green-bonus/SBGJDIKTVBAVP4ETK77ZAYX2GU/
282. Sigfussion, T. (2020). The New Fish Wave: How to Ignite the Seafood Industry. Leete's Island Books.
283. Kumar, V., Muzaddadi, A., Mann, S., Balakrishnan, R., Bembem, K., & Kalnar, Y. (2022). Utilization of fish processing waste: A waste to wealth approach. In Emerging Post-Harvest Engineering and Techological Interventions for Enhancing Farmer's Income (pp. 127–131). ICAR-CIPHET.
284. Fraser, C. (2020, October 4). A marae's simple solution to New Zealand's "atrocious" fish waste problem. Newshub. https://www.newshub.co.nz/home/shows/2020/10/a-marae-s-simple-solution-to-new-zealand-s-atrocious-fish-waste-problem.html
285. Office of the Prime Minister's Chief Science Advisor. (2021). The future of commercial fishing in Aotearoa New Zealand. https://doi.org/doi.org/10.17608/k6.OPMCSA.14257970
286. New Zealand fish oil prices. Selina Wamuchii. Retrieved 13 November 2023 from https://www.selinawamucii.com/insights/prices/new-zealand/fish-oil/
287. Stephens, T. J., Sigler, M. L., Herndon, J. H., Dispensa, L., & Le Moigne, A. (2016). A placebo-controlled, double-blind clinical trial to evaluate the efficacy of Imedeen® Time Perfection® for improving the appearance of photodamaged skin. Clinical, Cosmetic and Investigational Dermatology, 9, 63–70. https://doi.org/10.2147/CCID.S98787
288. Geahchan, S., Baharlouei, P., & Rahman, A. (2022). Marine collagen: A promising biomaterial for wound healing, skin anti-aging, and bone regeneration. Marine Drugs, 20(1), 61. https://doi.org/10.3390/md20010061
289. High quality marine collagen from Aotearoa New Zealand. Office of the Prime Minister's Chief Science Advisor. Retrieved 13 November 2023 from https://www.pmcsa.ac.nz/2021/02/21/high-quality-marine-collagen-from-aotearoa-new-zealand/
290. Sarkar, N., Ghosh, S. K., Bannerjee, S., & Aikat, K. (2012). Bioethanol production from agricultural wastes: An overview. Renewable Energy, 37(1), 19–27. https://doi.org/10.1016/j.renene.2011.06.045
291. Ali, I. (2016). Manufacturing and Evaluation of Panel Products using Kenaf Bast Fibres [PhD thesis, Department of Mechanical Engineering, University of Auckland]. https://researchspace.auckland.ac.nz/handle/2292/28486
292. New glue: A New Zealand solution to a sticky problem. Pure Advantage. Retrieved 23 November 2023 from https://pureadvantage.org/new-glue-new-zealand-solution-sticky-problem/
293. Particle Board. LignoStar Group BV. Retrieved 23 November 2023 from https://lignostar.com/en/your-industry/particle-board/
294. Guillard, V., Gaucel, S., Fornaciari, C., Angellier-Coussy, H., Buche, P., & Gontard, N. (2018). The next generation of sustainable food packaging to preserve our environment in a circular economy context. Frontiers in Nutrition, 5. https://doi.org/10.3389/fnut.2018.00121/full
295. Mapelli, F., Carullo, D., Farris, S., Ferrante, A., Bacenetti, J., Ventura, V., Frisio, D., & Borin, S. (2022). Food waste-derived biomaterials enriched by biostimulant agents for sustainable horticultural practices: A possible circular solution. Frontiers in Sustainability, 3. https://doi.org/10.3389/frsus.2022.928970

296. New hemp factory to pave the way for product innovation. Hemp New Zealand. Retrieved 13 November 2023 from https://hempnz.co.nz/new-hemp-factory-to-pave-the-way-for-product-innovation/
297. The ZESPRI biospife. Science Learning Hub | Pokapū Akoranga Pūtaiao. Retrieved 13 November 2023 from https://www.sciencelearn.org.nz/resources/1472-the-zespri-biospife
298. Ganasen, N., Bahrami, A., & Loganathan, K. (2023). A scientometric analysis review on agricultural wastes used as building materials. Buildings, 13(2), 426. https://doi.org/10.3390/buildings13020426
299. Al-Alwan, A. A. K., Al-Bazoon, M., I.Mussa, F., Alalwan, H. A., Hatem Shadhar, M., Mohammed, M. M., & Mohammed, M. F. (2022). The impact of using rice husk ash as a replacement material in concrete: An experimental study. Journal of King Saud University - Engineering Sciences. https://doi.org/10.1016/j.jksues.2022.03.002
300. Rice husk ash market. Transparency Market Research. Retrieved 13 November 2023 from https://www.transparencymarketresearch.com/rice-husk-ash-market.html
301. Strawlines—Mission Zero. Mission Zero. Retrieved 22 January 2024 from https://missionzero.nz/strawlines/
302. Love food hate waste. Love Food Hate Waste. Retrieved 31 May 2022 from https://lovefoodhatewaste.co.nz/
303. Non-avoidable food waste. Love Food Hate Waste. Retrieved 15 August 2023 from https://lovefoodhatewaste.co.nz/reduce-your-waste/non-avoidable-food-waste/
304. Chauhan, C., Dhir, A., Akram, M. U., & Salo, J. (2021). Food loss and waste in food supply chains. A systematic literature review and framework development approach. Journal of Cleaner Production, 295, 126438. https://doi.org/10.1016/j.jclepro.2021.126438
305. Relle, R. (2022, September 29). We can all help reduce food loss and waste. United Nations Chronicle. https://www.un.org/en/un-chronicle/we-can-all-help-reduce-food-loss-and-waste
306. Sisson, L. (2023, February 10). Food in a flood: What the rain means for all our dinner tables. The Spinoff. https://thespinoff.co.nz/kai/10-02-2023/food-in-a-flood-what-the-rain-means-for-all-our-dinner-tables
307. Guidance for harvesting flood-affected produce for human consumption. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 15 August 2023 from https://www.mpi.govt.nz/funding-rural-support/adverse-events/food-safety-in-natural-disasters-and-emergencies/guidance-for-harvesting-flood-affected-produce-for-human-consumption/
308. Le Pera, A., Sellaro, M., & Bencivenni, E. (2022). Composting food waste or digestate? Characteristics, statistical and life cycle assessment study based on an Italian composting plant. Journal of Cleaner Production, 350, 131552. https://doi.org/10.1016/j.jclepro.2022.131552
309. Barker, A. (1997). Composition and uses of compost. In J. E. Rechcigl & H. C. MacKinnon (Eds.), Agricultural Uses of By-Products and Wastes (Vol. 668). American Chemical Society. https://doi.org/10.1021/bk-1997-0668
310. Ontl, T. A., & Schulte, L. A. (2012). Soil carbon storage. Nature Education Knowledge, 3(10), 36. https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/.
311. European Commission, Directorate General for Environment. (2011). Soil—The hidden part of the climate cycle. https://data.europa.eu/doi/10.2779/30669
312. Closing the nutrient loop. Ellen Macarthur Foundation. Retrieved 21 August 2023 from https://ellenmacarthurfoundation.org/circular-examples/closing-the-nutrient-loop
313. Rogoff, M. J., & Screve, F. (2019). Waste-to-Energy: Technologies and Project Implementation. Academic Press.

314. Ministry for the Environment | Manatū Mō Te Taiao. (2020). A waste to energy guide for New Zealand. https://environment.govt.nz/assets/Publications/Files/waste-to-energy-guide-for-new-zealand.pdf
315. Silva-Martínez, R. D., Sanches-Pereira, A., Ortiz, W., Gómez Galindo, M. F., & Coelho, S. T. (2020). The state-of-the-art of organic waste to energy in Latin America and the Caribbean: Challenges and opportunities. Renewable Energy, 156, 509–525. https://doi.org/10.1016/j.renene.2020.04.056
316. Gardiner, B. (2021, April 1). In Europe, a backlash is growing over incinerating garbage. Yale E360. https://e360.yale.edu/features/in-europe-a-backlash-is-growing-over-incinerating-garbage
317. Waste to energy in New Zealand. Waste Management. Retrieved 30 August 2023 from https://www.wastemanagement.co.nz/news-and-media/waste-to-energy-in-new-zealand/
318. Seadon, J. Burning waste to generate electricity. Retrieved 30 August 2023 from https://www.aut.ac.nz/news/opinion/burning-waste-to-generate-electricity
319. Hall, P., & Gifford, J. (2007). Bioenergy options for New Zealand (p. 88). Scion. https://niwa.co.nz/sites/niwa.co.nz/files/import/attachments/Situation_Analysis_-_Bioenergy_Options.pdf
320. Salas, S. E. (2022, March 28). Here's how food waste can generate clean energy. The Conversation. http://theconversation.com/heres-how-food-waste-can-generate-clean-energy-176352
321. Sridhar, A., Kapoor, A., Senthil Kumar, P., Ponnuchamy, M., Balasubramanian, S., & Prabhakar, S. (2021). Conversion of food waste to energy: A focus on sustainability and life cycle assessment. Fuel, 302, 121069. https://doi.org/10.1016/j.fuel.2021.121069
322. Banks, C., Heaven, S., Zhang, Y., & Baier, U. (2018). Anaerobic Digestion of Food Waste for a Circular Economy. IEA Bioenergy.
323. Needelman, B. A. (2013). What Are Soils? Nature Education Knowledge, 4(3). https://www.nature.com/scitable/knowledge/library/what-are-soils-67647639/
324. Food and Agriculture Organization of the United Nations & Intergovernmental Technical Panel on Soils. (2015). Status of the World's Soil Resources: Main Report. http://www.fao.org/3/a-i5199e.pdf
325. The state of New Zealand soils. Manaaki Whenua | Landcare Research. Retrieved 8 November 2023 from https://soils.landcareresearch.co.nz/topics/soil-quality/state-of-nz-soils/
326. Soil quality and land use. StatsNZ | Tatauranga Aotearoa. Retrieved 8 November 2023 from https://www.stats.govt.nz/indicators/soil-quality-and-land-use
327. Parliamentary Commissioner for the Environment. (2015). Water quality in New Zealand: Land use and nutrient pollution. https://pce.parliament.nz/media/10mo2kwd/update-report-water-quality-in-new-zealand-web.pdf
328. Fertiliser use in NZ. Retrieved 4 December 2023 from http://www.fertresearch.org.nz/site/about-fertiliser/fertiliser_use_in_nz.aspx
329. New Zealand fertilizers, mineral or chemical; nitrogenous, urea, whether or not in aqueous solution imports by country in 2018. World Integrated Trade Solution. Retrieved 4 December 2023 from https://wits.worldbank.org/trade/comtrade/en/country/NZL/year/2018/tradeflow/Imports/partner/ALL/product/310210
330. New Zealand fertilizers, mineral or chemical; potassic, potassium chloride imports by country in 2019. World Integrated Trade Solution. Retrieved 4 December 2023 from https://wits.worldbank.org/trade/comtrade/en/country/NZL/year/2019/tradeflow/Imports/partner/ALL/product/310420

331. Czekała, W., Lewicki, A., Pochwatka, P., Czekała, A., Wojcieszak, D., Jóźwiakowski, K., & Waliszewska, H. (2020). Digestate management in polish farms as an element of the nutrient cycle. Journal of Cleaner Production, 242, 118454. https://doi.org/10.1016/j.jclepro.2019.118454
332. Dubis, B., Szatkowski, A., & Jankowski, K. J. (2022). Sewage sludge, digestate, and mineral fertilizer application affects the yield and energy balance of Amur silvergrass. Industrial Crops and Products, 175, 114235. https://doi.org/10.1016/j.indcrop.2021.114235
333. Zilio, M., Pigoli, A., Rizzi, B., Herrera, A., Tambone, F., Geromel, G., Meers, E., Schoumans, O., Giordano, A., & Adani, F. (2022). Using highly stabilized digestate and digestate-derived ammonium sulphate to replace synthetic fertilizers: The effects on soil, environment, and crop production. Science of The Total Environment, 815, 152919. https://doi.org/10.1016/j.scitotenv.2022.152919
334. Verdi, L., Kuikman, P. J., Orlandini, S., Mancini, M., Napoli, M., & Dalla Marta, A. (2019). Does the use of digestate to replace mineral fertilizers have less emissions of N2O and NH3? Agricultural and Forest Meteorology, 269–270, 112–118. https://doi.org/10.1016/j.agrformet.2019.02.004
335. Li, F., Yuan, Y., Gong, P., Imazumi, Y., Na, R., & Shimizu, N. (2023). Comparative effects of mineral fertilizer and digestate on growth, antioxidant system, and physiology of lettuce under salt stress. Horticulture, Environment, and Biotechnology, 64(3), 379–391. https://doi.org/10.1007/s13580-022-00492-w
336. Panuccio, M. R., Papalia, T., Attinà, E., Giuffrè, A., & Muscolo, A. (2019). Use of digestate as an alternative to mineral fertilizer: Effects on growth and crop quality. Archives of Agronomy and Soil Science, 65(5), 700–711. https://doi.org/10.1080/03650340.2018.1520980
337. Total nitrogen excess and reduction potential. AgResearch. Retrieved 4 December 2023 from https://agresearchnz.maps.arcgis.com/apps/webappviewer/index.html?id=67651ab38f434cf686115e3e8fbc19af
338. Pergola, M., Persiani, A., Palese, A. M., Di Meo, V., Pastore, V., D'Adamo, C., & Celano, G. (2018). Composting: The way for a sustainable agriculture. Applied Soil Ecology, 123, 744–750. https://doi.org/10.1016/j.apsoil.2017.10.016
339. Kuhlman, L. R. (1990). Windrow composting of agricultural and municipal wastes. Resources, Conservation and Recycling, 4(1–2), 151–160. https://doi.org/10.1016/0921-3449(90)90039-7
340. Types of composting and understanding the process. United States Environmental Protection Agency. Retrieved 6 September 2023 from https://www.epa.gov/sustainable-management-food/types-composting-and-understanding-process
341. Compost chemistry. Cornell Waste Management Institute. Retrieved 9 October 2023 from https://compost.css.cornell.edu/chemistry.html
342. Rastogi, M., Nandal, M., & Khosla, B. (2020). Microbes as vital additives for solid waste composting. Heliyon, 6(2), e03343. https://doi.org/10.1016/j.heliyon.2020.e03343
343. Greff, B., Szigeti, J., Nagy, Á., Lakatos, E., & Varga, L. (2022). Influence of microbial inoculants on co-composting of lignocellulosic crop residues with farm animal manure: A review. Journal of Environmental Management, 302, 114088. https://doi.org/10.1016/j.jenvman.2021.114088
344. Compost. Melissa Petruzzello, Britannica. Retrieved 27 November 2023 from https://www.britannica.com/topic/compost
345. Termorshuizen, A., Moolenaar, S., Veeken, A., & Blok, W. J. (2004). The value of compost. Reviews in Environmental Science & Bio/Technology, 3, 343–347. https://doi.org/10.1007/s11157-004-2333-2

346. Hernández, T., Chocano, C., Moreno, J.-L., & García, C. (2016). Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (Lactuca sativa L.) crops—Effects on soil and plant. Soil and Tillage Research, 160, 14–22. https://doi.org/10.1016/j.still.2016.02.005
347. Diaz, L. F., & de Bertoldi, M. (2007). Chapter 2 History of composting. In L. F. Diaz, M. de Bertoldi, W. Bidlingmaier, & E. Stentiford (Eds.), Waste Management Series (Vol. 8, pp. 7–24). Elsevier. https://doi.org/10.1016/S1478-7482(07)80005-4
348. The food recovery hierarchy: Prevention is better than cure. Office of the Prime Minister's Chief Science Advisor. Retrieved 23 January 2024 from https://www.pmcsa.ac.nz/topics/food-rescue-food-waste/what-can-i-do-with-my-food-waste/the-food-recovery-hierarchy-prevention-is-better-than-cure/
349. Composting at home. United States Environmental Protection Agency. Retrieved 30 October 2023 from https://www.epa.gov/recycle/composting-home
350. Gilbert, J., Ricci-Jürgensen, M., & Ramola, A. (2020). Benefits of compost and anaerobic digestate when applied to soil. International Solid Waste Association. https://www.iswa.org/knowledge-base/benefits-of-compost-and-anaerobic-digestate-when-applied-to-soil/?v=8e3eb2c69a18
351. Digestate and compost use in agriculture. WRAP. Retrieved 28 November 2022 from https://wrap.org.uk/resources/guide/compost-and-digestate-agriculture-good-practice-guide
352. Manu, M. K., Li, D., Liwen, L., Jun, Z., Varjani, S., & Wong, J. W. C. (2021). A review on nitrogen dynamics and mitigation strategies of food waste digestate composting. Bioresource Technology, 334, 125032. https://doi.org/10.1016/j.biortech.2021.125032
353. Nafez, A. H., Nikaeen, M., Kadkhodaie, S., Hatamzadeh, M., & Moghim, S. (2015). Sewage sludge composting: Quality assessment for agricultural application. Environmental Monitoring and Assessment, 187(11), 709. https://doi.org/10.1007/s10661-015-4940-5
354. Barrena, R., Artola, A., Vázquez, F., & Sánchez, A. (2009). The use of composting for the treatment of animal by-products: Experiments at lab scale. Journal of Hazardous Materials, 161(1), 380–386. https://doi.org/10.1016/j.jhazmat.2008.03.109
355. Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. Sustainability, 12(11), 4456. https://doi.org/10.3390/su12114456
356. Pipatti, R., Silva Alves, J. W., Gao, Q., Lopez Cabrera, C., Mareckova, K., Oonk, H., Scheehle, E., Sharma, C., Smith, A., Svardal, P., & Yamada, M. (2006). Biological treatment of solid waste. In S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf
357. Roy, D., Azaïs, A., Benkaraache, S., Drogui, P., & Tyagi, R. D. (2018). Composting leachate: Characterization, treatment, and future perspectives. Reviews in Environmental Science and Bio/Technology, 17(2), 323–349. https://doi.org/10.1007/s11157-018-9462-5
358. Chatterjee, N., Flury, M., Hinman, C., & Cogger, C. G. (2013). Chemical and physical characteristics of compost leachates. Washington State University (Prepared for Washington State Department of Transportation). https://www.wsdot.wa.gov/research/reports/fullreports/819.1.pdf
359. Organics processing plant. Christchurch City Council. Retrieved 27 November 2023 from https://ccc.govt.nz/services/rubbish-and-recycling/organicsplant
360. Hutton, B. J. (2022). Quantifying the greenhouse impacts of landfill, composting and incineration: A review of IPCC and US EPA models, and implications for climate change

policy [PhD thesis, School of Engineering, RMIT University]. https://researchrepository.rmit.edu.au/esploro/outputs/doctoral/Quantifying-the-greenhouse-impacts-of-landfill/9922255413401341
361. Kovačić, Đ., Lončarić, Z., Jović, J., Samac, D., Popović, B., & Tišma, M. (2022). Digestate management and processing practices: A review. Applied Sciences, 12(18), 9216. https://doi.org/10.3390/app12189216
362. Singh, J., & Kalamdhad, A. S. (2012). Reduction of heavy metals during composting—A review. International Journal of Environmental Protection, 2(9), 36–43. https://www.researchgate.net/publication/261638773_Reduction_of_Heavy_Metals_during_Composting-_A_Review.
363. Havas, V., Falk-Andersson, J., & Deshpande, P. (2022). Small circles: The role of physical distance in plastics recycling. Science of The Total Environment, 831, 154913. https://doi.org/10.1016/j.scitotenv.2022.154913
364. Dombroski, K., Diprose, G., Sharp, E., Graham, R., Lee, L., Scobie, M., Richardson, S., Watkins, A., & Martin-Neuninger, R. (2020). Food for people in place: Reimagining resilient food systems for economic recovery. Sustainability, 12(22), 9369. https://doi.org/10.3390/su12229369
365. Community solutions for food waste. Office of the Prime Minister's Chief Science Advisor. Retrieved 22 November 2023 from https://www.pmcsa.ac.nz/topics/food-rescue-food-waste/what-can-i-do-with-my-food-waste/community-solutions-for-food-waste/
366. Hutchings, J., Edwards, P., Edwards, H., & Smith, J. (2022). He whenua rongo summary report: Elevating Māori soil and kai resiliency. Papawhakaritorito Charitable Trust & Te Waka Kai Ora. https://s3.amazonaws.com/kajabi-storefronts-production/sites/2147595858/themes/2151315005/downloads/1PIpPvUUSteIHY0Qedc6_HWR_Summary_Report_Final_V2_Online_Version_29_Sep_22_Folder.pdf
367. Petrescu, D., Petcou, C., Safri, M., & Gibson, K. (2021). Calculating the value of the commons: Generating resilient urban futures. Environmental Policy and Governance, 31(3), 159–174. https://doi.org/10.1002/eet.1890
368. Schoen, V., Caputo, S., & Blythe, C. (2020). Valuing physical and social output: A rapid assessment of a London community garden. Sustainability, 12(13), 5452. https://doi.org/10.3390/su12135452
369. Kaicycle. Kaicycle. Retrieved 1 November 2022 from https://kaicycle.org.nz/
370. Standards New Zealand | Te Mana Tautikanga o Aotearoa. (2005). NZS 4454:2005 Composts, soil conditioners and mulches. https://www.standards.govt.nz/shop/nzs-44542005/
371. Soil Foodweb New Zealand. Soil Foodweb New Zealand. Retrieved 4 December 2023 from https://www.soilfoodweb.co.nz
372. Papa Taiao Earthcare. Papa Taiao Earthcare. Retrieved 4 December 2023 from https://www.papataiaoearthcare.nz/
373. Hua Parakore verification system. Te Waka Kai Ora. Retrieved 11 January 2024 from https://www.tewakakaiora.co.nz
374. Living Earth. Living Earth. Retrieved 4 December 2023 from https://livingearth.co.nz/
375. Pierre-Louis, R. C., Kader, M. A., Desai, N. M., & John, E. H. (2021). Potentiality of vermicomposting in the south Pacific island countries: A review. Agriculture, 11(9), 876. https://doi.org/10.3390/agriculture11090876
376. Chan, Y. C., Sinha, R. K., & Weijin Wang. (2011). Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia). Waste Management & Research: The Journal for a Sustainable Circular Economy, 29(5), 540–548. https://doi.org/10.1177/0734242X10375587

377. Fornes, F., Mendoza-Hernández, D., García-de-la-Fuente, R., Abad, M., & Belda, R. M. (2012). Composting versus vermicomposting: A comparative study of organic matter evolution through straight and combined processes. Bioresource Technology, 118, 296–305. https://doi.org/10.1016/j.biortech.2012.05.028
378. Vuković, A., Velki, M., Ečimović, S., Vuković, R., Štolfa Čamagajevac, I., & Lončarić, Z. (2021). Vermicomposting—Facts, benefits and knowledge gaps. Agronomy, 11(10), 1952. https://doi.org/10.3390/agronomy11101952
379. Ievinsh, G., Andersone-Ozola, U., & Zeipiņa, S. (2020). Comparison of the effects of compost and vermicompost soil amendments in organic production of four herb species. Biological Agriculture & Horticulture, 36(4), 267–282. https://doi.org/10.1080/01448765.2020.1812116
380. Yasmin, N., Jamuda, M., Panda, A. K., Samal, K., & Nayak, J. K. (2022). Emission of greenhouse gases (GHGs) during composting and vermicomposting: Measurement, mitigation, and perspectives. Energy Nexus, 7, 100092. https://doi.org/10.1016/j.nexus.2022.100092
381. Suthar, S. (2009). Bioremediation of agricultural wastes through vermicomposting. Bioremediation Journal, 13(1), 21–28. https://doi.org/10.1080/10889860802690513
382. Gupta, C., Prakash, D., Gupta, S., & Nazareno, M. A. (2019). Role of vermicomposting in agricultural waste management. In S. Shah, V. Venkatramanan, & R. Prasad (Eds.), Sustainable Green Technologies for Environmental Management (pp. 283–295). Springer. https://doi.org/10.1007/978-981-13-2772-8_15
383. Nigussie, A., Kuyper, T. W., Bruun, S., & de Neergaard, A. (2016). Vermicomposting as a technology for reducing nitrogen losses and greenhouse gas emissions from small-scale composting. Journal of Cleaner Production, 139, 429–439. https://doi.org/10.1016/j.jclepro.2016.08.058
384. Scion. (2013). Technical sheet: Vermicomposting. https://www.scionresearch.com/__data/assets/pdf_file/0003/40863/vermicomposting.pdf
385. Hajam, Y. A., Kumar, R., & Kumar, A. (2023). Environmental waste management strategies and vermi transformation for sustainable development. Environmental Challenges, 13, 100747. https://doi.org/10.1016/j.envc.2023.100747
386. Panda, A. K., Mishra, R., Dutta, J., Wani, Z. A., Pant, S., Siddiqui, S., Alamri, S. A., Alrumman, S. A., Alkahtani, M. A., & Bisht, S. S. (2022). Impact of vermicomposting on greenhouse gas emission: A short review. Sustainability, 14(18), 11306. https://doi.org/10.3390/su141811306
387. WasteMINZ & Plastics NZ. (2019). Best practice guidelines for the advertising of compostable packaging. https://www.wasteminz.org.nz/files/Organic%20Materials/Best%20practice%20guidelines%20for%20advertising%20compostable%20packaging.PDF
388. How are worm tea and worm leachate different? Uncle Jim's Worm Farm. Retrieved 4 December 2023 from https://unclejimswormfarm.com/how-are-worm-tea-and-worm-leachate-different/
389. Worm farms 101: Everything you need to know. Love Food Hate Waste. Retrieved 4 December 2023 from https://lovefoodhatewaste.co.nz/worm-farms-101-everything-you-need-to-know/
390. Roberto Carlos, G.-G., Dendooven, L., & Federico Antonio, G.-M. (2008). Vermicomposting leachate (worm tea) as liquid fertilizer for maize (Zea mays l.) forage production. Asian Journal of Plant Sciences, 7(4), 360–367. https://doi.org/10.3923/ajps.2008.360.367
391. Rehman, S. ur, De Castro, F., Aprile, A., Benedetti, M., & Fanizzi, F. P. (2023). Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. Agronomy, 13(4), 1134. https://doi.org/10.3390/agronomy13041134

392. Donohoe, K. (2018). Chemical and microbial characteristics of vermicompost leachate and their effect on plant growth [PhD thesis, School of Life and Environmental Sciences, University of Sydney]. https://ses.library.usyd.edu.au/handle/2123/18212
393. El-Haddad, M. E., Zayed, M. S., El-Sayed, G. A. M., Hassanein, M. K., & Abd El-Satar, A. M. (2014). Evaluation of compost, vermicompost and their teas produced from rice straw as affected by addition of different supplements. Annals of Agricultural Sciences, 59(2), 243–251. https://doi.org/10.1016/j.aoas.2014.11.013
394. Arancon, N. Q., Owens, J. D., & Converse, C. (2019). The effects of vermicompost tea on the growth and yield of lettuce and tomato in a non-circulating hydroponics system. Journal of Plant Nutrition, 42(19), 2447–2458. https://doi.org/10.1080/01904167.2019.1655049
395. van de Zande, E. M., Wantulla, M., van Loon, J. J. A., & Dicke, M. (2023). Soil amendment with insect frass and exuviae affects rhizosphere bacterial community, shoot growth and carbon/nitrogen ratio of a brassicaceous plant. Plant and Soil. https://doi.org/10.1007/s11104-023-06351-6
396. Mealworm FRASS | All Natural Fertiliser. Herbi. Retrieved 4 December 2023 from https://herbi.nz/product/mealworm-frass-terra-nutes
397. iNZect Direct. iNZect Direct New Zealand. Retrieved 17 January 2021 from https://inzectdirect.co.nz/
398. O'Connor, J., Hoang, S. A., Bradney, L., Rinklebe, J., Kirkham, M. B., & Bolan, N. S. (2022). Value of dehydrated food waste fertiliser products in increasing soil health and crop productivity. Environmental Research, 204, 111927. https://doi.org/10.1016/j.envres.2021.111927
399. United States Environmental Protection Agency. (2021). Emerging issues in food waste management: Commercial pre-processing technologies. https://www.epa.gov/system/files/documents/2021-09/commercial-pre-processing-technologies_508-tagged_0.pdf
400. Razak, I. (2023, February 17). Landmark trial turns apartment food scraps into fertiliser in bid to curb staggering food waste. ABC News. https://www.abc.net.au/news/2023-02-17/vic-food-waste-trial-melbourne-apartments-dehydrators/101978298
401. Gillman, A., Campbell, D. C., & Spang, E. S. (2019). Does on-farm food loss prevent waste? Insights from California produce growers. Resources, Conservation and Recycling, 150, 104408. https://doi.org/10.1016/j.resconrec.2019.104408
402. Heyman, H., Bassuk, N., Bonhotal, J., & Walter, T. (2019). Compost quality recommendations for remediating urban soils. International Journal of Environmental Research and Public Health, 16(17), 3191. https://doi.org/10.3390/ijerph16173191
403. Rojas, R. V., Achouri, M., Maroulis, J., & Caon, L. (2016). Healthy soils: A prerequisite for sustainable food security. Environmental Earth Sciences, 75(3), 180. https://doi.org/10.1007/s12665-015-5099-7
404. Ministry for the Environment | Manatū Mō Te Taiao & StatsNZ | Tatauranga Aotearoa. (2021). Our land 2021. https://environment.govt.nz/assets/Publications/our-land-2021.pdf
405. Rabot, E., Wiesmeier, M., Schlüter, S., & Vogel, H.-J. (2018). Soil structure as an indicator of soil functions: A review. Geoderma, 314, 122–137. https://doi.org/10.1016/j.geoderma.2017.11.009
406. Wallace, D., Almond, P., Carrick, S., & Thomas, S. (2020). Targeting changes in soil porosity through modification of compost size and application rate. Soil Research, 58(3), 268. https://doi.org/10.1071/SR19170
407. Menegat, S., Ledo, A., & Tirado, R. (2022). Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. Scientific Reports, 12(1), 14490. https://doi.org/10.1038/s41598-022-18773-w
408. King, E. (2023). Re-food. Mary Egan Publishing.

409. Fertilisers—Nitrogen and phosphorous. StatsNZ |Tatauranga Aotearoa. Retrieved 4 December 2023 from https://www.stats.govt.nz/indicators/fertilisers-nitrogen-and-phosphorus
410. Synthetic nitrogen fertiliser cap. Ministry for the Environment | Manatū mō te Taiao. Retrieved 31 July 2023 from https://environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/agriculture-and-horticulture/synthetic-nitrogen-fertiliser-cap-in-place-from-1-july/
411. Julian, J. P., de Beurs, K. M., Owsley, B., Davies-Colley, R. J., & Ausseil, A.-G. E. (2017). River water quality changes in New Zealand over 26 years: Response to land use intensity. Hydrology and Earth System Sciences, 21(2), 1149–1171. https://doi.org/10.5194/hess-21-1149-2017
412. Edmeades, D., Morton, J., Waller, J., Metherell, A., Roberts, A., & Carey, P. (2010). The diagnosis and correction of potassium deficiency in New Zealand pastoral soils: A review. New Zealand Journal of Agricultural Research, 53(2), 151–173. https://doi.org/10.1080/00288233.2010.482954
413. Cordell, D., & Neset, T.-S. S. (2014). Phosphorus vulnerability: A qualitative framework for assessing the vulnerability of national and regional food systems to the multi-dimensional stressors of phosphorus scarcity. Global Environmental Change, 24, 108–122. https://doi.org/10.1016/j.gloenvcha.2013.11.005
414. Gilbert, J., & Siebert, S. (2022). ECN data report 2022: Compost and digestate for a circular economy. European Compost Network. https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-rapport-2022.pdf
415. Roskruge, N. (2011). Traditional Maori (sic) horticultural and ethnopedological praxis in the New Zealand landscape. Management of Environmental Quality, 22(2), 200–212. https://doi.org/10.1108/14777831111113383
416. Roskruge, N. (2022, February 28). The whakapapa of soil. Stuff. https://www.stuff.co.nz/life-style/homed/garden/127806399/the-whakapapa-of-soil
417. Furey, L. (2006). Māori gardening: An archaeological perspective. Department of Conservation | Te Papa Atawhai. https://www.doc.govt.nz/documents/science-and-technical/sap235.pdf
418. Pai, S., Ai, N., & Zheng, J. (2019). Decentralized community composting feasibility analysis for residential food waste: A Chicago case study. Sustainable Cities and Society, 50, 101683. https://doi.org/10.1016/j.scs.2019.101683
419. Morrow, O., & Davies, A. (2022). Creating careful circularities: Community composting in New York City. Transactions of the Institute of British Geographers, 47(2), 529–546. https://doi.org/10.1111/tran.12523
420. Latif, J. (2022, March 17). Composting initiative to 'supercharge' Māngere marae's good works. RNZ. https://www.rnz.co.nz/news/ldr/463498/composting-initiative-to-supercharge-mangere-marae-s-good-works
421. Diprose, G., Levenson, E., Booth, P., Prince, L., & Blumhardt, H. (2023). Scaling-up, scaling-out & branching-out: Understanding & procuring diverse organic materials management models in Aotearoa New Zealand. Manaaki Whenua| Landcare Research; Zero Waste Network. https://drive.google.com/file/d/1EcHlj0OsWJvGO4HLVPfgUI4ASbVi2JXh/view
422. Safer and healthier gardening. HealthEd. Retrieved 4 December 2023 from https://healthed.govt.nz/products/safer-and-healthier-gardening
423. Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., & Sánchez, A. (2018). Composting of food wastes: Status and challenges. Bioresource Technology, 248(Pt A), 57–67. https://doi.org/10.1016/j.biortech.2017.06.133

424. Fisher, A. (2020). Ecogas—Overview for Auckland Council. Ecogas. https://ourauckland.aucklandcouncil.govt.nz/media/00rkdrcq/ecogas-overview-for-auckland-council.pdf
425. Bonnichsen, O., Jacobsen, B. H., & Tur-Cardona, J. (2020). Danish farmers' preferences for bio-based fertilisers—A choice experiment. IFRO Working Paper, 15. https://www.econstor.eu/bitstream/10419/227738/1/1743137117.pdf.
426. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. (2023). Energy in New Zealand in 2023. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/energy-in-new-zealand-2023/
427. Saqib, N. U., Sharma, H. B., Baroutian, S., Dubey, B., & Sarmah, A. K. (2019). Valorisation of food waste via hydrothermal carbonisation and techno-economic feasibility assessment. Science of the Total Environment, 690, 261–276. https://doi.org/10.1016/j.scitotenv.2019.06.484
428. Pham, T. P. T., Kaushik, R., Parshetti, G. K., Mahmood, R., & Balasubramanian, R. (2015). Food waste-to-energy conversion technologies: Current status and future directions. Waste Management, 38, 399–408. https://doi.org/10.1016/j.wasman.2014.12.004
429. Queensland Government Department of Environment and Science. (2021). Energy from waste policy. https://www.qld.gov.au/__data/assets/pdf_file/0020/118433/energy-from-waste-policy.pdf
430. Energy Efficiency & Conservation Authority | Te Tari Tiaki Pūngao, BECA, Fonterra, & Firstgas Group. (2021). Biogas and biomethane in New Zealand: Unlocking New Zealand's biomethane potential (2939894-1559009345–106). EECA, Firstgas Group, Fonterra. https://www.beca.com/getmedia/4294a6b9-3ed3-48ce-8997-a16729aff608/Biogas-and-Biomethane-in-NZ-Unlocking-New-Zealand-s-Renewable-Natural-Gas-Potential.pdf
431. International Energy Agency. (2020). Outlook for biogas and biomethane (World Energy Outlook Special Report). https://iea.blob.core.windows.net/assets/03aeb10c-c38c-4d10-bcec-de92e9ab815f/Outlook_for_biogas_and_biomethane.pdf
432. Lu, J., & Xu, S. (2021). Post-treatment of food waste digestate towards land application: A review. Journal of Cleaner Production, 303, 127033. https://doi.org/10.1016/j.jclepro.2021.127033
433. Bolzonella, D., Fatone, F., Gottardo, M., & Frison, N. (2018). Nutrients recovery from anaerobic digestate of agro-waste: Techno-economic assessment of full scale applications. Journal of Environmental Management, 216, 111–119. https://doi.org/10.1016/j.jenvman.2017.08.026
434. Bioenergy Association. (2021). The production and use as biofertiliser of digestate derived from source segregated organic waste. https://www.biogas.org.nz/documents/resource/TG08-Production-and-use-of-digestate-as-fertiliser.pdf
435. Herbes, C., Roth, U., Wulf, S., & Dahlin, J. (2020). Economic assessment of different biogas digestate processing technologies: A scenario-based analysis. Journal of Cleaner Production, 255, 120282. https://doi.org/10.1016/j.jclepro.2020.120282
436. Govasmark, E., Stäb, J., Holen, B., Hoornstra, D., Nesbakk, T., & Salkinoja-Salonen, M. (2011). Chemical and microbiological hazards associated with recycling of anaerobic digested residue intended for agricultural use. Waste Management, 31(12), 2577–2583. https://doi.org/10.1016/j.wasman.2011.07.025
437. Chen, T., Qiu, X., Feng, H., Yin, J., & Shen, D. (2021). Solid digestate disposal strategies to reduce the environmental impact and energy consumption of food waste-based biogas

systems. Bioresource Technology, 325, 124706. https://doi.org/10.1016/j.biortech.2021.124706
438. Ali, A., S. Nesse, A., Eich-Greatorex, S., A. Sogn, T., G. Aanrud, S., Bunæs, J. A. A., L. Lyche, J., & Kallenborn, R. (2019). Organic contaminants of emerging concern in Norwegian digestates from biogas production. Environmental Science: Processes & Impacts, 21(9), 1498–1508. https://doi.org/10.1039/C9EM00175A
439. Nesse, A. S., Aanrud, S. G., Lyche, J. L., Sogn, T., & Kallenborn, R. (2022). Confirming the presence of selected antibiotics and steroids in Norwegian biogas digestate. Environmental Science and Pollution Research, 29(57), 86595–86605. https://doi.org/10.1007/s11356-022-21479-1
440. Seadi, T. A., & Lukehurst, C. (2012). Quality management of digestate from biogas plants used as fertiliser. IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2012/05/digestate_quality_web_new.pdf
441. BSI PAS 110: Producing quality anaerobic digestate. WRAP. Retrieved 3 August 2023 from https://wrap.org.uk/resources/guide/bsi-pas-110-producing-quality-anaerobic-digestate
442. Huang, Y., Zhao, C., Gao, B., Ma, S., Zhong, Q., Wang, L., & Cui, S. (2022). Life cycle assessment and society willingness to pay indexes of food waste-to-energy strategies. Journal of Environmental Management, 305, 114364. https://doi.org/10.1016/j.jenvman.2021.114364
443. Nordahl, S. L., Devkota, J. P., Amirebrahimi, J., Smith, S. J., Breunig, H. M., Preble, C. V., Satchwell, A. J., Jin, L., Brown, N. J., Kirchstetter, T. W., & Scown, C. D. (2020). Life-cycle greenhouse gas emissions and human health trade-offs of organic waste management strategies. Environmental Science & Technology, 54(15), 9200–9209. https://doi.org/10.1021/acs.est.0c00364
444. Tinholt, R. (2022). Meeting with Watercare [Personal communication].
445. Crolla, A., Kinsley, C., & Pattey, E. (2013). Land application of digestate. In A. Wellinger, J. Murphy, & D. Baxter (Eds.), The Biogas Handbook (pp. 302–325). Woodhead Publishing. https://doi.org/10.1533/9780857097415.2.302
446. Salter, F., Litterick, A., & Crooks, B. (2022). Digestate use on Scottish Farms. Farming and Water Scotland. https://www.farmingandwaterscotland.org/wp-content/uploads/2022/05/202205_Digestate-Use-on-Scottish-Farms_Final.pdf
447. O'Connor, J., Mickan, B. S., Rinklebe, J., Song, H., Siddique, K. H. M., Wang, H., Kirkham, M. B., & Bolan, N. S. (2022). Environmental implications, potential value, and future of food-waste anaerobic digestate management: A review. Journal of Environmental Management, 318, 115519. https://doi.org/10.1016/j.jenvman.2022.115519
448. Monfet, E., Aubry, G., & Ramirez, A. A. (2018). Nutrient removal and recovery from digestate: A review of the technology. Biofuels, 9(2), 247–262. https://doi.org/10.1080/17597269.2017.1336348
449. Opatokun, S. A., Strezov, V., & Kan, T. (2015). Product based evaluation of pyrolysis of food waste and its digestate. Energy, 92, 349–354. https://doi.org/10.1016/j.energy.2015.02.098
450. Pilot plant & digestate trials. Ecogas. Retrieved 31 July 2023 from https://www.ecogas.co.nz/pilot-plant-digestate-trials
451. New South Wales Environment Protection Authority. (2022). Emissions impacts of anaerobic digestion for food waste processing. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4165-emissions-impacts-anaerobic-digestion-food-waste-processing.pdf

452. Albizzati, P. F., Tonini, D., Chammard, C. B., & Astrup, T. F. (2019). Valorisation of surplus food in the French retail sector: Environmental and economic impacts. Waste Management, 90, 141–151. https://doi.org/10.1016/j.wasman.2019.04.034
453. Moult, J. A., Allan, S. R., Hewitt, C. N., & Berners-Lee, M. (2018). Greenhouse gas emissions of food waste disposal options for UK retailers. Food Policy, 77, 50–58. https://doi.org/10.1016/j.foodpol.2018.04.003
454. Salemdeeb, R., Bin Daina, M., Reynolds, C., & Al-Tabbaa, A. (2018). An environmental evaluation of food waste downstream management options: A hybrid LCA approach. International Journal of Recycling of Organic Waste in Agriculture, 7(3), 217–229. https://doi.org/10.1007/s40093-018-0208-8
455. IEA Bioenergy. (2020). Production of food grade sustainable CO2 from a large biogas facility. https://www.ieabioenergy.com/wp-content/uploads/2020/11/Case-Story-CO2-recovery-Denmark-November-2020.pdf
456. Tanigawa, S. (2017). Fact sheet | biogas: Converting waste to energy. Environmental and Energy Study Institute. https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy
457. Cowley, C., & Brorsen, B. W. (2018). Anaerobic digester production and cost functions. Ecological Economics, 152, 347–357. https://doi.org/10.1016/j.ecolecon.2018.06.013
458. Das, J., Ravishankar, H., & Lens, P. N. L. (2022). Biological biogas purification: Recent developments, challenges and future prospects. Journal of Environmental Management, 304, 114198. https://doi.org/10.1016/j.jenvman.2021.114198
459. Sánchez-Rodríguez, A. R., Carswell, A. M., Shaw, R., Hunt, J., Saunders, K., Cotton, J., Chadwick, D. R., Jones, D. L., & Misselbrook, T. H. (2018). Advanced processing of food waste based digestate for mitigating nitrogen losses in a winter wheat crop. Frontiers in Sustainable Food Systems, 2. https://doi.org/10.3389/fsufs.2018.00035
460. Certification of biofertilizer. Research Institutes of Sweden. Retrieved 23 January 2024 from https://www.ri.se/en/what-we-do/services/certification-of-biofertilizer
461. Liu, C., Nishiyama, T., Kawamoto, K., & Sasaki, S. (2020). Waste-to-energy incineration. United Nations Environment Programme, International Environmental Technology Centre, & Institute for Global Environmental Strategies. https://wedocs.unep.org/bitstream/handle/20.500.11822/32795/WtEI.pdf?sequence=1&isAllowed=y
462. NZ Herald. (2023, October 16). Te Awamutu waste-to-energy plant proposal receives record number of submissions. https://www.nzherald.co.nz/waikato-news/news/te-awamutu-waste-to-energy-plant-proposal-receives-record-number-of-submissions/2LWYQA46TJC2ZCRH2622GD4GVU/
463. Pointon, N. (2021, September 15). Huge waste-to-energy plant proposed in South Canterbury. Radio New Zealand. https://www.rnz.co.nz/news/business/451555/huge-waste-to-energy-plant-proposed-in-south-canterbury?fbclid=IwAR2cEfnkTM3ZuPXwSGkaiWn2v_BLzxgo7O3wulbJpUFXlRLf8VrKCjF3Ce8
464. Ministry for the Environment | Manatū Mō Te Taiao. (2022). New Zealand’s greenhouse gas inventory. https://environment.govt.nz/assets/publications/GhG-Inventory/New-Zealand-Greenhouse-Gas-Inventory-1990-2020-Chapters-1-15.pdf
465. Bingham, A. (2022). 2022 Update of the New Zealand inventory of dioxin emissions to air, land and water, and reservoir sources. JCL Air and Environment (Prepared for Ministry for the Environment | Manatū Mō Te Taiao). https://environment.govt.nz/assets/publications/2022-Update-of-the-New-Zealand-Inventory-of-Dioxin-Emissions-to-Air-Land-and-Water-and-Reservoir-Sources.pdf

466. WasteMINZ Behaviour Change Sector Group urges action on waste-to-energy facilities. WasteMINZ. Retrieved 4 December 2023 from https://www.wasteminz.org.nz/blogs/post/wasteminz-urges-action-on-waste-to-energy-facilities
467. Zero Waste Europe. (2019). The hidden impacts of incineration residues. https://zerowasteeurope.eu/wp-content/uploads/2019/11/zero_waste_europe_cs_the-hidden-impacts-of-incineration-residues_en.pdf
468. Energy recovery from the combustion of municipal solid waste (MSW). United States Environmental Protection Agency. Retrieved 4 December 2023 from https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw
469. Elkhalifa, S., Al-Ansari, T., Mackey, H. R., & McKay, G. (2019). Food waste to biochars through pyrolysis: A review. Resources, Conservation and Recycling, 144, 310–320. https://doi.org/10.1016/j.resconrec.2019.01.024
470. Grycová, B., Koutník, I., & Pryszcz, A. (2016). Pyrolysis process for the treatment of food waste. Bioresource Technology, 218, 1203–1207. https://doi.org/10.1016/j.biortech.2016.07.064
471. Volpe, M., Panno, D., Volpe, R., & Messineo, A. (2015). Upgrade of citrus waste as a biofuel via slow pyrolysis. Journal of Analytical and Applied Pyrolysis, 115, 66–76. https://doi.org/10.1016/j.jaap.2015.06.015
472. Lazzari, E., Schena, T., Primaz, C. T., Da Silva Maciel, G. P., Machado, M. E., Cardoso, C. A. L., Jacques, R. A., & Caramão, E. B. (2016). Production and chromatographic characterization of bio-oil from the pyrolysis of mango seed waste. Industrial Crops and Products, 83, 529–536. https://doi.org/10.1016/j.indcrop.2015.12.073
473. Lehmann, J., Cowie, A., Masiello, C. A., Kammann, C., Woolf, D., Amonette, J. E., Cayuela, M. L., Camps-Arbestain, M., & Whitman, T. (2021). Biochar in climate change mitigation. Nature Geoscience, 14(12), 883–892. https://doi.org/10.1038/s41561-021-00852-8
474. Joseph, S., Cowie, A. L., Van Zwieten, L., Bolan, N., Budai, A., Buss, W., Cayuela, M. L., Graber, E. R., Ippolito, J. A., Kuzyakov, Y., Luo, Y., Ok, Y. S., Palansooriya, K. N., Shepherd, J., Stephens, S., Weng, Z., & Lehmann, J. (2021). How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. GCB Bioenergy, 13(11), 1731–1764. https://doi.org/10.1111/gcbb.12885
475. Dong, J., Tang, Y., Nzihou, A., & Chi, Y. (2019). Key factors influencing the environmental performance of pyrolysis, gasification and incineration Waste-to-Energy technologies. Energy Conversion and Management, 196, 497–512. https://doi.org/10.1016/j.enconman.2019.06.016
476. You, S., Ok, Y. S., Tsang, D. C. W., Kwon, E. E., & Wang, C.-H. (2018). Towards practical application of gasification: A critical review from syngas and biochar perspectives. Critical Reviews in Environmental Science and Technology, 48(22–24), 1165–1213. https://doi.org/10.1080/10643389.2018.1518860
477. Dallas, M. (2023, June 9). Contentious Feilding waste-to-fuel plant proposal withdrawn due to "technicalities." Stuff. https://www.stuff.co.nz/manawatu-standard/300901213/contentious-feilding-wastetofuel-plant-proposal-withdrawn-due-to-technicalities
478. Etter, H., Vera, A., Aggarwal, C., Delaney, M., & Manley, S. (2023). Methodology for biochar utilization in soil and non-soil applications, v1.1. Biochar Works, Delaney Forestry Servcies, Forliance, South Pole, & Verra. https://verra.org/methodologies/vm0044-methodology-for-biochar-utilization-in-soil-and-non-soil-applications/
479. Antonangelo, J. A., Sun, X., & Zhang, H. (2021). The roles of co-composted biochar (COMBI) in improving soil quality, crop productivity, and toxic metal amelioration. Journal of Environmental Management, 277, 111443. https://doi.org/10.1016/j.jenvman.2020.111443

480. Zhao, W., Yang, H., He, S., Zhao, Q., & Wei, L. (2021). A review of biochar in anaerobic digestion to improve biogas production: Performances, mechanisms and economic assessments. Bioresource Technology, 341, 125797. https://doi.org/10.1016/j.biortech.2021.125797
481. Ma, J., Wilson, K., Zhao, Q., Yorgey, G., & Frear, C. (2013). Odor in commercial scale compost: Literature review and critical analysis. Washington State Department of Ecology & Washington State University. https://apps.ecology.wa.gov/publications/documents/1307066.pdf
482. Guo, M., Song, W., & Tian, J. (2020). Biochar-facilitated soil remediation: Mechanisms and efficacy variations. Frontiers in Environmental Science, 8. https://www.frontiersin.org/articles/10.3389/fenvs.2020.521512
483. International Biochar Initiative. (2015). Standardized product definition and product testing guidelines for biochar that is used in soil. https://biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Standards_V2.1_Final.pdf
484. Liu, T., Miao, P., Shi, Y., Tang, K. H. D., & Yap, P.-S. (2022). Recent advances, current issues and future prospects of bioenergy production: A review. Science of the Total Environment, 810, 152181. https://doi.org/10.1016/j.scitotenv.2021.152181
485. Conesa, J. A., Font, R., Fullana, A., Martín-Gullón, I., Aracil, I., Gálvez, A., Moltó, J., & Gómez-Rico, M. F. (2009). Comparison between emissions from the pyrolysis and combustion of different wastes. Journal of Analytical and Applied Pyrolysis, 84(1), 95–102. https://doi.org/10.1016/j.jaap.2008.11.022
486. Rodriguez Correa, C., Hehr, T., Voglhuber-Slavinsky, A., Rauscher, Y., & Kruse, A. (2019). Pyrolysis vs. hydrothermal carbonization: Understanding the effect of biomass structural components and inorganic compounds on the char properties. Journal of Analytical and Applied Pyrolysis, 140, 137–147. https://doi.org/10.1016/j.jaap.2019.03.007
487. Elliott, D. C. (2011). Hydrothermal processing. In C. V. Stevens & R. C. Brown (Eds.), Thermochemical Processing of Biomass (pp. 200–231). John Wiley & Sons. https://doi.org/10.1002/9781119990840.ch7
488. Wang, Y., Qiu, L., Zhu, M., Sun, G., Zhang, T., & Kang, K. (2019). Comparative evaluation of hydrothermal carbonization and low temperature pyrolysis of Eucommia ulmoides Oliver for the production of solid biofuel. Scientific Reports, 9(1), 5535. https://doi.org/10.1038/s41598-019-38849-4
489. Sun, K., Han, L., Yang, Y., Xia, X., Yang, Z., Wu, F., Li, F., Feng, Y., & Xing, B. (2020). Application of hydrochar altered soil microbial community composition and the molecular structure of native soil organic carbon in a paddy soil. Environmental Science & Technology, 54(5), 2715–2725. https://doi.org/10.1021/acs.est.9b05864
490. Lachos-Perez, D., César Torres-Mayanga, P., Abaide, E. R., Zabot, G. L., & De Castilhos, F. (2022). Hydrothermal carbonization and liquefaction: Differences, progress, challenges, and opportunities. Bioresource Technology, 343, 126084. https://doi.org/10.1016/j.biortech.2021.126084
491. Carmona-Cabello, M., Leiva-Candia, D., Castro-Cantarero, J. L., Pinzi, S., & Dorado, M. P. (2018). Valorization of food waste from restaurants by transesterification of the lipid fraction. Fuel, 215, 492–498. https://doi.org/10.1016/j.fuel.2017.11.096
492. Matsakas, L., Kekos, D., Loizidou, M., & Christakopoulos, P. (2014). Utilization of household food waste for the production of ethanol at high dry material content. Biotechnology for Biofuels, 7, 4. https://doi.org/10.1186/1754-6834-7-4

493. WSP (Pepared for Ministry of Business, Innovation and Employment | Hīkina Whakatutuki). (2022). NZ Battery Project: Other technologies feasibility study. https://www.mbie.govt.nz/dmsdocument/27130-other-technologies-feasibility-study-feasibility-assessment-report
494. Municipal waste (indicator). Organisation for Economic Cooperation and Development. Retrieved 17 December 2023 from https://doi.org/10.1787/89d5679a-en
495. Perrot, J.-F., & Subiantoro, A. (2018). Municipal waste management strategy review and waste-to-energy potentials in new zealand. Sustainability, 10(9), 3114. https://doi.org/10.3390/su10093114
496. Types of landfills. Ministry for the Environment | Manatū Mō Te Taiao. Retrieved 17 December 2023 from https://environment.govt.nz/guides/types-of-landfills/
497. Buchholz, K. (2022, March 28). Infographic: A World of Waste. Statista Daily Data. https://www.statista.com/chart/18732/waste-generated-country
498. Environment and Communications References Committee. (2018). The waste and recycling industry in Australia. Commonwealth of Australia. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/WasteandRecycling/Report/c04
499. Landfill tax in 2023 UK. Waste Managed. Retrieved 17 December 2023 from https://www.wastemanaged.co.uk/landfill-tax/
500. Waste disposal levy expansion. Ministry for the Environment | Manatū mō te Taiao. Retrieved 3 November 2023 from https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/waste-disposal-levy/expansion/
501. WasteMINZ. (2022). Technical guidelines for disposal to land—Revision 3. https://www.wasteminz.org.nz/files/Disposal%20to%20Land/TG%20for%20Disposal%20to%20Land_12Oct22_FINAL.pdf
502. Ministry for the Environment | Manatū Mō Te Taiao. (2001). A guide for the management of closing and closed landfills in New Zealand. https://environment.govt.nz/assets/Publications/Files/closed-landfills-guide-may01_0.pdf
503. Woolf, A. L. (2020, January 3). Landfill shut in 1971 still making Wellington beach reek of petrol, resident says. Stuff. https://www.stuff.co.nz/environment/118557192/landfill-shut-in-1971-still-making-wellington-beach-reek-of-petrol-resident-says
504. RNZ. (2022, February 11). Fox River landfill clean up finally completed at a cost of over $3m. https://www.rnz.co.nz/news/national/461316/fox-river-landfill-clean-up-finally-completed-at-a-cost-of-over-3m
505. Landfills: A marvel of modern engineering. Waste Management. Retrieved 17 December 2023 from https://www.wastemanagement.co.nz/news-and-media/Landfills-A-marvel-of-modern-engineering/
506. Ministry for the Environment | Manatū Mō Te Taiao. (2019). Reducing waste: A more effective landfill levy. https://environment.govt.nz/assets/Publications/Files/reducing-waste-a-more-effective-landfill-levy-consultation-document.pdf
507. Landfill methane capture. Project Drawdown. Retrieved 28 June 2023 from https://drawdown.org/solutions/landfill-methane-capture
508. Modern landfill – a waste-to-energy innovation. Office of the Prime Minister's Chief Science Advisor. Retrieved 24 January 2024 from https://www.pmcsa.ac.nz/2019/11/05/modern-landfill-a-waste-to-energy-innovation/
509. Macdonald, N. (2021, August 1). "We are extremely wasteful": Is it time to dump the dumps? Stuff. https://www.stuff.co.nz/environment/125829093/we-are-extremely-wasteful-is-it-time-to-dump-the-dumps

510. New South Wales Environment Protection Authority. (2021). Emissions impacts of landfilling food waste. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4163-emissions-impacts-landfilling-food-waste.pdf
511. Ministry for the Environment | Manatū Mō Te Taiao. (2023). Measuring emissions: A guide for organisations—2023 detailed guide. https://environment.govt.nz/assets/publications/Measuring-Emissions-Guidance_DetailedGuide_2023_ME1764.pdf
512. Department of Environment and Science. (2022). Queensland Organics Action Plan 2022-3032. Queensland Government. https://www.qld.gov.au/__data/assets/pdf_file/0023/240746/organics-action-plan.pdf
513. Compost and food waste recycling. Brisbane City Council. Retrieved 25 October 2022 from https://www.brisbane.qld.gov.au/clean-and-green/green-home-and-community/sustainable-gardening/compost-and-food-waste-recycling
514. Food waste recycling service. Brisbane City Council. Retrieved 25 October 2022 from https://www.brisbane.qld.gov.au/clean-and-green/rubbish-tips-and-bins/rubbish-bins/food-waste-recycling-service-pilot
515. New South Wales Environment Protection Authority. (2022). Emissions impacts of food waste recovery technologies. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4168-emissions-impacts-food-waste-recovery-technologies.pdf?la=en&hash=54897B2223F64252BA77A9F1ED982C1D39EB72EC
516. Ministry for the Environment | Manatū Mō Te Taiao. (2023). Te Rārangi Haurehu Kati Mahana a Aotearoa: He Whakarāpopoto | New Zealand's Greenhouse Gas Inventory 1990–2021: Snapshot. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-19902021-snapshot/
517. Ngā wāhi para me te tukunga Waste facilities and disposal. Ministry for the Environment | Manatū Mō Te Taiao. Retrieved 17 December 2023 from https://environment.govt.nz/facts-and-science/waste/waste-facilities-and-disposal/#:~:text=Requirements)%20Regulations%202021.-,waste%20generation%20and%20disposal,-The%20waste%20tonnages
518. Bernstad, A., & la Cour Jansen, J. (2012). Review of comparative LCAs of food waste management systems – Current status and potential improvements. Waste Management, 32(12), 2439–2455. https://doi.org/10.1016/j.wasman.2012.07.023
519. Kwan, T. H., Pleissner, D., Lau, K. Y., Venus, J., Pommeret, A., & Lin, C. S. K. (2015). Techno-economic analysis of a food waste valorization process via microalgae cultivation and co-production of plasticizer, lactic acid and animal feed from algal biomass and food waste. Bioresource Technology, 198, 292–299. https://doi.org/10.1016/j.biortech.2015.09.003
520. Kocher, N. C. (2018). A cost-benefit analysis of food waste processing in Massachusetts [Master's Thesis, Harvard University]. https://dash.harvard.edu/handle/1/37945110
521. Lam, C.-M., Yu, I. K. M., Medel, F., Tsang, D. C. W., Hsu, S.-C., & Poon, C. S. (2018). Life-cycle cost-benefit analysis on sustainable food waste management: The case of Hong Kong International Airport. Journal of Cleaner Production, 187, 751–762. https://doi.org/10.1016/j.jclepro.2018.03.160
522. Makov, T., Shepon, A., Krones, J., Gupta, C., & Chertow, M. (2020). Social and environmental analysis of food waste abatement via the peer-to-peer sharing economy. Nature Communications, 11(1), 1156. https://doi.org/10.1038/s41467-020-14899-5
523. Rao, M., Bast, A., & de Boer, A. (2023). Understanding the phenomenon of food waste valorisation from the perspective of supply chain actors engaged in it. Agricultural and Food Economics, 11(1), 40. https://doi.org/10.1186/s40100-023-00279-2

524. Wardman, H. (2021). Food waste management alternatives for New South Wales: A life cycle assessment approach [Honour's Thesis, Department of Chemical and Biomolecular Engineering, University of Sydney].
525. Wasted Food Scale. United Stated Environmental Protection Agency. Retrieved 24 November 2023 from https://www.epa.gov/sustainable-management-food/wasted-food-scale
526. Rinot, O., Levy, G. J., Steinberger, Y., Svoray, T., & Eshel, G. (2019). Soil health assessment: A critical review of current methodologies and a proposed new approach. The Science of the Total Environment, 648, 1484–1491. https://doi.org/10.1016/j.scitotenv.2018.08.259
527. Bessou, C., Tailleur, A., Godard, C., Gac, A., de la Cour, J. L., Boissy, J., Mischler, P., Caldeira-Pires, A., & Benoist, A. (2020). Accounting for soil organic carbon role in land use contribution to climate change in agricultural LCA: Which methods? Which impacts? The International Journal of Life Cycle Assessment, 25(7), 1217–1230. https://doi.org/10.1007/s11367-019-01713-8
528. Rescued kitchen. Rescued Kitchen. Retrieved 15 December 2023 from https://www.rescued.co.nz/
529. Bell, M. (2023). Meeting with Food Bowl [Personal communication].
530. Kim, M. S. (2022, November 20). South Korea has almost zero food waste. Here's what the US can learn. The Guardian. https://www.theguardian.com/environment/2022/nov/20/south-korea-zero-food-waste-composting-system
531. Nakaishi, T., & Takayabu, H. (2022). Production efficiency of animal feed obtained from food waste in Japan. Environmental Science and Pollution Research, 29, 61187–61203. https://doi.org/10.1007/s11356-022-20221-1
532. Fush* skin face mask anyone? New Zealand Story. Retrieved 15 December 2023 from https://www.nzstory.govt.nz/stories/sustainable-fish-skin-face-mask-anyone/
533. Zaid, O., Ahmad, J., Siddique, M. S., & Aslam, F. (2021). Effect of incorporation of rice husk ash instead of cement on the performance of steel fibers reinforced concrete. Frontiers in Materials, 8. https://www.frontiersin.org/articles/10.3389/fmats.2021.665625
534. Compost Collective: Helping Aucklanders reduce food and garden waste. Compost Collective. Retrieved 1 November 2022 from https://compostcollective.org.nz/
535. Envirofert NZ. Envirofert. Retrieved 15 December 2023 from https://www.envirofert.co.nz/
536. Welcome to the world's largest earthworm farms. MyNoke. Retrieved 15 December 2023 from https://www.mynoke.co.nz
537. Wang, X., Tu, M., & Liu, W. (2019). Household biogas digesters or medium–large-scale biogas plants: A conflicting issue in rural China. Environmental Science and Pollution Research, 26(32), 32919–32927. https://doi.org/10.1007/s11356-019-06426-x
538. Giwa, A. S., Ali, N., Ahmad, I., Asif, M., Guo, R.-B., Li, F.-L., & Lu, M. (2020). Prospects of China's biogas: Fundamentals, challenges and considerations. Energy Reports, 6, 2973–2987. https://doi.org/10.1016/j.egyr.2020.10.027
539. Hutchings, J., & Smith, J. (2020). Building a Rauemi Hua Parakore for understanding soil health and wellbeing. In J. Hutchings & J. Smith (Eds.), Te Mahi Oneone Hua Parakore: A Māori Soil Sovereignty and Wellbeing Handbook (pp. 14–27). Freerange Press.
540. Processing food waste at large scales. Office of the Prime Minister's Chief Science Advisor. Retrieved 24 November 2023 from https://www.pmcsa.ac.nz/topics/food-rescue-food-waste/what-can-i-do-with-my-food-waste/processing-food-waste-at-large-scales/
541. Ministry for the Environment | Manatū Mō Te Taiao. (2022). Transforming recycling: Consultation document. https://environment.govt.nz/assets/publications/Transforming-recycling-consultation-document.pdf

542. Ministry for the Environment | Manatū Mō Te Taiao. (2023). Food scraps collections: Requirements, how to get started, and best practice. https://environment.govt.nz/assets/Food-scraps-collections-webinar-slides.pdf
543. About Kai Commitment. Kai Commitment. Retrieved 15 August 2023 from https://kaicommitment.org.nz/about/
544. Paraskevopoulou, C., Vlachos, D., Bechtsis, D., & Tsolakis, N. (2022). An assessment of circular economy interventions in the peach canning industry. International Journal of Production Economics, 249, 108533. https://doi.org/10.1016/j.ijpe.2022.108533
545. WRAP. (2020). Review: Technologies to optimise the value of digestate (2020). https://www.r-e-a.net/wp-content/uploads/2021/01/Review-Technologies-to-Optimise-the-Value-of-Digestate.pdf
546. Wedwitschka, H., Gallegos Ibanez, D., & Reyes Jáquez, D. (2023). Biogas production from residues of industrial insect protein production from black soldier fly larvae Hermetia ilucens (l.): An evaluation of different insect frass samples. Processes, 11(2), 362. https://doi.org/10.3390/pr11020362
547. Hol, S., Elissen, H., & Van Der Weide, R. (2022). Combined digestion of insect frass and cow manure for biogas production. Wageningen University & Research. https://research.wur.nl/en/publications/2d0ec028-d4f8-42ad-b936-ae984525319f
548. Odlare, M., Arthurson, V., Pell, M., Svensson, K., Nehrenheim, E., & Abubaker, J. (2011). Land application of organic waste – Effects on the soil ecosystem. Applied Energy, 88(6), 2210–2218. https://doi.org/10.1016/j.apenergy.2010.12.043
549. Torok, V. A., Luyckx, K., & Lapidge, S. (2022). Human food waste to animal feed: Opportunities and challenges. Animal Production Science, 62(12), 1129–1139. https://doi.org/10.1071/AN20631
550. Agricultural Compounds and Veterinary Medicines Act 1997. New Zealand Parliament. https://www.legislation.govt.nz/act/public/1997/0087/latest/DLM414577.html
551. Animal Products Act 1999. New Zealand Parliament. https://www.legislation.govt.nz/act/public/1999/0093/latest/whole.html
552. Biosecurity (Meat and Food Waste for Pigs) Regulations 2005. New Zealand Parliament. https://www.legislation.govt.nz/regulation/public/2005/0150/latest/DLM332617.html
553. Biosecurity (Ruminant Protein) Regulations 1999. New Zealand Parliament. https://www.legislation.govt.nz/regulation/public/1999/0410/latest/whole.html
554. University of Auckland | Waipapa Taumata Rau. (2021, November 23). Kiwis quite keen on the idea of eating insects. https://www.auckland.ac.nz/en/news/2021/09/22/kiwis-quite-keen-on-the-idea-of-eating-insects.html
555. De Goede, D. M., Erens, J., Kapsomenou, E., & Peters, M. (2013). Large scale insect rearing and animal welfare. In H. Röcklinsberg & P. Sandin (Eds.), The Ethics of Consumption: The Citizen, the Market and the Law (pp. 236–242). Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-784-4_38
556. van Huis, A. (2020). Welfare of farmed insects. Journal of Insects as Food and Feed, 7(5), 573–584. https://doi.org/10.3920/JIFF2020.0061
557. Brown, S., Kruger, C., & Subler, S. (2008). Greenhouse gas balance for composting operations. Journal of Environmental Quality, 37(4), 1396–1410. https://doi.org/10.2134/jeq2007.0453
558. Blue Environment. (2021). Emissions impacts of composting food waste. New South Wales Environment Protection Authority. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4164-emissions-impacts-composting-food-waste.pdf

559. Cooperband, L. (2002). The art and science of composting. University of Wisconsin-Madison. https://www.iowadnr.gov/Portals/idnr/uploads/waste/sw_compost_artandscienceofcomposting.pdf
560. Pace, S. A., Yazdani, R., Kendall, A., Simmons, C. W., & VanderGheynst, J. S. (2018). Impact of organic waste composition on life cycle energy production, global warming and water use for treatment by anaerobic digestion followed by composting. Resources, Conservation and Recycling, 137, 126–135. https://doi.org/10.1016/j.resconrec.2018.05.030
561. Diprose, G., Dombroski, K., Sharp, E., Barnes, M., Peryman, P., & Yates, A. Emerging transitions in organic waste infrastructure in Aotearoa New Zealand. New Zealand Geographer.
562. Harmsworth, G., & Awatere, S. (2013). Indigenous Māori knowledge and perspectives of ecosystems. In J. Dymond (Ed.), Ecosystem services in New Zealand: Conditions and trends. Manaaki Whenua Press.
563. Ataria, J., Baker, V., Goven, J., Langer, E. R. (Lisa), Leckie, A., Ross, M., & Horswell, J. (2016). From Tapu to Noa—Māori cultural views on biowastes management: A focus on biosolids. Centre for Integrated Biowaste Research,. http://www.cibr.org.nz/assets/Uploads/Newsletter-Thumb/CIBR-From-Tapu-to-Noa.pdf
564. Pauling, C., & Ataria, J. (2010). Tiaki Para: A study of Ngāi Tahu values and issues regarding waste (Landcare Research Science Series). Manaaki Whenua. http://www.mwpress.co.nz/__data/assets/pdf_file/0016/70513/LRSS_39_Tiaki_Para.pdf
565. WRAP. (2020). AD and composting industry market survey report. https://wrap.org.uk/sites/default/files/2021-01/AD%20%26%20Composting%20Market%20Survey%20Report.pdf
566. Ministry for the Environment | Manatū Mō Te Taiao. (2022). Compostable products: Ministry for the Environment position statement. https://environment.govt.nz/assets/publications/compostables-packaging-position-statement.pdf
567. Meeting with MyNoke. (2022). [Personal communication].
568. Singh, R. P., Singh, P., Araujo, A. S. F., Hakimi Ibrahim, M., & Sulaiman, O. (2011). Management of urban solid waste: Vermicomposting a sustainable option. Resources, Conservation and Recycling, 55(7), 719–729. ScienceDirect. https://doi.org/10.1016/j.resconrec.2011.02.005
569. Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. (2015). The use of vermicompost in organic farming: Overview, effects on soil and economics. Journal of the Science of Food and Agriculture, 95(6), 1143–1156. https://doi.org/10.1002/jsfa.6849
570. New South Wales Environmental Protection Agency. (2022). Emissions impacts of food waste dehydration. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wasteregulation/fogo/22p4166-emissions-impacts-food-waste-dehydration.pdf
571. Technologies: Food waste dehydrators. CalRecycle. Retrieved 17 November 2022 from https://calrecycle.ca.gov/organics/food/commercial/dehydrators/
572. Kiyasudeen, K., Ibrahim, M. H., Quaik, S., & Ismail, S. A. (2016). An introduction to anaerobic digestion of organic wastes. In Prospects of Organic Waste Management and the Significance of Earthworms (pp. 23–44). Springer. https://link.springer.com/book/10.1007/978-3-319-24708-3
573. Horan, N., Smyth, M., & Cessford, I. (2015). Optimising the value of digestate and digestion systems. AquaEnviro (Prepared for WRAP). https://www.researchgate.net/publication/281620267_Optimising_the_value_of_digestate_and_digestion_systems
574. Al-Rumaihi, A., Shahbaz, M., McKay, G., Mackey, H., & Al-Ansari, T. (2022). A review of pyrolysis technologies and feedstock: A blending approach for plastic and biomass towards optimum biochar yield. Renewable and Sustainable Energy Reviews, 167, 112715. https://doi.org/10.1016/j.rser.2022.112715

575. Czajczyńska, D., Nannou, T., Anguilano, L., Krzyżyńska, R., Ghazal, H., Spencer, N., & Jouhara, H. (2017). Potentials of pyrolysis processes in the waste management sector. Energy Procedia, 123, 387–394. https://doi.org/10.1016/j.egypro.2017.07.275
576. Kirkels, A. F., & Verbong, G. P. J. (2011). Biomass gasification: Still promising? A 30-year global overview. Renewable and Sustainable Energy Reviews, 15(1), 471–481. https://doi.org/10.1016/j.rser.2010.09.046
577. Brown, J. (2006). Biomass gasification: Fast internal fluidised bed gasifier characterisation and comparison [Master's Thesis, School of Engineering, University of Canterbury]. https://ir.canterbury.ac.nz/bitstream/handle/10092/1187/thesis_fulltext.pdf;sequence=1
578. Kambo, H. S., & Dutta, A. (2015). A comparative review of biochar and hydrochar in terms of production, physico-chemical properties and applications. Renewable and Sustainable Energy Reviews, 45, 359–378. https://doi.org/10.1016/j.rser.2015.01.050
579. Raza, M., Inayat, A., Ahmed, A., Jamil, F., Ghenai, C., Naqvi, S. R., Shanableh, A., Ayoub, M., Waris, A., & Park, Y.-K. (2021). Progress of the pyrolyzer reactors and advanced technologies for biomass pyrolysis processing. Sustainability, 13(19), 11061. https://doi.org/10.3390/su131911061
580. Rada, E. C. (2017). Thermochemical Waste Treatment: Combustion, Gasification, and Other Methodologies. Apple Academic Press. https://www.routledge.com/Thermochemical-Waste-Treatment-Combustion-Gasification-and-Other-Methodologies/Rada/p/book/9781774635957#
581. Kundu, S., Patel, S., Halder, P., Patel, T., Hedayati Marzbali, M., Pramanik, B. K., Paz-Ferreiro, J., de Figueiredo, C. C., Bergmann, D., Surapaneni, A., Megharaj, M., & Shah, K. (2021). Removal of PFASs from biosolids using a semi-pilot scale pyrolysis reactor and the application of biosolids derived biochar for the removal of PFASs from contaminated water. Environmental Science: Water Research & Technology, 7(3), 638–649. https://doi.org/10.1039/D0EW00763C
582. Raheem, A., He, Q., Mangi, F. H., Areeprasert, C., Ding, L., & Yu, G. (2022). Roles of heavy metals during pyrolysis and gasification of metal-contaminated waste biomass: A review. Energy & Fuels, 36(5), 2351–2368. https://doi.org/10.1021/acs.energyfuels.1c04051
583. Rauch, R., Hrbek, J., & Hofbauer, H. (2014). Biomass gasification for synthesis gas production and applications of the syngas. WIREs Energy and Environment, 3(4), 343–362. https://doi.org/10.1002/wene.97
584. Feedstock requirements. Pyrocal. Retrieved 7 June 2023 from https://www.pyrocal.com.au/feedstock-requirements
585. Calvelo Pereira, R., Camps Arbestain, M., Kaal, J., Vazquez Sueiro, M., Sevilla, M., & Hindmarsh, J. (2014). Detailed carbon chemistry in charcoals from pre-European Māori gardens of New Zealand as a tool for understanding biochar stability in soils. European Journal of Soil Science, 65(1), 83–95. https://doi.org/10.1111/ejss.12096
586. Thoma, E. D., Wright, R. S., George, I., Krause, M., Presezzi, D., Villa, V., Preston, W., Deshmukh, P., Kauppi, P., & Zemek, P. G. (2022). Pyrolysis processing of PFAS-impacted biosolids, a pilot study. Journal of the Air & Waste Management Association, 72(4), 309–318. https://doi.org/10.1080/10962247.2021.2009935
587. Conesa, J. A., Ortuño, N., & Palmer, D. (2020). Estimation of Industrial Emissions during Pyrolysis and Combustion of Different Wastes Using Laboratory Data. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-63807-w
588. Dioxins and their effects on human health. World Health Organisation. Retrieved 18 November 2022 from https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health

589. Polycyclic Aromatic Hydrocarbons (PAHs) factsheet. Centers for Disease Control and Prevention. Retrieved 18 November 2022 from https://www.cdc.gov/biomonitoring/PAHs_FactSheet.html
590. Dal Pozzo, A., & Cozzani, V. (2021). Wastewater management of wet scrubbers in waste-to-energy facilities: A life cycle analysis. Chemical Engineering Transactions, 86, 619–624. https://doi.org/10.3303/CET2186104
591. Jones, C. R., Lee, R. P., & Kaklamanou, D. (2022). Understanding public perceptions of chemical recycling: A comparative study of public attitudes towards coal and waste gasification in Germany and the United Kingdom. Sustainable Production and Consumption, 32, 125–135. https://doi.org/10.1016/j.spc.2022.04.011
592. Standardized product definition and product testing guidelines for biochar that is used in soil. (2015). International Biochar Initiative. https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Standards_V2.1_Final.pdf
593. Nagappan, S., Bhosale, R. R., Nguyen, D. D., Chi, N. T. L., Ponnusamy, V. K., Woong, C. S., & Kumar, G. (2021). Catalytic hydrothermal liquefaction of biomass into bio-oils and other value-added products – A review. Fuel, 285, 119053. https://doi.org/10.1016/j.fuel.2020.119053
594. Elliott, D. C., Biller, P., Ross, A. B., Schmidt, A. J., & Jones, S. B. (2015). Hydrothermal liquefaction of biomass: Developments from batch to continuous process. Bioresource Technology, 178, 147–156. https://doi.org/10.1016/j.biortech.2014.09.132
595. Bayat, H., Dehghanizadeh, M., Jarvis, J. M., Brewer, C. E., & Jena, U. (2021). Hydrothermal liquefaction of food waste: Effect of process parameters on product yields and chemistry. Frontiers in Sustainable Food Systems, 5. https://doi.org/10.3389/fsufs.2021.658592
596. Swetha, A., ShriVigneshwar, S., Gopinath, K. P., Sivaramakrishnan, R., Shanmuganathan, R., & Arun, J. (2021). Review on hydrothermal liquefaction aqueous phase as a valuable resource for biofuels, bio-hydrogen and valuable bio-chemicals recovery. Chemosphere, 283, 131248. https://doi.org/10.1016/j.chemosphere.2021.131248
597. Makarichi, L., Jutidamrongphan, W., & Techato, K. (2018). The evolution of waste-to-energy incineration: A review. Renewable and Sustainable Energy Reviews, 91, 812–821. https://doi.org/10.1016/j.rser.2018.04.088
598. Correspondence with Ministry for the Environment | Manatū Mō Te Taiao. (2022, June 23). Personal Communication.
599. Bioenergy Association. (2021). The production and use as biofertiliser of digestate derived from source segregated organic waste. https://www.biogas.org.nz/documents/resource/TG08-Production-and-use-of-digestate-as-fertiliser.pdf
600. Ministry for the Environment | Manatū Mō Te Taiao. (2022). Measuring emissions: A guide for organisations. https://environment.govt.nz/assets/publications/Measuring-emissions-guidance-August-2022/Detailed-guide-PDF-Measuring-emissions-guidance-August-2022.pdf
601. Mohobane, T. (2008). The characteristics and impacts of landfill leachate from Horotiu, New Zealand and Maseru, Lesotho: A comparative study [Master's Thesis, School of Science, University of Waikato]. https://hdl.handle.net/10289/2421
602. Leachate leaking from landfills. Waste Management. Retrieved 19 November 2022 from https://www.wastemanagement.co.nz/my-region/auckland/auckland-regional-landfill/waste-managements-view/
603. Schlesinger, A. P. (2016). Pop-Up Compost Project: Reframing the processes and perceptions of community composting in New Brunswick, NJ [Master's Thesis, Graduate Program in

Landscape Architecture, Rutgers University]. https://rucore.libraries.rutgers.edu/rutgers-lib/50175/
604. Bioreactor landfills in the United States: An overview. Parson Jericho Galicia & Nicholas Brown, Geoengineer. Retrieved 8 November 2022 from https://www.geoengineer.org/education/web-class-projects/ce-176-environmental-geotechnics/assignments/bioreactor-landfills
605. Burke, E., & Napawan, N. C. (2020). Between kitchen sink and city sewer: A socio-ecological approach to food waste in environmental design. In E. Närvänen, N. Mesiranta, M. Mattila, & A. Heikkinen (Eds.), Food Waste Management: Solving the Wicked Problem (pp. 169–191). Springer International Publishing. https://doi.org/10.1007/978-3-030-20561-4_7
606. Email from Rob Tinholt at Watercare. (2023). [Personal communication].
607. Introduction to LCA. Life Cycle Association of New Zealand. Retrieved 23 August 2023 from https://lcanz.org.nz/lca-guidance/lca-intro/
608. Tillman, A.-M., Ekvall, T., Baumann, H., & Rydberg, T. (1994). Choice of system boundaries in life cycle assessment. Journal of Cleaner Production, 2(1), 21–29. https://doi.org/10.1016/0959-6526(94)90021-3
609. ISO 14040:2006 Life cycle assessment: Principles and framework. ISO. Retrieved 23 August 2023 from https://www.iso.org/standard/37456.html
610. Guven, H., Wang, Z., & Eriksson, O. (2019). Evaluation of future food waste management alternatives in Istanbul from the life cycle assessment perspective. Journal of Cleaner Production, 239, 117999. https://doi.org/10.1016/j.jclepro.2019.117999
611. Eriksson, M., & Spångberg, J. (2017). Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. Waste Management, 60, 786–799. https://doi.org/10.1016/j.wasman.2017.01.008
612. Opatokun, S. A., Lopez-Sabiron, A., Ferreira, G., & Strezov, V. (2017). Life cycle analysis of energy production from food waste through anaerobic digestion, pyrolysis and integrated energy system. Sustainability, 9(10), 1804. https://doi.org/10.3390/su9101804
613. Thyberg, K. L., & Tonjes, D. J. (2016). Drivers of food waste and their implications for sustainable policy development. Resources, Conservation and Recycling, 106, 110–123. https://doi.org/10.1016/j.resconrec.2015.11.016
614. Ahamed, A., Yin, K., Ng, B. J. H., Ren, F., Chang, V. W.-C., & Wang, J.-Y. (2016). Life cycle assessment of the present and proposed food waste management technologies from environmental and economic impact perspectives. Journal of Cleaner Production, 131, 607–614. https://doi.org/10.1016/j.jclepro.2016.04.127
615. Eriksson, M., Strid, I., & Hansson, P.-A. (2015). Carbon footprint of food waste management options in the waste hierarchy – a Swedish case study. Journal of Cleaner Production, 93, 115–125. https://doi.org/10.1016/j.jclepro.2015.01.026
616. Bernstad, A., & la Cour Jansen, J. (2011). A life cycle approach to the management of household food waste – A Swedish full-scale case study. Waste Management, 31(8), 1879–1896. https://doi.org/10.1016/j.wasman.2011.02.026
617. Levis, J. W., & Barlaz, M. A. (2011). What is the most environmentally beneficial way to treat commercial food waste? Environmental Science & Technology, 45(17), 7438–7444. https://doi.org/10.1021/es103556m
618. Fair Trading Act 1986. New Zealand Parliament. https://www.legislation.govt.nz/act/public/1986/0121/latest/DLM96439.html
619. Commerce Commission. (2020). Environmental claims guidelines: A guide for traders. https://comcom.govt.nz/__data/assets/pdf_file/0017/220247/Environmental-claims-guidance-July-2020.pdf

620. Nous Group. (2021). Modernising the FSANZ Act. Draft regulatory impact statement. https://consultations.health.gov.au/chronic-disease-and-food-policy-branch/fsanz-act-review-draft-ris/supporting_documents/FSANZ%20Act%20Review%20%20draft%20 Regulatory%20Impact%20Statement.pdf
621. Organic Products and Production Act 2023. New Zealand Parliament. https://www.parliament.nz/en/pb/bills-and-laws/bills-proposed-laws/document/ BILL_94967/organic-products-and-production-bill
622. Certification FAQs. Upcycled Food Association. Retrieved 25 January 2022 from https://www.upcycledfood.org/certification-faqs-1
623. Where Food Comes From. (2022). Where Food Comes From, Inc Upcycled Certified annual fee schedule. https://static1.squarespace.com/static/606ce580b6b9b6777f470253/t/ 62dec6a5151ce73d93c17836/1658767013426/Upcycled+Certification+Fee+Schedule_v2.pdf
624. Saez de Bikuña, K., & Robertson, K. (2022). Verified Carbon Standard: Methodology for reducing food loss and waste. Quantis, WRAP, & Verra. https://verra.org/methodology/ methodology-for-avoiding-greenhouse-gas-emissions-by-keeping-food-in-the-human-supply-chain/
625. Ministry for the Environment | Manatū Mō Te Taiao. (2022). Interim guidance for voluntary climate change mitigation. https://environment.govt.nz/assets/publications/interim-guidance-voluntary-climate-change-mitigation.pdf
626. Duerrschmid, K., & Danner, L. (2018). Eye tracking in consumer research. In G. Ares & P. Varela (Eds.), Methods in Consumer Research, Volume 2 (pp. 279–318). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-101743-2.00012-1
627. Low, J. Y., Janin, N., Traill, R. M., & Hort, J. (2022). The who, what, where, when, why and how of measuring emotional response to food. A systematic review. Food Quality and Preference, 100, 104607. https://doi.org/10.1016/j.foodqual.2022.104607
628. Young, E. (2022). The use of eye-tracking and physiological measures in consumer food science. New Zealand Institute of Food Science & Technology Annual Conference, Rotorua. https://nzifst.org.nz/resources/Documents/2022%20Conference%20Abstracts%20-%20ORAL.pdf
629. Imram, N. (1999). The role of visual cues in consumer perception and acceptance of a food product. Nutrition & Food Science, 99(5), 224–230. https://doi.org/10.1108/ 00346659910277650
630. Kemp, S. E., Hollowood, T., & Hort, J. (2009). Sensory Evaluation: A Practical Handbook. Wiley-Blackwell. https://onlinelibrary.wiley.com/doi/book/10.1002/9781118688076
631. O'Sullivan, M. (2016). A Handbook for Sensory and Consumer-Driven New Product Development: Innovative Technologies for the Food and Beverage Industry. Woodhead Publishing. https://books.google.co.nz/books?hl=en&lr=&id=kYV4CgAAQBAJ&oi=fnd&pg=PP1&ots=0V5601pueC&sig=r8X3hEcuHIbJTXDYB7jBPeWpIn4&redir_esc=y#v=onepage&q&f=false.
632. Świąder, K., & Marczewska, M. (2021). Trends of using sensory evaluation in new product development in the food industry in countries that belong to the EIT regional innovation scheme. Foods, 10(2), 446. https://doi.org/10.3390/foods10020446
633. Food Experience and Sensory Testing Laboratory (Feast). Massey University. Retrieved 10 January 2023 from https://www.massey.ac.nz/massey/learning/colleges/college-of-sciences/clinics-and-services/feast/feast_home.cfm
634. Sensory science. University of Otago. Retrieved 10 January 2023 from https://www.otago.ac.nz/food-science/industry/consultancy/otago083116.html

635. How do consumers think, feel and behave? Plant and Food Research. Retrieved 10 February 2023 from plantandfood.com/en-nz/article/how-do-consumers-think-feel-and-behave
636. FoodSouth Otago sensory panel. Food Innovation Network. Retrieved 10 January 2023 from https://foodinnovationnetwork.co.nz/foodsouth-otago/
637. Chen, A. W., Resurreccion, A. V. A., & Paguio, L. P. (1996). Age appropriate hedonic scales to measure food preferences of young children. Journal of Sensory Studies, 11(2), 141–163. https://doi.org/10.1111/j.1745-459X.1996.tb00038.x
638. Deubler, G., Swaney-Stueve, M., Jepsen, T., & Su-Fern, B. P. (2020). The K-State emoji scale. Journal of Sensory Studies, 35(1), e12545. https://doi.org/10.1111/joss.12545
639. Gramegna, G., Scortica, A., Scafati, V., Ferella, F., Gurrieri, L., Giovannoni, M., Bassi, R., Sparla, F., Mattei, B., & Benedetti, M. (2020). Exploring the potential of microalgae in the recycling of dairy wastes. Bioresource Technology Reports, 12, 100604. https://doi.org/10.1016/j.biteb.2020.100604]
640. Elshamy, M., & Rösch, C. (2022). Animal feed from microalgae grown on biogas digestate as sustainable alternative to imported soybean meal. BioEnergy Research, 15(4), 2056–2075. https://doi.org/10.1007/s12155-022-10397-2
641. Pires, A. J. V., Carvalho, G. G. P. de, & Ribeiro, L. S. O. (2010). Chemical treatment of roughage. Forage Crops, 39, 192–203. https://doi.org/10.1590/S1516-35982010001300022
642. Schroeder, J. T., Labuzetta, A. L., & Trabold, T. A. (2020). Assessment of dehydration as a commercial-scale food waste valorization strategy. Sustainability, 12(15), 5959. https://doi.org/10.3390/su12155959
643. Luciano, A., Espinosa, C. D., Pinotti, L., & Stein, H. H. (2022). Standardized total tract digestibility of phosphorus in bakery meal fed to pigs and effects of bakery meal on growth performance of weanling pigs. Animal Feed Science and Technology, 284, 115148. https://doi.org/10.1016/j.anifeedsci.2021.115148
644. Jinno, C., He, Y., Morash, D., McNamara, E., Zicari, S., King, A., Stein, H. H., & Liu, Y. (2018). Enzymatic digestion turns food waste into feed for growing pigs. Animal Feed Science and Technology, 242, 48–58. https://doi.org/10.1016/j.anifeedsci.2018.05.006
645. Mok, C. H., Kong, C., & Kim, B. G. (2015). Combination of phytase and β-mannanase supplementation on energy and nutrient digestibility in pig diets containing palm kernel expellers. Animal Feed Science and Technology, 205, 116–121. https://doi.org/10.1016/j.anifeedsci.2015.04.012
646. Dou, Z., Toth, J. D., Pitta, D. W., Bender, J. S., Hennessy, M. L., Vecchiarelli, B., Indugu, N., Chen, T., Li, Y., Sherman, R., Deutsch, J., Hu, B., Shurson, G. C., Parsons, B., & Baker, L. D. (2022). Proof of concept for developing novel feeds for cattle from wasted food and crop biomass to enhance agri-food system efficiency. Scientific Reports, 12(1), 13630. https://doi.org/10.1038/s41598-022-17812-w
647. Shi, C., Zhang, Y., Lu, Z., & Wang, Y. (2017). Solid-state fermentation of corn-soybean meal mixed feed with Bacillus subtilis and Enterococcus faecium for degrading antinutritional factors and enhancing nutritional value. Journal of Animal Science and Biotechnology, 8(1), 50. https://doi.org/10.1186/s40104-017-0184-2
648. Andrade, E., Gonçalves, A., Mendes-Ferreira, A., Silva, V., Pinheiro, V., Rodrigues, M., & Ferreira, L. (2017). A novel feedstuff: Ensiling of cowpea (Vigna unguiculata L.) stover and apple (Malus domestica Borkh.) mixtures. Journal of the Science of Food and Agriculture, 97(13), 4306–4313. https://doi.org/10.1002/jsfa.8307
649. Agriculture Victoria. (2020). A guide to introducing grain to sheep and cattle. https://agriculture.vic.gov.au/__data/assets/pdf_file/0005/567104/Introducing-grain-to-sheep-and-cattle.pdf

650. Fly farm. Fly Farm. Retrieved 21 February 2023 from https://flyfarm.com/
651. Beef + Lamb New Zealand. (2017). Guide to New Zealand cattle farming. https://beeflambnz.com/knowledge-hub/PDF/guide-new-zealand-cattle-farming.pdf
652. Marinus, F. W. te P., Veldkamp, T., de Haas, Y., Bannink, A., & Ellen, E. D. (2021). Adaptation of livestock to new diets using feed components without competition with human edible protein sources—A review of the possibilities and recommendations. Animals, 11(8), 2293. https://doi.org/10.3390/ani11082293
653. Correspondence with Ministry for Primary Industries | Manatū Ahu Matua. (2023, November 3). [Personal communication].
654. Ruminant feed regulations for preventing BSE or "mad cow disease." Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 20 February 2023 from https://www.mpi.govt.nz/animals/animal-feed-preventing-disease-transfer/ruminant-feed-regulations/
655. Feeding offal to dogs and preventing hydatids. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 20 February 2023 from https://www.mpi.govt.nz/animals/animal-feed-preventing-disease-transfer/feeding-offal-to-dogs-and-preventing-hydatids/
656. Niederwerder, M. C., & Rowland, R. R. R. (2017). Is there a risk for introducing Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) through the legal importation of pork? Food and Environmental Virology, 9(1), 1–13. https://doi.org/10.1007/s12560-016-9259-z
657. African swine fever disease prevention. Ministry for Primary Industries | Manatū Ahu Matua. Retrieved 14 August 2023 from https://www.mpi.govt.nz/biosecurity/pests-and-diseases-not-in-new-zealand/animal-diseases-not-in-nz/african-swine-fever/
658. Stenfeldt, C., Bertram, M. R., Meek, H. C., Hartwig, E. J., Smoliga, G. R., Niederwerder, M. C., Diel, D. G., Dee, S. A., & Arzt, J. (2022). The risk and mitigation of foot-and-mouth disease virus infection of pigs through consumption of contaminated feed. Transboundary and Emerging Diseases, 69(1), 72–87. https://doi.org/10.1111/tbed.14230
659. Chen, T., Jin, Y., & Shen, D. (2015). A safety analysis of food waste-derived animal feeds from three typical conversion techniques in China. Waste Management, 45, 42–50. https://doi.org/10.1016/j.wasman.2015.06.041
660. Hedlin, P., Taschuk, R., Potter, A., Griebel, P., & Napper, S. (2012). Detection and control of prion diseases in food animals. ISRN Veterinary Science, 2012. https://doi.org/10.5402/2012/254739
661. Scheckel, C., & Aguzzi, A. (2018). Prions, prionoids and protein misfolding disorders. Nature Reviews Genetics, 19(7), 405–418. https://doi.org/10.1038/s41576-018-0011-4
662. What are prions? Virginia Department of Wildlife Resources. Retrieved 6 January 2024 from https://dwr.virginia.gov/wildlife/diseases/cwd/what-are-prions/
663. Sakudo, A. (2020). Inactivation methods for prions. Current Issues in Molecular Biology, 36, 23–32. https://doi.org/10.21775/cimb.036.023
664. Herrera, V. (2020). New Zealand's position with regard to scrapie. Biosecurity New Zealand | Tiakitanga Pūtaiao Aotearoa. https://www.mpi.govt.nz/dmsdocument/10475/direct
665. Herrera, V. (2020). New Zealand's position with regard to CWD. Biosecurity New Zealand | Tiakitanga Pūtaiao Aotearoa. https://www.mpi.govt.nz/dmsdocument/10472-New-Zealands-position-with-regard-to-chronic-wasting-disease-CWD
666. Herrera, V. (2022). New Zealand's condition with regard to BSE. Biosecurity New Zealand | Tiakitanga Pūtaiao Aotearoa. https://www.mpi.govt.nz/dmsdocument/19196-New-Zealands-position-in-regards-to-BSE-letter-from-the-Director-of-Diagnostic-and-Surveillance-services

667. Gallardo, M. J., & Delgado, F. O. (2021). Animal prion diseases: A review of intraspecies transmission. Open Veterinary Journal, 11(4), 707–723. https://doi.org/10.5455/OVJ.2021.v11.i4.23
668. StatsNZ | Tatauranga Aotearoa. (2022). Agricultural production statistics: Year to June 2022 (provisional). https://www.stats.govt.nz/information-releases/agricultural-production-statistics-year-to-june-2022-provisional/
669. The Poultry Industry Association of New Zealand. (2022). NZ poultry production statistics. https://www.pianz.org.nz/wp-content/uploads/2020/06/Poultry-Production-Dec-2022-Final-.pdf
670. About layer hens. Egg Producers Federation of New Zealand. Retrieved 13 February 2023 from https://www.eggfarmers.org.nz/about-eggs/about-layer-hens
671. Environmental Health Intelligence New Zealand | Rapu Mātauranga Hauora mo te Taiao. (2021). Number and density of livestock in New Zealand. https://www.ehinz.ac.nz/assets/Factsheets/Released_2021/Livestock-Numbers-Density-2021.pdf
672. Diet selection. Deer Industry New Zealand. Retrieved 13 February 2023 from https://www.deernz.org/deer-hub/feeding/feeding-deer/diet-selection/
673. Ministry for Primary Industries | Manatū Ahu Matua. (2019). Feed consumed by New Zealand dairy cows. https://www.mpi.govt.nz/dmsdocument/46231-Feed-Consumed-by-NZ-Dairy-Cows
674. Grazing management. Deer Industry New Zealand. Retrieved 13 February 2023 from https://www.deernz.org/deer-hub/feeding/feeding-deer/grazing-management/
675. Sise, J., McCorkindale, B., & Fennessy, P. (2017). Analysis of supplemental feed use in the New Zealand sheep industry. Ministry for Primary Industries | Manatū Ahu Matua. https://mpi.govt.nz/dmsdocument/20909-analysis-of-supplemental-feed-use-in-the-new-zealand-sheep-industry
676. Caring for hens. Egg Producers Federation of New Zealand. Retrieved 13 February 2023 from https://www.eggfarmers.org.nz/egg-farming-in-nz/caring-for-hens
677. Pigs in New Zealand farms. Figure NZ. Retrieved 13 February 2017 from https://figure.nz/chart/L7Wzd4SZBjYyXTUf-kPA0FayFBrkwCIzF
678. Businesses in the poultry farming industry (eggs) in New Zealand. Figure NZ. Retrieved 13 February 2023 from https://figure.nz/chart/qD7YkkfAFcmrk6MJ-r38TqmkvkksqN5jh
679. Our feed. New Zealand King Salmon. Retrieved 13 February 2023 from https://www.kingsalmon.co.nz/our-farms/our-feed/
680. Stenton-Dozey, J. M. E., Heath, P., Ren, J. S., & Zamora, L. N. (2021). New Zealand aquaculture industry: Research, opportunities and constraints for integrative multitrophic farming. New Zealand Journal of Marine and Freshwater Research, 55(2), 265–285. https://doi.org/10.1080/00288330.2020.1752266
681. Aquaculture New Zealand. Aquaculture New Zealand. Retrieved 13 February 2023 from https://www.aquaculture.org.nz/
682. Companion Animals NZ. (2020). Companion animals in New Zealand. https://static1.squarespace.com/static/5d1bf13a3f8e880001289eeb/t/5f768e8a17377653bd1eebef/1601605338749/Companion+Animals+in+NZ+2020+%281%29.pdf
683. Feeding your horse the right food. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/feeding-your-horse-the-right-food
684. Feeding your cat. Cornell Feline Health Center. Retrieved 14 February 2023 from https://www.vet.cornell.edu/departments-centers-and-institutes/cornell-feline-health-center/health-information/feline-health-topics/feeding-your-cat

685. What to feed your backyard chickens. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/what-to-feed-your-backyard-chickens
686. Caring for Rainbow Lorikeets. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/caring-for-rainbow-lorikeets
687. Caring for budgies. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/caring-for-budgies
688. Beitz, D., Bauer, J., Behnke, K., Dzanis, D., Fahey, G., Hill, R., Kallfelz, F., Kienzle, E., Morris, J., & Rogers, Q. (2006). Your dog's nutritional needs: A science-based guide for pet owners. National Research Council of the National Academies. https://nap.nationalacademies.org/resource/10668/dog_nutrition_final_fix.pdf
689. Sharpe, S. Feeding your aquarium fish the right type of food. The Spruce Pets. Retrieved 14 February 2023 from https://www.thesprucepets.com/feeding-your-aquarium-fish-1380920
690. Understanding aquarium fish nutrition. Live Aquaria. Retrieved 14 February 2023 from https://www.liveaquaria.com/article/198/?aid=198
691. What to feed your rabbits. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/what-to-feed-your-rabbits
692. Kerrigan, L. (2015, April 7). Small mammal nutrition: Significance of feeding a species-specific diet. Vet Times. https://www.vettimes.co.uk/app/uploads/wp-post-to-pdf-enhanced-cache/1/small-mammal-nutrition-significance-of-feeding-a-species-specific-diet.pdf
693. Caring for terrapins. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/advice-and-welfare/article/caring-for-terrapins
694. I'm thinking of adopting... A bearded dragon. SPCA New Zealand. Retrieved 14 February 2023 from https://www.spca.nz/news-and-events/news-article/im-thinking-of-adopting-a-bearded-dragon
695. Wilkinson, K., Price, J., Biala, J., & McDonald, D. (2021). Review of regulations and standards for recycled organics in Australia—Final report. Frontier Ag and Environment (Prepared for the Australian Department of Agriculture, Water and Environment). https://www.dcceew.gov.au/environment/protection/waste/publications/review-regulations-standards-recycled-organics-in-australia
696. Digestate – specification for safe use. Engage Victoria & Environment Protection Authority Victoria. Retrieved 17 July 2023 from https://engage.vic.gov.au/digestate-specification-for-safe-use
697. World Biogas Association. (2017). Anaerobic digestion market report Australia. http://www.worldbiogasassociation.org/wp-content/uploads/2018/07/Australia-International-Market-Report.pdf
698. Carlu, E., Truong, T., & Kundevski, M. (2019). Biogas opportunities for Australia. ENEA Consulting. https://www.energynetworks.com.au/resources/reports/biogas-opportunities-for-australia-enea-consulting/
699. Australian Economic Advocacy Solutions (Prepared for Australian Organics Recycling Association in partnership with the Australian Department of Agriculture, Water and the Environment & Green Industries South Australia). (2021). Australian organics recycling industry capacity assessment: 2020-21. https://www.dcceew.gov.au/environment/protection/waste/publications/australian-organics-recycling-industry-capacity-assessment-2020-21
700. About composting. International Compost Awareness Week. Retrieved 2 August 2023 from https://www.compostweek.com.au/about-composting/

701. Regulation of compost under the Fertilizers Act and Regulations. Government of Canada. Retrieved 17 July 2023 from https://inspection.canada.ca/plant-health/fertilizers/trade-memoranda/t-4-120/eng/1307910204607/1307910352783
702. Canadian digestate management guideline. Azura Associates. Retrieved 2 August 2023 from https://azuraassociates.com/canadian-digestate-management-guideline/
703. Composting organics in Canada. Peter Gorrie, Biocycle Connect. Retrieved 2 August 2023 from https://www.biocycle.net/composting-organics-in-canada/#:~:text=Bans%20on%20landfilling%20of%20organic,growth%20of%20composting%20in%20Canada
704. Biogas projects. Canadian Biogas Association. Retrieved 17 July 2023 from https://biogasassociation.ca/biogas_101/projects/
705. The dirt on composting. Statistics Canada. Retrieved 17 July 2023 from https://www.statcan.gc.ca/o1/en/plus/1327-dirt-composting
706. Chen, L., Zhao, L., Ren, C., & Wang, F. (2012). The progress and prospects of rural biogas production in China. Energy Policy, 51, 58–63. https://doi.org/10.1016/j.enpol.2012.05.052
707. Chen, Z., Wei, Y., Zhang, Z., Wang, G., & Li, J. (2023). Organic carbon sequestration in Chinese croplands under compost application and its contribution to carbon neutrality. Environmental Science and Pollution Research, 30(4), 9022–9035. https://doi.org/10.1007/s11356-022-21254-2
708. China to expand use of organic fertilizers. The State Council, The People’s Republic of China. Retrieved 10 August 2023 from http://english.www.gov.cn/statecouncil/ministries/202212/12/content_WS63966a16c6d0a757729e45b6.html
709. Li, J., & Xu, Z. (2007). Development of the composting industry in China. BioCycle, 48(8), 57. https://www.biocycle.net/development-of-the-composting-industry-in-china/.
710. Safe and effective fetilising products on the EU market. EUR-Lex. Retrieved 24 July 2023 from https://eur-lex.europa.eu/EN/legal-content/summary/safe-and-effective-fertilising-products-on-the-eu-market.html#keyterm_E0001
711. Hermann, L., Hermann, R., & Schoumans, O. F. (2019). Report on regulations governing anaerobic digesters and nutrient recovery and reuse in EU member states. Wageningen Environmental Research. https://research.wur.nl/en/publications/6c47737e-91fd-4597-a42e-1a305aedca12
712. Wood Environment and Infrastructure Solutions (Prepared for Directorate General - Environment, European Commission). (2019). Digestate and compost as fertilisers: Risk assessment and risk management options. https://www.circularonline.co.uk/research-reports/digestate-and-compost-as-fertilisers-risk-assessment-and-risk-management-options/
713. Stürmer, B., Pfundtner, E., Kirchmeyr, F., & Uschnig, S. (2020). Legal requirements for digestate as fertilizer in Austria and the European Union compared to actual technical parameters. Journal of Environmental Management, 253, 109756. https://doi.org/10.1016/j.jenvman.2019.109756
714. Foster, P., & Prasad, M. (2018). Development of quality standards for compost and digestate in Ireland. Ireland Environmental Protection Agency. https://www.epa.ie/publications/research/waste/Research_Report_375.pdf
715. ECN country report: Austria. (2019). European Compost Network. https://www.compostnetwork.info/download/country-report-austria-2023/
716. Ordinance on the recovery of bio-waste on land used for agricultural, silvicultural and horticultural purposes 2013. German Bundestag. https://www.bmuv.de/GE38-1

717. Jain, S. (2019). Market report: Germany. World Biogas Association. https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-Germany-4ppa4_.pdf
718. Waste action plan for a circular economy. Government of Ireland. Retrieved 5 August 2023 from https://www.gov.ie/en/publication/4221c-waste-action-plan-for-a-circular-economy/
719. Ministerial Decree concerning the criteria and general technical standards for the regional regulation of the agronomic use of livestock manure and waste water, and for the production and use of agronomy of digestate. United Nations Environment Programme. Retrieved 7 August 2023 from https://leap.unep.org/countries/it/national-legislation/ministerial-decree-concerning-criteria-and-general-technical
720. World Biogas Association. (2018). Anaerobic digestion market report: Italy. http://www.worldbiogasassociation.org/wp-content/uploads/2018/07/Italy-International-Market-Report.pdf
721. Altereko. (2020). From organic waste to compost and back to soil. https://www.altereko.it/wp-content/uploads/2020/05/Composting-in-Italy-2020_web.pdf
722. European Compost Network. (2020). Country report: Italy. https://www.compostnetwork.info/download/country-report-italy-2023/
723. European Biogas Association. (2022). Statistical report 2022. https://www.europeanbiogas.eu/wp-content/uploads/2022/12/EBA-Statistical-Report-2022_Full-version-1.pdf
724. World Biogas Association. (2018). Anaerobic digestion market report: The Netherlands. http://www.worldbiogasassociation.org/wp-content/uploads/2018/07/The-Netherlands-International-Market-Report.pdf
725. European Compost Network. (2018). Country report: Netherlands. https://www.compostnetwork.info/download/country-report-netherlands/
726. Organic fertilising products. Norwegian Government Security and Service Organisation. Retrieved 9 August 2023 from https://www.regjeringen.no/en/topics/business-and-industry/product-contact-point/norwegian-technical-rules/agriculture-fishing-and-foodstuffs/organic-fertilising-products/id2788888/
727. European Compost Network. (2017). Country report: Norway. https://www.compostnetwork.info/download/country-report-norway/
728. European Compost Network. (2015). Country report: Sweden. https://www.compostnetwork.info/download/country-report-sweden/
729. Avfall Sverige. (2021). Swedish waste management 2022. https://www.avfallsverige.se/media/lbdg3vcp/svensk_avfallshantering_2022_en.pdf
730. European Environment Agency. (2022). Early warning assessment related to the 2025 targets for municipal waste and packaging waste: Sweden. https://www.eea.europa.eu/publications/many-eu-member-states/sweden/view
731. Swiss Federal Office for the Environment. (2016). Kompostier und vergärungsanlagen. https://www.bafu.admin.ch/bafu/de/home/themen/abfall/publikationen-studien/publikationen/kompostieranlagen-vergaerungsanlagen.html
732. Japan: Diet passes new act aimed at reducing food loss. United States Library of Congress. Retrieved 10 August 2023 from https://www.loc.gov/item/global-legal-monitor/2019-10-09/japan-diet-passes-new-act-aimed-at-reducing-food-loss/
733. ECOS GmbH (Prepared for EU-Japan Centre for Industrial Cooperation). (2021). The market for biogas plants in Japan and opportunities for EU companies. https://www.ecos.eu/files/content/downloads/publikationen/REPORT_Biogas_2021.pdf
734. Jain, S. (2019). Market report: Japan. World Biogas Association. http://epower.pw/wp-content/themes/epower/img/WBA-japan-4ppa4.pdf

735. Standards New Zealand | Te Mana Tautikanga o Aotearoa. (2005). NZS 4454:2005 Composts, soil conditioners and mulches. https://www.standards.govt.nz/shop/nzs-44542005/
736. Establishment of a biofertiliser certification scheme. Bioenergy Association. Retrieved 24 August 2023 from https://www.biogas.org.nz/resource/biofertiliser-certification-scheme
737. New Zealand Water and Wastes Association. (2003). Guidelines for the safe application of biosolids to land in New Zealand. https://www.waternz.org.nz/Folder?Action=View%20File&Folder_id=101&File=biosolids_guidelines.pdf
738. Dingle, L. (2022). Meeting with Living Earth [Personal communication].
739. Yoo, K. (2019). Food waste management in Korea: Focusing on Seoul. United Nations Development Programme. https://www.undp.org/sites/g/files/zskgke326/files/migration/seoul_policy_center/USPC-Policy-Brief-6-Food-Waste.pdf
740. Kang, H. (2014). Korea country report. IEA Energy Technology Network & IEA Bioenergy. https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/02/Korea_Country_Report_10-2014.pdf
741. Yoon, J., & Lee, C. W. (2023, June 14). How South Korea puts its food scraps to good use. The New York Times. https://www.nytimes.com/2023/06/14/world/asia/south-korea-food-waste.html
742. Galchen, R. (2020, March 2). How South Korea is composting its way to sustainability. The New Yorker. https://www.newyorker.com/magazine/2020/03/09/how-south-korea-is-composting-its-way-to-sustainability
743. Quality protocol: Anaerobic digestate. UK Environment Agency. Retrieved 2 August 2023 from https://www.gov.uk/government/publications/quality-protocol-anaerobic-digestate
744. Quality protocol: Compost. UK Environment Agency. Retrieved 2 August 2023 from https://www.gov.uk/government/publications/quality-protocol-for-the-production-and-use-of-compost-from-waste
745. Waste—Detailed information. United Kingdom Environment Agency. Retrieved 2 August 2023 from https://www.gov.uk/topic/environmental-management/waste
746. Overview of the REAL's Biofertiliser Certification Scheme. Renewable Energy Assurance Limited. Retrieved 3 August 2023 from https://www.biofertiliser.org.uk/overview
747. Compost certification mark. Renewable Energy Assurance Limited. Retrieved 16 January 2023 from https://www.qualitycompost.org.uk/standards/pas100
748. UK Department for Environment Food & Rural Affairs. (2021). Official statistics Section 3: Anaerobic digestion. https://www.gov.uk/government/statistics/area-of-crops-grown-for-bioenergy-in-england-and-the-uk-2008-2020/section-3-anaerobic-digestion
749. Anaerobic digestion and composting: Latest industry survey report, new summaries of technology, and impacts. WRAP. Retrieved 3 August 2023 from https://wrap.org.uk/resources/report/anaerobic-digestion-and-composting-latest-industry-survey-report-new-summaries
750. WRAP. (2020). AD and composting industry market survey report 2020. https://wrap.org.uk/sites/default/files/2021-01/AD%20%26%20Composting%20Market%20Survey%20Report.pdf
751. Lamolinara, B., Pérez-Martínez, A., Guardado-Yordi, E., Guillén Fiallos, C., Diéguez-Santana, K., & Ruiz-Mercado, G. J. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. Waste Management, 140, 14–30. https://doi.org/10.1016/j.wasman.2021.12.035
752. Nutrient Management (Ac.) (590) conservation practice standard. US Department of Agriculture. Retrieved 17 July 2023 from https://www.nrcs.usda.gov/resources/guides-and-instructions/nutrient-management-ac-590-conservation-practice-standard

753. Biogas market snapshot. American Biogas Council. Retrieved 18 July 2023 from https://americanbiogascouncil.org/biogas-market-snapshot/
754. Basic information about anaerobic digestion. United States Environmental Protection Agency. Retrieved 18 July 2023 from https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion
755. Digestate utilization in the U.S. Ron Alexander, Biocycle. Retrieved 2 August 2023 from https://www.biocycle.net/digestate-utilization-in-the-u-s/
756. Composting in America. Environment America Research and Policy Center. Retrieved 18 July 2023 from https://environmentamerica.org/center/resources/composting-in-america/
757. Daalder, M. (2023, November 1). Geothermal and wood chips for dry years, but no hydrogen. Newsroom. http://newsroom.co.nz/2023/11/01/geothermal-and-wood-chips-for-dry-years-but-no-hydrogen/
758. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. (2023). Gas Transition Plan issues paper. https://www.mbie.govt.nz/dmsdocument/27255-gas-transition-plan-issues-paper-pdf
759. Ministry of Business, Innovation & Employment | Hīkina Whakatutuki. (2023). Energy balance tables. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-balances/
760. Energy statistics data browser. International Energy Agency. Retrieved 15 December 2023 from https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser
761. Te Tari Tiaki Pūngao | Energy Efficiency and Conservation Authority. The future of energy in New Zealand. Retrieved 15 December 2023 from https://www.eeca.govt.nz/insights/energys-role-in-climate-change/the-future-of-energy-in-new-zealand/
762. Abanades, S., Abbaspour, H., Ahmadi, A., Das, B., Ehyaei, M. A., Esmaeilion, F., El Haj Assad, M., Hajilounezhad, T., Jamali, D. H., Hmida, A., Ozgoli, H. A., Safari, S., AlShabi, M., & Bani-Hani, E. H. (2022). A critical review of biogas production and usage with legislations framework across the globe. International Journal of Environmental Science and Technology, 19(4), 3377–3400. https://doi.org/10.1007/s13762-021-03301-6
763. Jain, S. (2020). Market report: Germany. World Biogas Association. https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-Germany-4ppa4_.pdf
764. Bernstad Saraiva Schott, A., & Andersson, T. (2015). Food waste minimization from a life-cycle perspective. Journal of Environmental Management, 147, 219–226. https://doi.org/10.1016/j.jenvman.2014.07.048
765. Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2017). Sustainable waste management: Waste to energy plant as an alternative to landfill. Energy Conversion and Management, 131, 18–31. https://doi.org/10.1016/j.enconman.2016.11.012
766. Michel Devadoss, P. S., Agamuthu, P., Mehran, S. B., Santha, C., & Fauziah, S. H. (2021). Implications of municipal solid waste management on greenhouse gas emissions in Malaysia and the way forward. Waste Management, 119, 135–144. https://doi.org/10.1016/j.wasman.2020.09.038
767. Waste to energy (WTE): The preferred approach for waste management in Malaysia. Malaysian Investment Development Authority. Retrieved 4 December 2023 from https://www.mida.gov.my/waste-to-energy-wte-the-preferred-approach-for-waste-management-in-malaysia/
768. Tian, Y., Themelis, N. J., Zhao, D., Thanos Bourtsalas, A. C., & Kawashima, S. (2022). Stabilization of Waste-to-Energy (WTE) fly ash for disposal in landfills or use as cement

substitute. Waste Management, 150, 227–243. https://doi.org/10.1016/j.wasman.2022.06.043

769. Abdullah, M. H., Rashid, A. S. A., Anuar, U. H. M., Marto, A., & Abuelgasim, R. (2019). Bottom ash utilization: A review on engineering applications and environmental aspects. IOP Conference Series: Materials Science and Engineering, 527(1), 012006. https://doi.org/10.1088/1757-899X/527/1/012006
770. Huang, T. Y., Chiueh, P. T., & Lo, S. L. (2017). Life-cycle environmental and cost impacts of reusing fly ash. Resources, Conservation and Recycling, 123, 255–260. https://doi.org/10.1016/j.resconrec.2016.07.001
771. Smith, P. (2016). Soil carbon sequestration and biochar as negative emission technologies. Global Change Biology, 22(3), 1315–1324. https://doi.org/10.1111/gcb.13178
772. Glushkov, D., Nyashina, G., Shvets, A., Pereira, A., & Ramanathan, A. (2021). Current status of the pyrolysis and gasification mechanism of biomass. Energies, 14(22), 7541. https://doi.org/10.3390/en14227541
773. Andooz, A., Eqbalpour, M., Kowsari, E., Ramakrishna, S., & Ansari Cheshmeh, Z. (2023). A comprehensive review on pyrolysis from the circular economy point of view and its environmental and social effects. Journal of Cleaner Production, 388, 136021. https://doi.org/10.1016/j.jclepro.2023.136021