Residual Waste Management Options Review

Metro Vancouver Solid Waste Management Plan

Prepared for:
Solid Waste Services, Metro Vancouver
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Executive Summary

The Environmental Management Act mandates all regional districts in British Columbia (BC) to develop long term plans for managing municipal solid waste and recyclable materials. A solid waste management plan guides solid waste management strategies and actions, targets, and priorities for the next decade. The Guide to Solid Waste Management Planning 2016, developed by the Ministry of Environment and Parks, provides advice to aid in plan development that is consistent with legislative requirements. It sets out expectations regarding plans and desirable outcomes, defined by provincial targets and principles.

As part of the overall process for updating Metro Vancouver's solid waste management plan, Metro Vancouver commissioned Stantec to review residual waste management options.

Residual waste is the leftover non-hazardous (residual) waste from the residential and commercial/institutional sectors and demolition, land clearing or construction sources that is destined for disposal. Residual waste is the fraction of the municipal solid waste stream that is left after waste prevention and recycling. This study focuses on management of residual waste from the residential, commercial and institutional sectors.

The main objectives of the review are to:

- Provide technical information in support of solid waste management plan discussions related to options for management of residual residential and commercial/institutional waste following efforts to maximize waste reduction and recycling.
- Provide an overview of the considerations of all potential options as well as identifying potential criteria for evaluating options in the future.

The review is not intended to rank residual waste management options.

A key component of the residual waste management options review was to complete a literature review with the objective to summarize international practices related to the management of residual waste and provide a high-level overview of approaches being taken around the world in countries or regions with a similar standard of living to Canada.

In addition to a general overview of the approaches taken in other regions, the literature review includes discussion of some of the economic and regulatory drivers that have helped define the residual waste management approach for each region. This review highlights and summarizes the primary goals for managing waste, waste reduction efforts, and residual waste management within the regions. Also identified are residual waste management systems and approaches that are working well or may be experiencing some challenges.

Similarities to Metro Vancouver were considered when selecting the regions for the literature review. Regions were selected because they have one or more of the following similarities: standards of living to Canada, waste streams, economic models, and apply a waste hierarchy as a guide for managing wastes.

The following regions/countries were selected for review:

- Canada
- United States
- European Union with a focus on Scandinavian countries and Germany
- Australia
- Japan

Canada

Landfilling is the most common approach for managing residual waste in Canada and a small portion is treated using mass burn and two-stage waste-to-energy technologies. Low landfill tipping fees are one of the factors favouring landfills as the most common approach for managing residual waste in Canada. Low landfill tipping fees are driven by the availability of landfill capacity across much of the country. In comparison, mass burn and two-stage waste-to-energy facilities are characterized by high initial capital costs. Other barriers to development of waste-to-energy facilities include public risk perceptions.

The mass burn and two-stage waste-to-energy facilities currently operating in Canada are well established with the newest mass burn facility beginning operations in 2016. The Alberta Utilities Commission has approved Varme Energy's application to build a waste-to-energy facility near Edmonton (Anchan, 2025). Some facility owners are looking into district heating upgrades. The facility owners of two-stage waste-to-energy facilities are exploring the potential to replace the systems with mass-burn waste-to-energy.

Waste-to-energy technologies, other than the mass burn and two-stage waste-to-energy technologies, such as gasification and pyrolysis have not been successfully implemented at a commercial scale to process residual waste in Canada. Mixed waste processing has also not been implemented successfully in Canada. Studies have shown that mixed waste processing of residual waste would be unlikely to meet target outcomes of recycling and resource recovery and be less cost-effective than current waste recycling program efforts (City of Toronto, 2021; City of Toronto, 2020).

United States

In the United States most of the residual waste is managed through landfilling and the remaining is treated or managed primarily at mass burn waste-to-energy facilities. Between 2000 and 2019, 31 mass burn waste-to-energy facilities in the United States have stopped operation due to economic constraints related to decreasing electricity prices and lower landfill tipping fees (Baptista, 2019). While no new mass burn waste-to-energy facilities opened in the United States between 1995 and 2015, some were expanded to handle additional waste and generate more energy. In 2015, the first new mass burn waste-to-energy facility in 20 years was built and commissioned in Palm Beach County, Florida (United States Department of Energy, 2019; United States Energy Information Administration, 2023).

There are two demonstration gasification facilities in North Carolina and California, United States (National Renewable Energy Laboratory (United States Department of Energy), 2023). The Fulcrum's

Sierra Biofuels gasification facility in Nevada started operations in 2022, however, the facility later closed in 2024 due to permitting and operational issues (Bettenhausen, 2024). Like Canada, gasification and pyrolysis technologies have not been successfully implemented at a commercial scale for residual waste management in the United States.

European Union

After the rapid growth of the mass burn waste-to-energy facilities between 1991 and 2010, and the implementation of the Circular Economy Act in 2012 in Germany, overcapacity in the mass burn waste-to-energy market was reported in 2013. The Circular Economy Act increased the focus on reduction and recycling efforts, which created a competitive mass burn waste-to-energy market with low tipping fees as per the reports of 2013 (Roll, 2013).

The developed recycling infrastructure and overcapacity in the German and Scandinavian mass burn waste-to-energy markets has resulted in the importation of refuse derived fuel from countries like the United Kingdom. For instance, Germany was the second largest refuse derived fuel recipient from England with 415,000 tonnes being imported in 2021 (GPT, 2020; Langley, 2022). Importing unprocessed residual waste into Germany or Sweden is prohibited. Only refuse-derived fuels may be imported, resulting in the processing of residual waste through mixed waste processing facilities prior to export in countries such as the United Kingdom (Environment Agency UK, 2025).

Countries with the highest gross domestic product per capita (i.e. Luxembourg, Ireland, Denmark, Netherlands, Austria, Sweden, Finland, Belgium, Germany, France) and recycling rates at 40% or higher rely more on waste-to-energy for disposal of residual waste compared to countries with a lower per capita gross domestic product and generally lower recycling rates rely more on landfilling for the management of residual waste.

Australia

Australia's residual waste management approach is heavily reliant on disposal in landfills. The first two mass burn waste-to-energy facilities planned in Western Australia are currently working towards starting their commercial operations. As of 2025, the Kwinana Energy from Waste project owned and operated by ACCIONA is going through the commissioning phase, which started on July 2024 with initial waste deliveries prior to combustion start up in September 2024 and full ramp up to commercial scale operations later in 2025. As of December 2024, the East Rockingham mass burn waste-to-energy project is at the pre-construction phase, with the construction cost estimate under review and an external specialist engineering consulting firm engaged to provide support.

According to Waste Management and Resource Recovery Association of Australia, one of the main reasons for the historically low adoption of mass burn waste-to-energy facilities in the country appears to be public opposition, which stems from the perception that air pollution and control systems are inadequate (Waste Management and Resource Recovery Association of Australia, 2021).

Japan

The shortage of landfill sites has been one of the most critical challenges of waste management in Japan due to the difficulty in constructing new landfills (limited land availability). In addition, waste export would be costly since it is an isolated island as compared to other countries in the European Union where waste export to neighboring countries is easier and less costly. Waste-to-Energy is used to manage effectively all residual waste in Japan.

In Japan, the primary waste-to-energy technology is mass burn with some two-stage waste-to-energy facilities. Japan also has few Thermoselect facilities (combines pyrolysis and gasification) constructed in the early 2000s that have been reported to yield syngas suitable for gas turbine or conversion to liquid fuels and chemicals. However, performance of Thermoselect processes in Japan is not known due to the lack of public information.

Summary of National and International Practices

The approaches for managing residual waste in Canada, United States, European Union, Japan and Australia were reviewed and presented in this report. In general, these countries/regions align their goals with the waste management hierarchy and make efforts to move waste and related initiatives up the hierarchy. All countries/regions have set goals to reduce, reuse and recycle and decrease the total amount of residual waste to be managed.

The two main residual waste management approaches that have been adopted across the five countries/regions are mass burn waste-to-energy and landfilling. Among the regions reviewed, land availability, the prevalence of landfills and the low fees of landfilling have been important factors in determining the prevalent approach to manage residual waste. Other factors impacting the selection of options include the regulatory setting, public perceptions, energy prices/availability and incentives such as subsidies or carbon credits. Japan has the highest average landfill tipping fees in the world due to the limited landfilling capacity. Similarly, limited landfill space and policy have been the main drivers of the widespread adoption of mass burn waste-to-energy in many parts of Europe. In the United States, where overall landfilling of residual waste is the dominant approach, the majority of mass burn waste-to-energy facilities are used in states with dense populations and limited available land for landfills.

Key Considerations & Technical Criteria for Evaluating Future Options

In Canada, landfilling is expected to continue to be the most common approach to managing residual waste for the foreseeable future. Mass burn waste-to-energy is the primary alternative to landfilling around the world with communities choosing mass burn waste-to-energy rather than landfilling based on both local and national circumstances.

Technical criteria have been developed that could be considered during the decision-making process when selecting the most appropriate approach to manage residual waste, through landfilling or waste-to-energy. This report presents technical criteria for evaluating residual waste management which covers six different main criteria categories, as identified in the figure below.

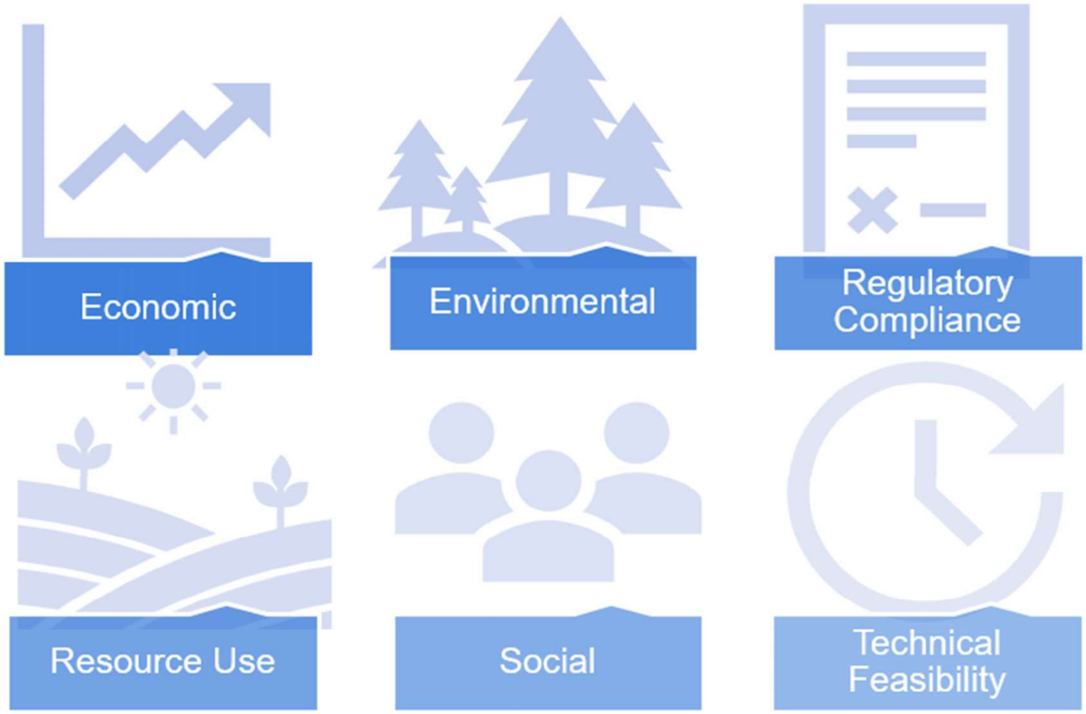

Figure: Six categories of the technical criterial for evaluating residual waste management options

Definitions

Commercial Scale Facility	Commercial scale operation of a facility that provides consistent treatment capacity for residual waste to meet community disposal needs and regulatory standards and refers to the state in which the complete equipment is officially declared by the owner to be available for continuous operation at different loads up to and including rated capacity. Commercial scale facilities must operate at a high utilization to increase productivity and control costs. Information with respect to the ongoing performance of the facility is publicly available and verified by independent third parties.
Gasification	Thermal treatment process in which the majority of the carbon in the waste is converted into the gaseous form (syngas), leaving an inert residue (char). The upgrading process involves the partial combustion (partial oxidation) of a portion of the fuel in the reactor with air, pure oxygen, and oxygen enriched air or by reaction with steam. The energy content of the waste is therefore transferred into the gas phase as chemical energy, which can be utilized to generate power. The term “gasification plant” is typically used to name the entire system that converts the primary feedstock into useful energy carriers. As opposed to two-stage combustion, gasification plants typically use the syngas for a separate chemical process or as a fuel after cleaning/refining. Gasification typically involves shredding and other residual waste pre-processing steps.
Landfilling	Landfilling is the process of disposing of waste in or on the land in an organized manner while establishing systems and approaches for minimizing the impacts from things like leachate, landfill gas and vectors.
Mass Burn Waste-to-Energy	Sometimes referred to as incineration, is the direct controlled burning of waste in one or more chambers with excess amounts of oxidant (typically air) at temperatures of 850ºC and above. The energy stored in the feedstock is released into the combustion chamber as well as in the flue gases generated during the combustion process. These technologies are often also called “conventional waste-to-energy” or “mass burn”. Compared to other technologies, mass burn waste-to-energy involves full oxidization in one step without pre-processing of the residual waste feedstock, and typically includes energy recovery either as electricity or heat for either space heating and hot water or for industrial purposes.
Mixed Waste Processing	Refers to residual waste that undergoes one or more manual, mechanical, and/or biological processing stages to separate recyclables and the organic fraction from the residual waste before final disposal.
Municipal Solid Waste	Refers to recyclables and compostable materials, as well as residual waste from residential, commercial, institutional, demolition, land clearing and construction sources.
Pyrolysis	Thermal degradation of carbonaceous materials, typically at temperatures between 400ºC and 600ºC either in the complete absence of oxygen, or with such a limited supply, that gasification does not occur to any appreciable extent. The products of pyrolysis always include gas (syngas),

	liquid (pyrolytic oil) and solid char. Pyrolysis, similar to gasification, typically involves shredding and other residual waste pre-processing steps.
Recycling	Recycling is the processing of source separated materials to produce products and includes composting and anaerobic digestion.
Residual Waste	The non-hazardous waste collected from residential, commercial, institutional, demolition, land clearing or construction sources that is destined for disposal. It does not include material that is collected and diverted to recycling. Residual waste is the fraction of the municipal solid waste stream that is left after prevention, reuse, and recycling. For the purposes of this study residual waste refers to waste from residential, commercial and institutional sources.
Refuse Derived Fuel	Fuel product produced from residual waste which has undergone some level of mechanical and sometimes biological processing, that can be used in conventional mass-burn waste-to-energy, cement plants or in gasification and pyrolysis, where feedstock quality is more critical.
Renewable Energy	Energy obtained from non-fossil based resources such as sunlight, wind, geothermal, and biomass.
Two-stage Waste-to-Energy	Two-stage waste-to-energy is similar to conventional mass burn waste-to-energy except that the individual stages of combustion occur in separate chambers. The first chamber involves incomplete combustion and the creation of a syngas. The syngas is then combusted in a second chamber without additional cleaning and heat is typically recovered. This technology is also sometimes called “staged gasification” because gasification is the first step. However, true gasification plants use the syngas for a separate chemical process or as a fuel after cleaning/refining. Staged gasification directly followed by combustion of the syngas is considered two stage waste-to-energy for the purpose of this study.
Waste-to-Energy	Thermal processing or thermal treatment, involving the conversion of residual waste at high temperatures into gaseous, liquid, and solid products with a concurrent and subsequent release of heat energy. In this report, the term "waste-to-energy" is used in a broader context, encompassing not only mass burn waste-to-energy but also other thermal processes such as gasification, pyrolysis, and others.
Waste Hierarchy	The waste hierarchy is a framework that ranks waste management practices by environmental impact, from most to least favorable, such as: prevention, reuse, recycling, energy recovery and landfill. In this paper the term Waste Hierarchy refers to the Environment and Climate Change Canada’s Waste Hierarchy: Waste Prevention, Reuse – Repair, Remanufacture – Refurbish, Recycle, Energy Recovery and Landfill.

1 Introduction

1.1 Purpose and Objectives

The Environmental Management Act mandates all regional districts in British Columbia (BC) to develop long term plans for managing municipal solid waste. A solid waste management plan guides solid waste management strategies and actions, targets, and priorities for the next decade. The Guide to Solid Waste Management Planning 2016, developed by the Ministry of Environment and Parks provides guidance to aid in plan development that is consistent with legislative requirements (Government of British Columbia, 2024b). It sets out expectations regarding plans and desirable outcomes, defined by provincial targets and principles.

As part of the overall process for updating Metro Vancouver's solid waste management plan, Metro Vancouver commissioned Stantec to review residual waste management options.

The main objectives of the review are to:

- Provide technical information in support of solid waste management plan discussions related to options for management of residual waste.
- Provide an overview of the considerations of all potential options as well as identifying potential criteria for evaluating options in the future.

The review is not intended to rank residual waste management options.

1.2 Scope Summary

The scope of the residual waste management options review was developed through discussions with Metro Vancouver and feedback received from advisory committees involved in the solid waste management planning process, including the Solid Waste Management Plan Public/Technical Advisory Committee, Solid Waste and Recycling Industry Advisory Committee, and Regional Engineers Advisory Committee Solid Waste Subcommittee. The proposed tasks were:

1. Literature review
2. Review options for management of residual waste
3. Prepare historic case studies (up to 10) on alternative/non-mainstream technologies
4. Prepare current case studies (up to 10) on alternative (non-mainstream) technologies
5. Summarize considerations for residual waste management approaches
6. Identify potential criteria for evaluating residual waste management options
7. Reporting

During the development of the literature review, and through discussions with Metro Vancouver, it was decided that there would be more value in a comprehensive literature review integrating case studies rather than developing stand-alone case studies. The scope was updated to focus on the following:

- A literature review of how other regions manage residual waste with examples of key considerations such as waste management goals, economic and regulatory drivers, successes and challenges.
- A summary of key considerations for future options within the context of Metro Vancouver when looking at residual waste management options.
- A set of potential evaluation criteria when assessing future options for managing residual waste from Metro Vancouver.

This report presents the findings of the residual waste management options review.

2 Literature Review of Residual Waste Management in Different Countries and Regions

2.1 Introduction

The purpose of the literature review is to summarize international practices related to the management of residual waste and provide a high-level overview of approaches being taken around the world in countries or regions with socio-economic conditions similar to Canada, which included the United States, Europe, Japan, and Australia.

In addition to a general overview of the approaches taken in other regions, included in the following sections is a discussion of some of the economic and regulatory drivers that have helped define the residual waste management approach for each region. This review highlights and summarizes the primary goals for managing waste, waste reduction efforts, and residual waste management within the regions. Also identified are residual waste management systems and approaches that are working well or may be experiencing some challenges.

2.2 Countries & Regions Selected for Review

Similarities to Metro Vancouver were considered when selecting the regions for the literature review. Regions were selected because they have one or more of the following similarities to Canada: standards of living, waste streams, economic systems, and apply a waste hierarchy as a guide for managing wastes. These regions were also selected to provide a broad cross section of practices and approaches for managing residual waste. For example, some regions focus on waste-to-energy while others rely more on landfilling.

The following regions/countries were selected for review:

- Canada

- United States
- European Union with a focus on Scandinavian countries and Germany
- Australia
- Japan

Included in the following sections is an overview of these regions and their approaches to managing residual waste.

2.3 Canada

2.3.1 Overall Waste Management Goals & Objectives

The federal government has adopted a waste hierarchy (waste prevention-reduce, reuse-repair, remanufacture-refurbish, recycle, energy recovery, landfill) (Environment and Climate Change Canada, 2021), where energy recovery from residual waste is preferred over landfill disposal and mass burn without energy recovery. All provinces and territories follow a similar hierarchy (Canadian Council of Ministers of the Environment, 2014). Generally, a similar strategy of achieving maximum waste reduction and diversion through reduce, reuse and recycle is favoured before disposal.

In 2022, Canada generated approximately 36 million tonnes of municipal solid waste, with approximately 9.9 million tonnes (27.1%) diverted from disposal and 26.6 million tonnes (72.9%) managed as residual waste (Environment and Climate Change Canada, 2022a). As per Environment and Climate Change Canada, approximately 97% (25.8 million tonnes)[1] of the waste requiring final disposal is sent to landfills and 3% (0.79 million tonnes)[2] is treated in mass burn and two-stage waste-to-energy technologies (Environment and Climate Change Canada, 2024a). Figure 1 shows the amount of residual waste landfilled and thermally treated in waste-to-energy facilities in Canada.

[1] Calculated based on 2022 tonnages.
[2] Calculated based on 2022 tonnages.

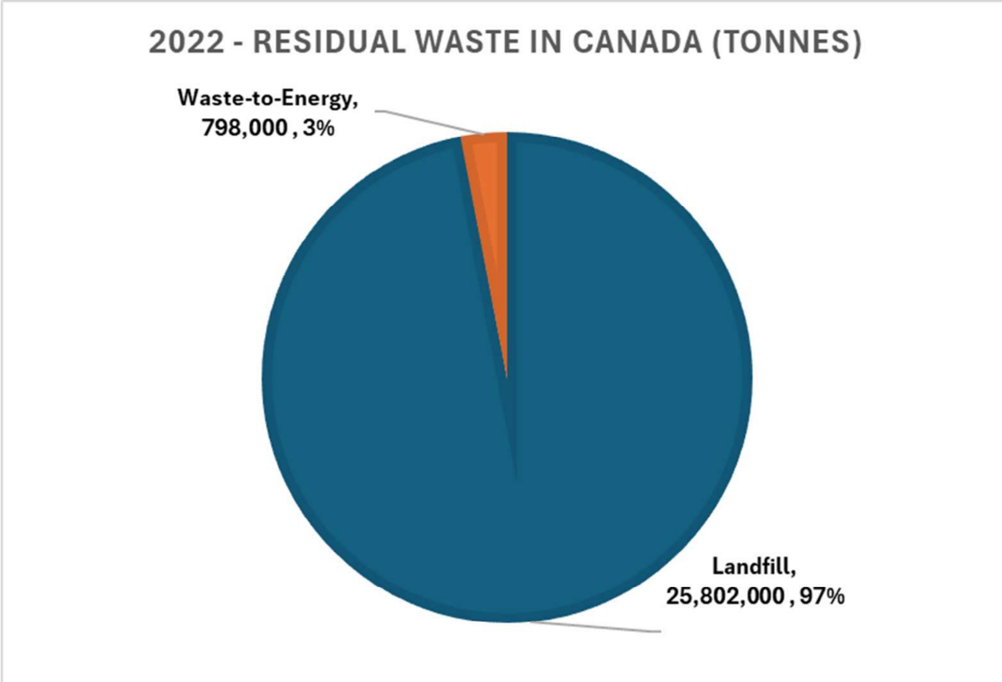

Figure 1: Residual waste management in Canada (Environment and Climate Change Canada, 2022a; Environment and Climate Change Canada, 2024a).

The Government of Canada has set goals to decrease the country's 2014 per capita disposal rate by 30% by 2030 and by 50% by 2040 (Environment and Climate Change Canada, 2025). All provinces and territories have intentions of reducing the amount of waste disposed or generated, with some having set provincial/territorial targets. Some of the targets by province and territory are given below:

Targets for Waste Reduction:

- Saskatchewan aims to reduce their per capita waste generation rate by 30% by 2030 and 50% by 2050 (Saskatchewan, N.D.).
- Metro Vancouver, in its 2011 solid waste management plan, set a waste generation reduction goal of 10% compared to 2010 (Metro Vancouver, 2010).

Targets for Recycling:

- Ontario plans to achieve 50% diversion[3] by 2030 and 80% by 2050 (Ministry of the Environment, Conservation and Parks, N.D.).
- Yukon has set a target to increase the amount of recycling to 40% by 2025 (Government of Yukon, N.D.).

[3] Ontario was planning to achieve diversion mainly through reduce, reuse and recycling (as defined in this report), however, treatment of non-recyclables waste in waste-to-energy technologies was also considered to achieve the diversion goal.

- The Regional District of Nanaimo has a recycling diversion target of 90% of waste diverted from landfill through recycling, composting, and other recovery methods by 2027 in their 2019-2029 Solid Waste Management Plan (Regional District of Nanaimo, 2019).
- Metro Vancouver, as part of its 2011 solid waste management plan, set an aspirational 80% recycling target (Metro Vancouver, 2010).

Targets for Disposal:

- British Columbia has set a provincial target to lower the municipal solid waste disposal rate to 350 kg per capita per year (Government of British Columbia, 2022).
- The Capital Regional District aims to decrease annual municipal solid waste disposal from 380 kg per capita to 250 kg per capita within a 10-year planning period (2020 – 2030) (Capital Regional District , 2020).
- The Regional District of Nanaimo has a disposal target of 109 kilograms per capita per year of waste sent to landfill by 2027 in their 2019-2029 Solid Waste Management Plan (Regional District of Nanaimo, 2019).
- Similarly, Regional Districts across British Columbia have set their own target of decreasing per capita municipal solid waste disposal rates. The Central Coast Regional District aims to decrease the estimated per capita municipal solid waste disposal rate by 20% from the estimated 2016 baseline of 450 kg/year (Central Coast Regional District, 2017). The Cowichan Valley Regional District plans to decrease the disposal rate to 250 kg per capita per year by 2028 (Cowichan Valley Regional District, N.D.).
- Alberta had set a target to reduce per capita disposal to 500 kg per person by the year 2010. However, the annual waste per capita disposal rate in Alberta was still 1,034 kg per person in 2021, 45.6% higher than the national average of 710 kg per person per year (Government of Alberta, 2024b).
- Newfoundland and Labrador's goal in it's 2002 Waste Management Strategy is to reduce materials going to landfill by 50% by 2010 and had reached 25% in 2019 (Newfoundland and Labrador, 2019).

2.3.2 Summary of Residual Waste Management Approaches

Landfilling is the most common approach for residual waste management in Canada. In 2022, Environment and Climate Change Canada reported that there are over 3,000 open and closed municipal solid waste landfills in the country, with slightly more than half in operation (Environment and Climate Change Canada, 2022b). According to landfill gas inventory data from Environment and Climate Change Canada, there are approximately 267 large landfills in Canada that received almost 90% of the waste landfilled in 2019 (Environment and Climate Change Canada, 2022b; Environment and Climate Change Canada, 2024b). Of these, 214 are open and have a remaining capacity of more than 100,000 tonnes of waste and 53 are closed (1 temporarily closed) which contain over 450,000 tonnes of waste in place. According to Canada's Greenhouse Gas Inventory in 2022, 36% of the generated methane from landfills in Canada was captured and flared or used for energy, and the remaining was emitted into the atmosphere (Environment and Climate Change Canada, 2024c).

Canada has five commercial-scale mass burn and two-stage waste-to-energy facilities located in Ontario, British Columbia, Quebec, and Prince Edward Island as listed in Table 1 (Environment and Climate Change Canada, 2020).

Table 1. Waste-to-Energy Technologies Operating in Canada

Facility Name	Waste-to-Energy Technology	Location	Capacity (Tonnes/Year)	Output
L'incinérateur de la Ville de Québec, QC	Mass burn Waste-to-Energy	Quebec, Quebec	245,000 [b]	Heat for industry [c]
Metro Vancouver Waste-to-Energy Facility	Mass burn Waste-to-Energy	Burnaby, BC	240,000	Electricity [c]
Emerald Energy from Waste Facility	Two-stage Waste-to-Energy [a]	Mississauga, Ontario	180,000	Heat, electricity
Durham York Energy Centre	Mass burn Waste-to-Energy	Durham Region, Ontario	140,000	Electricity
Prince Edward Island (PEI) Energy Systems Waste-to-Energy Facility	Two-stage Waste-to-Energy [a]	Charlottetown, PEI	26,000	Heat, electricity

[a] Current thermal treatment facility is in the process of being replaced with a mass burn waste-to-energy facility.
[b] Note permitted capacity is approximately 310,000 tonnes. Tonnages shown in table represent annual tonnages reported in 2021 and 2022.
[c] Facilities have plans for district heating expansions.

The Durham York Energy Centre commenced full operations in 2016. The Alberta Utilities Commission has approved Varme Energy's application to build a waste-to-energy facility in Strathcona County, northeast of Edmonton (Anchan, 2025). The Emerald Energy from Waste Facility plans to replace their two-stage waste-to-energy system with a higher capacity mass burn waste-to-energy system at the facility in phases, adding processing capacity in response to market demand (GHD, 2024). The Prince Edward Island Energy Systems Waste-to-Energy Facility also plans to replace their two-stage waste-to-energy system with higher capacity mass burn waste-to-energy systems that would include a waste reception hall, waste bunker, boiler hall, emissions treatment hall, auxiliary plant rooms, control room and residue silos (Stantec Consulting Ltd., 2022).

In addition to the waste-to-energy facilities noted above, Sustane Technologies is working to develop a facility in Chester, Nova Scotia. The Sustane facility was designed to use a mechanical process (shredding, separation and thermal hydrolysis) to produce biomass pellets and rotary kiln pyrolysis to produce synthetic diesel. Built in 2019, the Sustane facility was expected to be fully commissioned by spring 2019, with a processing capacity of 70,000 tonnes of residual waste annually (Government of Canada, 2024b; Comox Strathcona Waste Management, 2023a; Environment and Climate Change Canada, 2023). The facility aimed to convert 10–20% of the incoming residual waste into fuel, and the remaining (80 – 90% of the residual waste) into biomass pellets (Environment and Climate Change Canada, 2023). However, the Sustane facility faced several setbacks over the years and has not performed at a commercial scale. The facility has not demonstrated an ability to continuously process residual waste (Comox Strathcona Waste Management, 2023a; Comox Strathcona Waste Management, 2023b).

A facility in Edmonton owned by Enerkem Alberta Biofuels (Enerkem) began operations in 2014 under a 25-year agreement with the City of Edmonton. The facility used fluidized bed gasification to produce methanol and ethanol from refuse derived fuel supplied by the City of Edmonton. The City produced refuse derived fuel from residual waste at the Integrated Processing and Transfer Facility in Edmonton (CBC, 2024; City of Edmonton, 2025). The Enerkem Edmonton facility closed in 2024 after producing a total of 5 million litres of biofuels – the initial projection was to create 36 million litres per year. The $80 million Enerkem facility never processed residual waste at a commercial scale (CBC, 2024). Enerkem has stated that another facility is under construction in Varennes, Quebec – this gasification facility is intended to produce biofuels from various feedstock with an estimated capital cost of $875 million (Enerkem, 2025). However, construction of the gasification facility in Varennes, Quebec has paused due to lack of funds (La Presse, 2025).

A third gasification facility, constructed by Plasco Energy Group (Plasco) in Ottawa in the 2000s shutdown in 2015 after raising $300 million dollars in investment. It was never able to effectively process residual waste and failed to meet its contractual obligations with the City of Ottawa (Ottawa Citizen, 2015).

Mixed waste processing facilities have not been implemented successfully in Canada. In 2021, the City of Toronto conducted a study to evaluate whether a mixed waste processing facility, with a focus on recycling and organics recovery, could help achieve its 70% residential waste recycling target. The findings of the study indicated that such a facility would be unlikely to meet target outcomes of resource recovery and recycling and be less cost-effective than current waste recycling program efforts. The study also found that recovering recyclables from residual waste through a mixed waste processing facility would have a minimal impact on the City's diversion rate with the most likely material recovery scenario resulting in a contribution of 5.3% to the City's overall diversion rate. Toronto's most likely recovery scenario focuses on the recovery of acceptable green bin organics (including paper and paper packaging) and high-value blue bin recycling (PET, HDPE, and metals) that meet market quality parameters. This scenario would result in processing 279,000 tonnes of garbage at a processing cost of $126 per tonne. The mixed waste processing facility and organics processing costs were estimated at approximately $310 million in capital costs (adjusted for inflation) and $19.5 million in annual operating costs. It was also concluded that the potential revenues from recycling and renewable natural gas generation, plus potential landfill cost savings, do not result in significant cost savings for diversion via mixed waste processing and organics processing (City of Toronto, 2023; City of Toronto, 2021). Metro Vancouver and Toronto have similar waste composition results for organics and recyclable materials from single family and multi-family residences, hence similar capital and operating costs for a mixed waste processing facility and organics processing could be expected. In addition, Metro Vancouver would have a similar diverted cost of $688 per tonne as Toronto.

There have been facilities in Canada that incorporate a form of mixed waste processing as part of an overall process to produce refuse derived fuels for thermal treatment. However, these facilities (e.g. Enerkem facility in Edmonton and Sustane facility in Chester) have not been able to process residual waste at a commercial scale.

2.3.3 Summary of Economic & Regulatory Drivers

Some of the economic and regulatory drivers affecting residual waste management are outlined below.

2.3.3.1 Disposal Levies

At the provincial level, Quebec and Manitoba have introduced disposal levies to be paid by the owner/operator of the waste management facilities per tonne of waste disposed. In Quebec the regulations apply to both landfills and waste-to-energy (Canadian Legal Information Institute, 2024; Canadian Legal Information Institute, 2023). In Manitoba the levy applies to landfilling and waste-to-energy (Manitoba, N.D.). Similarly, Prince Edward Island and Saskatchewan are considering introducing disposal levies in the future to help fund waste reduction and recycling efforts across the province (Prince Edward Island, 2018; Saskatchewan, N.D.).

2.3.3.2 Disposal Bans

Some jurisdictions in Canada focus on increasing recycling by implementing disposal bans at the regional or provincial levels (e.g., Metro Vancouver, Capital Regional District, Nova Scotia and Newfoundland and Labrador) (Government of Nova Scotia, N.D.; Pollution Prevention Division, 2023). Disposal bans provide a signal to generators and haulers to encourage recycling of the banned material.

2.3.3.3 Energy Costs

The price of electricity in British Columbia, Quebec, Newfoundland and Labrador, and Manitoba is relatively low because of the presence of numerous large hydro electric power developments. In contrast, provinces that rely on fossil fuels have higher electricity prices. Since waste-to-energy facilities typically produce electricity, the value of electricity impacts the financial model for waste-to-energy facilities. The Maritimes and Quebec have the highest average natural gas costs in Canada, where few homes in these provinces use natural gas for heating. This could improve the feasibility of steam supply (district heating) from mass burn waste-to-energy facilities (Environment and Climate Change Canada, 2023).

2.3.3.4 Landfill Tipping Fees

Landfill tipping fees in most of Canada are relatively low. Multiple factors, including total landfill capacity, the number of landfills, and relatively inexpensive design and operation of landfills, tends to keep tipping fees low. Tipping fees are a consideration in selecting a disposal option (Environment and Climate Change Canada, 2023).

2.3.3.5 Incentives/Funding

Provincial and federal emission offset policies provide opportunities for different emission reducing projects to generate carbon credits. The Alberta Emission Offset System allows certain waste-to-energy projects to generate carbon credits through the Quantification Protocol for Waste Heat Recovery or the Energy Generation from the Combustion of Biomass Waste (Government of Alberta, 2024a). There are federal and some provincial quantification protocols that help generate carbon credits from landfill methane recovery and destruction (Government of British Columbia, 2024a; Government of Canada, 2024a; Gouvernement du Québec, 2024).

2.3.4 Overview – Successes & Challenges

Landfilling is the most common approach for managing residual waste in Canada and a small portion is treated using mass burn and two-stage waste-to-energy technologies. Low landfill tipping fees are one of the factors favouring landfills as the most common approach for managing residual waste in Canada. Low landfill tipping fees are driven by the availability of landfill capacity across much of the country. In comparison, waste-to-energy facilities are characterized by high initial capital costs. Other barriers to development of waste-to-energy facilities include risk perceptions (Leung & Heacock, N.D.).

The mass burn and two-stage waste-to-energy facilities currently operating in Canada are well established. Some facility owners are looking into district heating upgrades, and the two two-stage waste-to-energy facilities are planning to replace the technology with higher capacity mass burn systems (GHD, 2024) (Stantec Consulting Ltd., 2022).

Waste-to-energy technologies, other than the mass burn and two-stage waste-to-energy technology, such as gasification and pyrolysis have not been successfully implemented at a commercial scale to process residual waste in Canada. Mixed waste processing has also not been implemented successfully in Canada. As indicated above, the Edmonton Enerkem, Ottawa Plasco, and Halifax Sustane technologies have been unsuccessful in meeting their intended objectives. Studies have shown that mixed waste processing of residual waste would be unlikely to meet target outcomes of recycling and resource recovery and be less cost-effective than current waste recycling program efforts (City of Toronto, 2021).

2.4 United States

2.4.1 Overall Waste Management Goals & Objectives

In general, the United States promotes reduction, reuse and recycling of waste. The 2030 Food Loss and Waste Reduction Goal was introduced by the United States Environmental Protection Agency on September 16, 2015. This goal's objective is to cut food loss and waste in half by the year 2030 (United States Environmental Protection Agency, 2024a).

In addition, a national goal of increasing the recycling rate to 50% by 2030 was announced by the United States Environmental Protection Agency on November 17, 2020. As a parallel effort, the United States Environmental Protection Agency developed a National Recycling Strategy that identifies objectives and actions needed to create a stronger, more resilient United States recycling system (United States Environmental Protection Agency, 2024b).

There are differing waste management approaches across the United States depending on the goals and initiatives within each state. Many states, such as Washington, Oregon, and California, have similar goals and initiatives to Metro Vancouver, BC., and have a strong focus on sustainable waste management practices (State of Washington, 2020; Oregon, N.D.; State of California, 2020). These regions emphasize the importance of reducing waste and increasing recycling. In 2018, San Francisco took a pledge along with other major cities to reduce municipal solid waste generation by 15% by 2030 and reduce disposal to landfill and incineration 50% by 2030 (San Francisco, 2018). In 2018, the United States generated a total of 265.2 million tonnes of municipal solid waste, of which 32% was recycled and composted. An additional 16 million tonnes of food waste (6% of the total municipal solid waste) was managed by other methods such as bio-based materials/biochemical processing and co-digestion/anaerobic digestion (United States Environmental Protection Agency, 2022).

Across the United States, after considering recycling, composting, and food waste management efforts, there is still roughly 62% (164 million tonnes) of the waste stream left as residual waste that is mainly managed through mass burn waste-to-energy and landfill disposal. In 2018, 19% of the residual waste (31 million tonnes) was treated in mass burn waste-to-energy facilities and 81% (132 million tonnes) was landfilled (Figure 2).

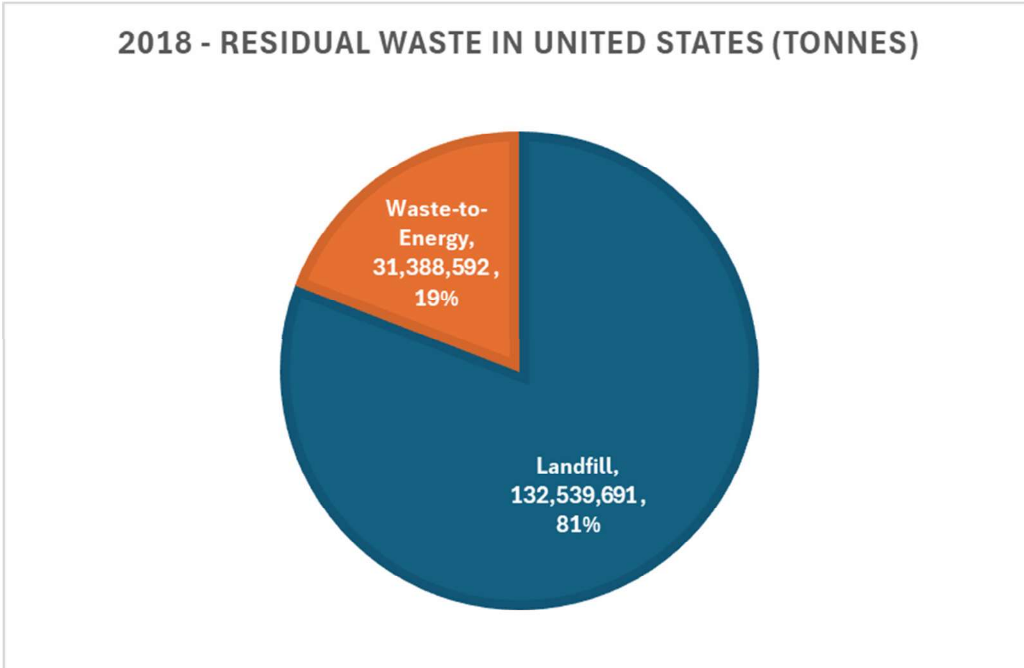

Figure 2: Residual waste management in the United States (United States Environmental Protection Agency, 2022).

2.4.2 Summary of Residual Waste Management Approaches

Residual waste in the United States is either treated at waste-to-energy facilities (19% of residual waste) or disposed of in landfills (81% of residual waste). Landfilling is the most common option to manage residual waste in the United States. As of September 2024, there were 2,639 landfills of which 488 municipal solid waste landfills provide landfill gas to 542 projects and the Environmental Protection Agency estimates that an additional 444 additional landfills could cost-effectively capture methane and convert it to an energy resource (United States Environmental Protection Agency, 2024a; United States Environmental Protection Agency, 2025).

Mass burn waste-to-energy facilities are the most common thermal treatment technology. The total number of waste-to-energy facilities in the United States, based on the 2018 directory of waste-to-energy facilities by the Energy Recovery Council was reported as 75 facilities (United States Environmental Protection Agency, 2022). According to a 2022 U.S. Energy Information Report, low electricity prices, local opposition and policies related to emissions have resulted in some facility closures in recent years. At the beginning of 2022, there were 60 mass burn waste-to-energy facilities operating and generating electricity in the United States, with a total generating capacity of 2,051 megawatts (MW) (United States Energy Information Administration, 2022).

The United States has two demonstration gasification facilities: one in Durham, North Carolina, featuring a two-stage steam reforming process in a deep fluidized bed (3.6 tonnes per day of processing capacity), and the other at the United States Army Garrison Fort Hunter Liggett in Monterey County, California, utilizing FastOx gasification technology (18 tonnes per day of processing capacity). Both facilities employ the Fischer-Tropsch method at the final stage to produce liquid fuels. A third small pyrolysis plant is in Knoxville, Tennessee, commissioned in 2007 with a design waste processing capacity of 907 tonnes per year and 1 MW electricity generation capacity (National Renewable Energy Laboratory (United States Department of Energy), 2023). There is no publicly available information on the ongoing performance of any of these facilities, and none have reached commercial scale operations.

In 2015, Florida's Palm Beach Renewable Energy Facility Number 2 became the first new mass burn waste-to-energy facility in the United States to come online since 1995 (United States Energy Information Administration, 2016). In 2023, Pasco County, Florida, approved a $260 million (approx. CAD $374 million) expansion of its existing mass burn waste-to-energy facility. Other communities are considering building new mass burn waste-to-energy facilities, but none are currently under construction (Behrendt, 2023). While no new plants opened in the United States between 1995 and 2015, some expanded to handle additional waste and generate more energy (United States Department of Energy, 2019).

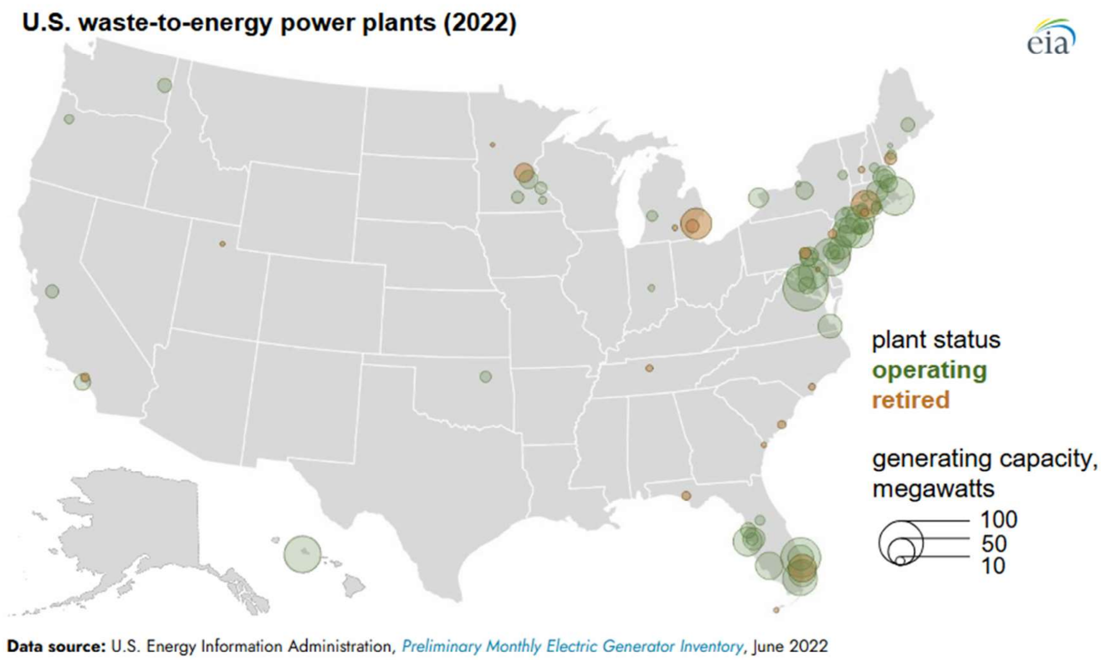

Figure 3: States within the United States with Mass Burn Waste-to-Energy Facilities in 2022 (United States Energy Information Administration, 2023; United States Energy Information Administration, 2025).

There are a few mixed waste processing facilities in operation in the United States, some which operate with a thermal process (e.g. production of refuse derived fuel). Mixed waste processing facilities not using a thermal process, identified in the City of Toronto study, are located in California. The remaining mixed waste processing facilities reported in the City of Toronto study are primarily located in Minnesota (City of Toronto, 2021).

A study completed in 2025 on operations, revenue and impact of scale of material recovery facilities in the United States concluded that the majority of material recovery facilities are single stream and source recyclables from residential sources; hence they are not operating as mixed waste processing facilities (Sabrina L. Bradshaw, 2025).

2.4.3 Summary of Economic & Regulatory Drivers

2.4.3.1 Land Availability

Within the United States there is generally an abundance of available land which supports landfilling and lower tipping fees, relative to many other countries. As a result, landfilling generally remains a cost-effective and popular option to manage residual waste (United States Environmental Protection Agency, 2024b). Some areas in the United States, such as the northeast, where there are highly populated areas and limited land, have adopted mass burn waste-to-energy as a preferred option. Typically, the first step for large communities, once local landfills reach capacity, is typically to explore sending residual waste to remote landfills in smaller communities, which may or may not be privately owned.

2.4.3.2 Capital Costs

Landfilling in the United States is often considered the most viable residual waste disposal option, especially in the short term, due to the low cost of building or expanding landfills in comparison to high initial capital costs of mass burn waste-to-energy facilities (United States Environmental Protection Agency, 2024b). The economic benefits of mass burn waste-to-energy may take several years to be fully realized due to its high capital costs.

2.4.3.3 Landfill Tipping Fees

The distribution of mass burn waste-to-energy facilities is closely linked to a state's landfill tipping fee (International Solid Waste Association, 2023a). In northeastern states, highly populated areas with less available land played a role in increasing landfill tipping fees up to $144.5 per tonne (USD), creating favourable financial conditions for mass burn waste-to-energy facilities (Themelis, 2013). In 2015, Florida and four states in the northeast accounted for 61% of the total mass burn waste-to-energy facility power capacity in the United States, and they produced 64% of the total mass burn waste-to-energy electricity generation (United States Energy Information Administration, 2016). In 2023, the average landfill tipping fees were highest in the Northeastern states (average $134 per tonne) and the Pacific states (average $99 per tonne) (Environmental Research & Education Foundation, 2024). The average tipping fees are significantly lower in the Midwest, Mountains/Plains (e.g., Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming), and Southeastern states with the lowest average tipping fees of $72 per tonne reported in the South Central states (Environmental Research & Education Foundation, 2024).

2.4.3.4 Electricity Prices

The main sources of revenue for mass burn waste-to-energy facilities are tipping fees, sale of co-products (e.g., recovered metals) and sale of electricity, heat and steam. In the United States, long-term power purchase agreement prices have been trending much lower at the wholesale level due to the rapid deployment of natural gas, wind, and solar in recent years. For example, recent data shows contractual wind prices in the range of 2.9¢/kWh and solar at approximately 4.3¢/kWh, price points at which, depending on other factors, mass burn waste-to-energy may not be able to compete with landfilling (United States Department of Energy, 2019).

2.4.3.5 The Public Utility Regulatory Policies Act (PURPA) 1978

The Public Utility Regulatory Policies Act 1978 is a federal law that requires utility companies to buy energy from cogeneration and renewable energy facilities to promote energy security (Mukherjee, 2020). The qualifying facilities include small power production facilities, which produce electricity from renewable resources or biomass and waste (Chernyakhovskiy, Tian, McLaren, Miller, & Geller, 2016). Throughout the 1980s and 1990s, this prompted the development of multiple mass burn waste-to-energy facilities and resulted in long-term contracts between utility and mass burn waste-to-energy companies which are now coming to an end (Mukherjee, 2020).

2.4.3.6 Renewable Energy Policy

In United States, individual states determine whether the energy recovered from the residual waste is considered renewable energy. There are multiple statutes and policies at the Federal level that consider energy recovery from the biogenic portion of residual waste renewable, including the Environmental Protection Agency's Clean Power Plan.

Some or all of the energy produced by mass burn waste-to-energy facilities is viewed as renewable by 34 states, as defined in various state statutes and regulations, including renewable portfolio standards. Therefore, facilities in the remaining states do not receive any incentives related to renewable energy (e.g., grants, subsidies, etc.). Some states which define the electricity/energy produced from biogenic portion of residual waste through mass burn waste-to-energy as renewable include Oregon, Washington, Oklahoma, Michigan, New York, Pennsylvania, Ohio, Florida, and Iowa while states like Texas, California, Illinois, North Carolina, and Georgia do not (Environment and Climate Change Canada, 2023).

2.4.3.7 Clean Air Act (CAA)

The Clean Air Act came into effect in 1970, which placed new standards onto existing mass burn waste-to-energy facilities. These standards banned the uncontrolled burning of residual waste and placed restrictions on particulate emissions. The facilities that did not install the technologies needed to meet the Clean Air Act requirements were required to close (United States Environmental Protection Agency, 2024b).

2.4.3.8 State Specific Waste Management Policies

Following the waste hierarchy, many states have implemented waste reduction programs, such as recycling and composting, which have reduced the amount of residual waste requiring disposal. For example, California and Washington had a target of 75% and 70% reduction in waste disposal by 2020, respectively. Both states implemented several programs, including mandatory commercial recycling, organic waste recycling, statewide recycling, and a ban on certain materials in landfills (International Solid Waste Association, 2023a). Both states consider mass burn waste-to-energy as disposal in their waste hierarchy.

2.4.4 Overview – Successes & Challenges

As discussed in previous sections, across the United States, most of the residual waste is managed through landfilling and the remaining is treated or managed primarily at mass burn waste-to-energy facilities. Between 2000 and 2019, 31 mass burn waste-to-energy facilities in the United States have stopped operation due to economic constraints related to decreasing electricity prices and lower landfill tipping fees (Baptista, 2019). While no new mass burn waste-to-energy facilities opened in the United States between 1995 and 2015, some were expanded to handle additional waste and generate more energy. In 2015, the first new mass burn waste-to-energy in 20 years was built and commissioned in Palm Beach County, Florida. Electricity generation by mass burn waste-to-energy facilities has had a slight downward trend over the past 14 years with approximately 15 thousand gigawatt hours generated in 2001 declining to approximately 14 thousand gigawatt hours in 2014 and 13 thousand gigawatt hours in 2022 (United States Department of Energy, 2019; United States Energy Information Administration, 2023).

There are 2 demonstration gasification facilities in North Carolina and California, United States (National Renewable Energy Laboratory (United States Department of Energy), 2023). The Fulcrum's Sierra Biofuels gasification facility in Nevada started operations in 2022, however, the facility later closed in 2024 due to permitting and operational issues (Bettenhausen, 2024). Similar to Canada, no pyrolysis or gasification facilities have achieved commercial scale operations in the United States.

2.5 European Union

2.5.1 Overall Waste Management Goals & Objectives

The 2008 European Union Waste Framework Directive, which is a legal framework for treating and managing waste, sets out a clear five-step waste hierarchy which promotes waste prevention, reuse and recycling. The waste hierarchy defines mass burn waste-to-energy and landfilling as options for management of residual waste. Landfilling is the least preferred residual waste management option per the Waste Framework and Landfill Directive (European Commission, N.D.b).

The European Union generated 229 million tonnes of municipal solid waste in 2023. Almost half of the generated municipal solid waste was recycled and composted (52%) and the remainder (48%) was residual waste that was treated in the mass burn waste-to-energy facilities, mass burn facilities without energy recovery, and disposed in landfills (see Figure 4) (Eurostat, 2023). Figure 4 shows the overall residual waste disposal distribution, with 52% (56.8 million tonnes) of the residual waste treated using mass burn waste-to-energy facilities, 1% (1.2 million tonnes) treated in mass burn facilities without energy recovery, and 47% (51.4 million tonnes) ending up in landfills.

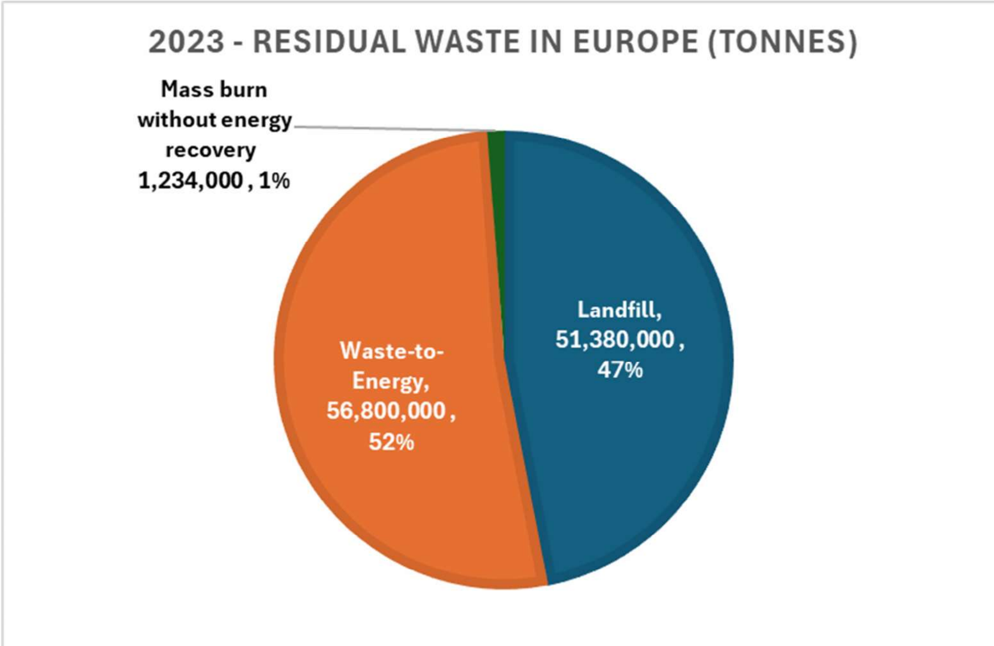

Figure 4: Residual waste management in Europe (Eurostat, 2023).

The following directives are in place (European Environment Agency, 2022a; European Union, 2023; European Commission, N.D.a):

- The Landfill Directive's landfill diversion target aims to limit the share of municipal waste landfilled to 10% by 2035.
- The Packaging and Packaging Waste Directive established a recycling target of 65% by 2025.
- The Waste Framework Directive targets a 55% increase in recycling and reuse by 2025, and 60% and 65% increase by 2030 and 2035, respectively.

To comply with the objectives outlined in the directives, European Union Member Countries are required to implement measures that address specific recycling targets within set time frames (European Union, 2023). After the implementation of these pieces of legislation, a 32% reduction in landfilling rates and a 19% increase in recycling rates was reported between 2001 and 2017. Mass burn waste-to-energy use also increased by 12% during the same time frame (Confederation of European Waste-to-Energy Plants, 2019).

In the European Union, different member countries have different waste management strategies. Germany, the Netherlands, Belgium, and Denmark all have high rates of recycling and composting (between 57% and 68% of municipal solid waste), with almost all residual waste managed using mass burn waste-to-energy. In Sweden and Finland, recycling and composting rates are lower (around 40%), with almost all residual waste management through mass burn waste-to-energy facilities. These countries have reduced landfill disposal to less than 1%-3% of the municipal solid waste generated. (Confederation of European Waste-to-Energy Plants, 2023; European Environmental Agency, 2024; Weghmann, 2023; Psomopoulos C.S. et al., 2021).

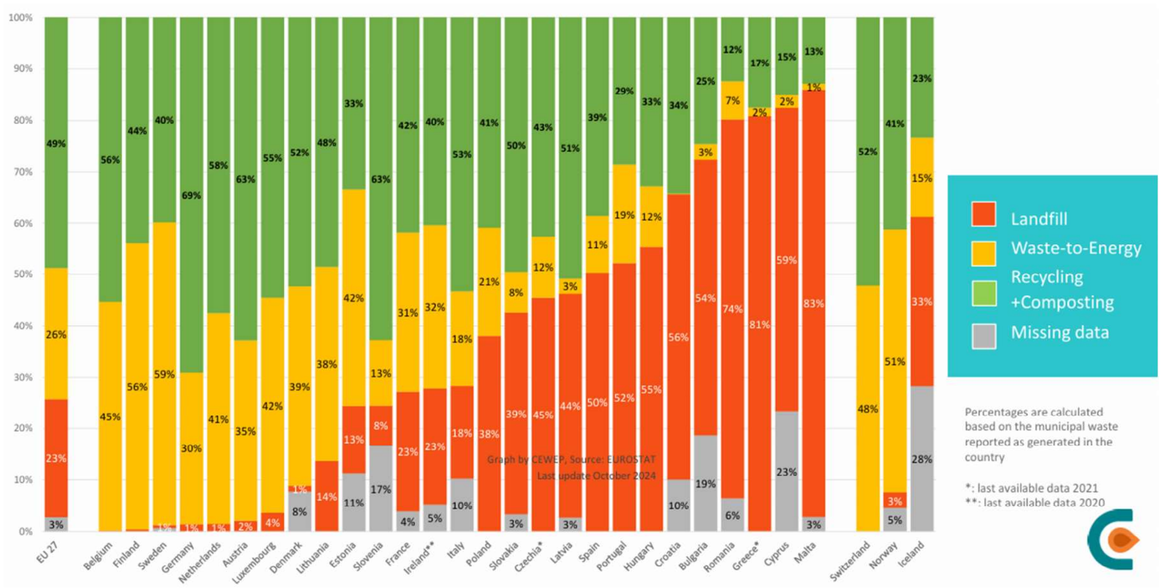

Figure 5: Municipal solid waste management practices across Europe (Confederation of European Waste-to-Energy Plants, 2025) .

In almost half of the European Union member countries, such as Spain, Portugal and the eastern countries, landfilling is the most common method for disposing of residual waste (Confederation of European Waste-to-Energy Plants, 2023). As shown in Figure 5, recycling and composting rates are the lowest (below 25%) in four countries that rely primarily on landfilling for residual waste disposal.

2.5.2 Summary of Residual Waste Management Approaches

Overall, the reliance on mass burn waste-to-energy facilities for management of residual waste is slightly higher than landfilling in European Union member countries. However, certain European Union member countries rely mostly on landfilling residual waste (Confederation of European Waste-to-Energy Plants, 2023; Weghmann, 2023)

The exact number of mass burn waste-to-energy facilities within the European Union is difficult to determine due to the constant commissioning and decommissioning of operating facilities and numerous new projects still in the planning stage. However, according to the data presented by the Confederation of European Waste-to-Energy Plants there were approximately 498 mass burn waste-to-energy facilities in 2021 which delivered 35 billion kWh of electricity and 87 billion kWh of heat through local district heating networks (Confederation of European Waste-to-Energy Plants, 2021a; Confederation of European Waste-to-Energy Plants, 2021b).

There are currently 98 mass burn waste-to-energy facilities in Germany. These facilities treat 103.35 million tonnes of residual waste yearly. Overall, the mass burn waste-to-energy facilities in Germany supply 1% of the energy consumed throughout the country (Weber, 2019).

Both Sweden and Finland rely heavily on mass burn waste-to-energy facilities to manage almost all of their residual waste, with less than 1% of residual waste disposed in landfills (Confederation of European Waste-to-Energy Plants, 2023).

As inferred from Figure 5, countries with the highest gross domestic product per capita (i.e. Luxembourg, Ireland, Denmark, Netherlands, Austria, Sweden, Finland, Belgium, Germany, France) and recycling rates at 40% or higher rely more on waste-to-energy for disposal of residual waste. Countries with a lower per capita gross domestic product and generally lower recycling rates rely more on landfilling for the management of residual waste (Statista, 2025).

A report commissioned by Zero Waste Europe entitled: Mixed Waste Sorting to Meet the European Union's Circular Economy Objectives, considered what the likely contribution to the municipal waste recycling rate would be through a full roll-out of mixed waste processing for papers (packaging and non-packaging), plastics, metals, packaging glass and polyester rich textiles (for chemical recycling) across the EU 27 and against several different separate collection scenarios. The conclusions were an increase to the diversion rate between 2.9% (for communities with high levels of source separation) and 6.1% (low levels of source separation) where all residual waste is processed through effective mixed waste processing facilities (Eunomia, 2023). The Eunomia study assumed an improvement in the recyclability of these materials by 2030 and does not discuss the financial implications of this type of mixed waste processing with respect to capital or operational costs.

2.5.3 Summary of Economic & Regulatory Drivers

2.5.3.1 European Union

2.5.3.1.1 Regulation/Policies

All European Union member countries are required to abide by European Union law such as the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive, described in Section 2.5.1.

An objective of the 1991/31/EC Landfill Directive required that national strategies be developed by 2003 to include measures and pre-treatment technologies to reduce biodegradable municipal waste going to landfill to 35% of 1995 levels by 2016 with a caveat for member states landfilling more than 80% in 1995 to delay goal attainment by up to four years (European Union, 2006a).

Since 1993, European Union law on the shipment of waste that included rules for transporting waste across borders. European Union Regulation No 1013/2006 establishes procedures and control regimes for the shipment of waste, depending on the origin, destination and route of the shipment, the type of waste shipped and the type of treatment to be applied to the waste at its destination (European Union, 2006b).

Recently, a new regulation of waste shipments, entered into force on May 20, 2024, with most provisions to apply starting May 21, 2026, and most export rules to apply from May 21, 2027. The regulation focuses on three aspects (European Commission, 2024b):

- Ensuring that the European Union does not export its waste challenges to countries outside of European Union and contributes to environmentally sound management of waste.
- Strengthen enforcement to prevent illegal shipments of waste occurring within the European Union, as well as from the European Union to third countries.

- Increase traceability of waste shipments within the European Union and facilitate recycling and reuse.

The European Union Landfill Directive 2018/850 amends Directive 1999/31/EC on the landfill of waste to ensure a progressive reduction of landfilling of waste, particularly of waste that is suitable for recycling or other recovery, and to provide for measures, procedures and guidance to prevent or reduce as far as possible negative effects on the environment. The Directive also states, that as of 2030 all waste suitable for recycling or other recovery (with a focus on municipal solid waste), should not be disposed of in a landfill, except for waste where landfilling delivers the best environmental outcome (European Commission, 2024a).

2.5.3.1.2 Land Availability

Generally, European countries have dense populations with limited available land for new landfills, therefore the adoption of mass burn waste-to-energy is high across the region. Globally there is a correlation between land availability (related partly to population density) and the prevalence of landfills. The prevalence of mass burn waste-to-energy facilities in Europe is also related to other drivers, as outlined in the other sub-sections of section 2.5.3.

2.5.3.1.3 Energy Prices

The current energy market may incentivize or increase interest in mass burn waste-to-energy as part of countries' strategies to address high energy prices. In 2022, gas and electricity prices in the European Union reached all-time highs due to global instability and disruptions in gas supply (European Commission, 2022). Energy prices are expected to remain high due to market uncertainty. The European Commission reports that the European Union has been experiencing lower than usual electricity generation. This is due to increased maintenance work at power stations, reduced hydropower output caused by extreme summer weather conditions, and the closure of some older power stations. These factors have also contributed to the ongoing energy scarcity and rising energy prices (European Commission, 2022).

2.5.3.2 Germany

Regulations/policies and economic factors that may affect residual waste management in Germany are below.

2.5.3.2.1 Regulation/Policies

The "Circular Economy Act," enacted in 2012, is the implementation of the European Union Waste Framework Directive, which promotes a hierarchy of waste management approaches. This is achieved by setting a mandatory recycling rate of 65% from 2035 onwards and requiring each state in Germany to separate organics, paper, metals, plastics, and glass. Meanwhile, the "Packaging Act" is a mandatory policy that defines recycling targets and rates (Schroeder, 2019). Together, these Acts can influence the composition, and the amount of residual waste produced in the country.

Germany has no national support mechanisms for mass burn waste-to-energy facilities as they are not identified as renewable sources of electricity in the "Renewable Energy Sources Act 2009" (Schroeder, 2019).

2.5.3.2.2 Waste Availability and Energy Prices

Policies under the Directive 1999/31/EC, also known as Landfill Directive, along with high energy prices provided the initial drivers for the mass burn waste-to-energy market. The Landfill Directive has a policy that limits the percent of municipal waste landfilled to 10% by 2035. In addition, when spare capacity arises at mass burn waste-to-energy facilities the opportunity to import residual waste from other European Union member countries exists (Behrsin, 2019). However, with the new waste shipment regulation, discussed in section 2.5.3.1.1, the shipment of residual waste for disposal at landfill or mass burn waste-to-energy facilities from other member countries will require prior notification and a consent procedure to be followed before shipment can take place (European Commission, 2024b).

2.5.3.3 Scandinavian Countries

2.5.3.3.1 Regulation/Policies

Sweden introduced a tax on landfilling waste, which was put into effect in the beginning of 2000. Since then, the landfill tax has been adjusted yearly. In 2021, the landfill tax was reported to be 573 SEK/tonne (approx. CAD $74/tonne), which is an overall increase of 141% since its introduction in 2000. Under this regulation all material entering landfill facilities is taxed, while material removed from the facility qualifies for a deduction (European Environment Agency, 2016; European Environment Agency, 2022b).

Between 2006 and 2010, Sweden also implemented a tax on waste-to-energy to promote recycling. The waste-to-energy tax was repealed by the Swedish government in 2010 (Sandhi & Rosenlund, 2024; European Environment Agency, 2016). The tax was re-established from April 1, 2020 to December 22, 2022 (IEA Bioenergy, 2023).

2.5.4 Overview – Successes & Challenges

After the rapid growth of the mass burn waste-to-energy facilities between 1991 and 2010, and the implementation of the Circular Economy Act in 2012 in Germany, overcapacity in the mass burn waste-to-energy market was reported in 2013 (Roll, 2013).

The developed recycling infrastructure and overcapacity in the German and Scandinavian mass burn waste-to-energy markets has resulted in the importation of refuse derived fuel from countries like the United Kingdom. For instance, Germany was the second largest refuse derived fuel recipient from England with 415,000 tonnes being imported in 2021 (GPT, 2020; Langley, 2022). However, importing unprocessed residual waste into Germany or Sweden is prohibited. Only refuse-derived fuels may be imported resulting in the requirement to process residual waste through mixed waste processing facilities prior to export from countries such as the United Kingdom (Environment Agency UK, 2025).

2.6 Australia

2.6.1 Overall Waste Management Goals & Objectives

Australia and Canada have geographic and economic similarities. Australia and Canada share similar land areas, population, and gross domestic product (Bank, 2021).

Similar to other countries discussed, Australia follows the same waste hierarchy, with a focus on reduce, reuse and resource recovery prior to landfilling. Australia is one of the world's largest municipal solid waste generators on a per capita basis with an estimated 76 million tonnes generated in 2023. Of the total municipal solid waste generated, 63% is reused and recycled, and 37% is residual waste (The Department of Climate Change, Energy, the Environment and Water, 2024). In 2023, 2% (0.5 million tonnes) of residual waste was used for energy recovery (refuse-derived fuels) and 98% (26 million tonnes) was disposed in landfills (Figure 6).

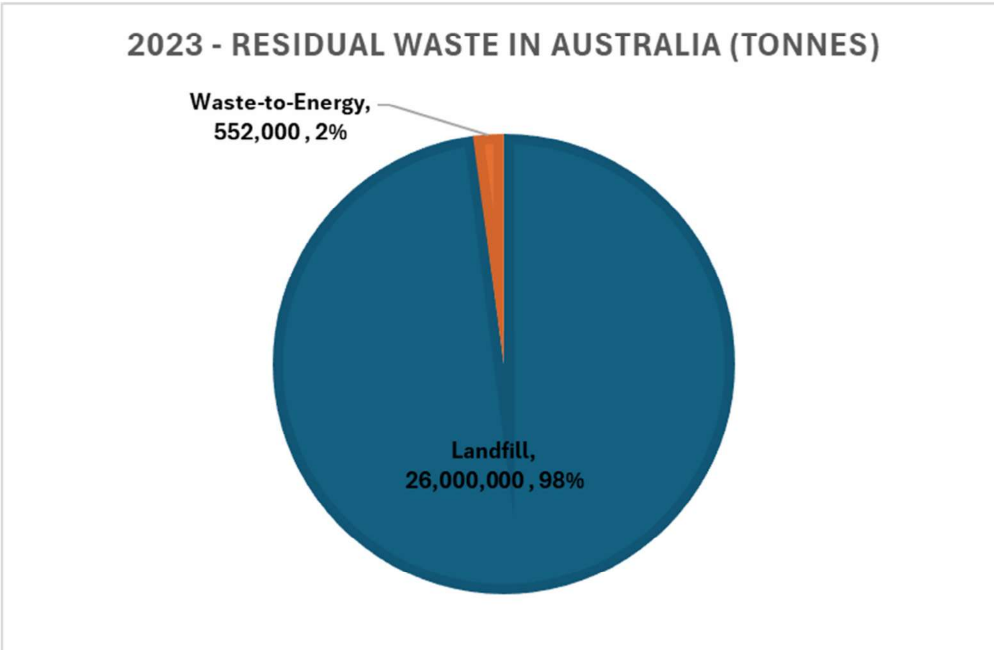

Figure 6: Residual waste management in Australia (The Department of Climate Change, Energy, the Environment and Water, 2024).

Australia has targets to reduce the amount of waste going to landfill for disposal. According to the National Waste Policy Action Plan, the targets include 80% average resource recovery rate (the percentage of waste recovered for reuse, recycling and waste-to-energy) from all waste streams following the waste hierarchy, by 2030. This was anticipated to be done through measures such as increasing reuse, recycling and energy recovery (e.g. heat, steam or electricity generation), with the target to halving the amount of organic waste sent to landfills, and reducing total waste generation by 10% per person by 2030. The country has also introduced policies to promote recycling and waste reduction (Australian Government, 2024).

2.6.2 Summary of Residual Waste Management Approaches

With the abundance of land in Australia, landfilling is the most common waste disposal method, receiving 98% of the residual waste. In 2017, it was estimated that there were 600 officially registered landfill sites in Australia, along with potentially up to 2,000 small, private, and unregistered landfills (The University of Queensland, 2017).

As of 2024, Australia had no mass burn waste-to-energy facilities operating. Australia uses only 2% of its residual waste to produce refuse derived fuels, which are then sent to the cement kilns to be used as an energy source (The Department of Climate Change, Energy, the Environment and Water, 2024).

There are two mass burn waste-to-energy facilities in Western Australia that aimed to start operation in 2024. The Kwinana Energy from Waste project, which began construction in 2018, is located at Kwinana Beach, Western Australia and is Australia's first mass burn waste-to-energy facility. The facility aims to process 400,000 tonnes of residual waste per year. The site utilizes a Keppel Seghers mass burn waste-to-energy to thermally treat residual waste and produce approximately 36 MW of baseload power for grid export (Australian Renewable Energy Agency, 2018). As of 2025, the facility owned and operated by ACCIONA is going through the commissioning phase, which started on July 2024 with initial waste deliveries prior to combustion start up in September 2024 and planned full ramp up to commercial scale operations later in 2025 (Kwinana Energy Recovery, 2024).

The East Rockingham mass burn waste-to-energy project began construction in 2019. This facility is in Perth, Western Australia, and aims to process 330,000 tonnes of residual waste per year using mass burn waste-to-energy technology to produce around 30 MW of power after it starts its operation (Enterprise, 2019; Australian Renewable Energy Agency, 2018). As of December 2024, the project is at the pre-construction phase, with the construction cost estimate under review and an external specialist engineering consulting firm engaged to provide support. A business case including the construction cost has been completed and is being assessed by the consortium partners prior to their final investment decision (Opal Australian Paper, 2025).

2.6.3 Summary of Economic & Regulatory Drivers

2.6.3.1 Land Availability

With the large abundance of land in Australia, landfilling is the predominant waste disposal method.

2.6.3.2 Landfill Levy

A landfill levy in Australia must be paid for all waste received at licensed landfills. The licensed waste facilities are required to pay the government for each tonne of waste received at the facility. One of the key purposes of the waste levy is to reduce waste that is disposed in landfills. The waste levy is intended to encourage waste generators to look for ways to reduce the amount of waste they generate and send to landfill. Usually, it is up to the landfill operator to decide on if, and how, the levy is passed through to their customers. Currently, the waste levy is executed on a state level with different states imposing different rates (Australia, 2022).

2.6.3.3 Incentives/Funding

The Australian Renewable Energy Agency was established in 2012 and is an independent agency operating under the federal Australian government (Australian Renewable Energy Agency, 2018). Australia's only two mass burn waste-to-energy facilities in Western Australia (under construction/commissioning) have both received approximately $20 million AUD (approx. CAD $18 million) in funding from Australian Renewable Energy Agency. This has incentivized private waste management organizations to invest in mass burn waste-to-energy technologies leading to growth in the Australian mass burn waste-to-energy industry (Australian Renewable Energy Agency, 2024; Australian Renewable Energy Agency, 2018).

2.6.4 Overview – Successes & Challenges

Australia's residual waste management approach is heavily reliant on disposal in landfills. The first two mass burn waste-to-energy facilities planned in Western Australia are currently in the commissioning and pre-construction phase as of 2025.

According to Waste Management and Resource Recovery Association of Australia, one of the main reasons for the historically low adoption of mass burn waste-to-energy facilities in the country appears to be public opposition, which stems from the perception that air pollution and odour pollution control systems are inadequate (Waste Management and Resource Recovery Association of Australia, 2021).

2.7 Japan

2.7.1 Overall Waste Management Goals and Objectives

Japan has a robust waste management strategy which highlights the importance of reducing waste generation where possible. This has been strongly influenced by rapid economic growth in the late 19^{th} century and the country's mountainous terrain which limits the ability to site and operate landfills. Japan generated 40.3 million tonnes of municipal solid waste in 2022 which is a 21.4% reduction from 2000 (Organisation for Economic Co-Operation and Development (OECD), 2021; Government of Japan, 2024). This decrease in waste generation can be attributed to several factors, including enhanced public awareness, better waste segregation practices, and government policies promoting waste reduction (Moshkal, Akhapov, & Ogihara, 2024).

Japan recycles 20% of the generated municipal solid waste leaving behind 80% of the entire waste stream as residual waste. Japan is heavily reliant on mass burn waste-to-energy as a waste treatment and energy recovery method (Organisation for Economic Co-Operation and Development (OECD), 2021). In 2021, Japan treated 93% (31 million tonnes) of residual waste in waste-to-energy facilities, 6% (1.8 million tonnes) in mass burn facilities without energy recovery, and 1% (0.34 million tonnes) was disposed in the landfills (Figure 7).

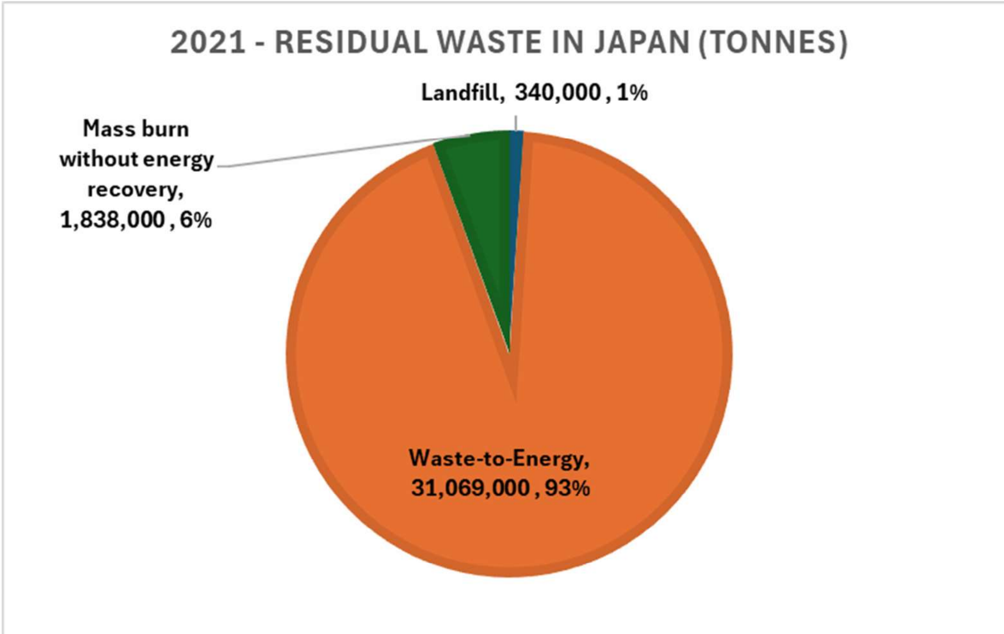

Figure 7: Residual waste management in Japan (Organisation for Economic Co-Operation and Development (OECD), 2021).

Japan developed the Packaging Recycling Act that requires producers to recycle paper and plastic packaging for products (Yamakawa, 1977; Moshkal, Akhapov, & Ogihara, 2024). In 2000, the Japanese central government introduced a new plan to establish a Sound Material-Cycle Society by working closely with regional governments to promote the reduce, reuse, recycle philosophy (Moshkal, Akhapov, & Ogihara, 2024).

2.7.2 Summary of Residual Waste Management Approaches

As of 2023 there were 1,016 operational mass burn waste-to-energy facilities in Japan. Of these facilities, 730 recover residual heat while 404 facilities generate electricity. The number of facilities without energy recovery is unknown. The largest facility is the Maishima mass burn waste-to-energy facility located in Osaka, Japan, operated by Hitachi Zosen. The project was commissioned in 2001 and has the potential to produce 32 MW of electricity (Carmen, 2022; Ministry of the Environment Government of Japan, 2022). The Yokohama City plans to reconstruct the Hodogaya Plant (mass burn waste-to-energy) to address future processing capacity shortages. The facility is expected to be completed in 2031 (Mitsubishi Heavy Industries, 2024).

There were 109 installed non-mass burn waste-to-energy facilities in Japan in 2011 (50 shaft furnaces, 39 fluid beds and 12 rotary kilns as well as 7 units for gas reforming), while another 3 units were added in 2012 (IEA Bioenergy, 2018). Most of these facilities in Japan are two-stage waste-to-energy facilities (sometime referred as "staged gasification"). These facilities use pre-processed residual waste and/or sludge and ash (Environment and Climate Change Canada, 2023; Nippon Steel Engineering, N.D.). The two-stage waste-to-energy facilities often have a dual purpose of processing residual waste and vitrifying bottom ash with the goal of creating a glass-like amorphous solid that can potentially be used for beneficial uses. According to Environment and Climate Change Canada (2023) and Ciuta et al.

(2018), Japan has been operating two plasma gasification facilities since the 2000s, and five Thermoselect process were in operation as of 2016. The Thermoselect process involves both pyrolysis and gasification stages, capable of processing sludge and as-received residual waste, while plasma gasification facilities accept a combination of residual waste, auto shredder residue, and sludge (United States Department of Energy, N.D.; Environment and Climate Change Canada, 2023; Vivera, 2024a; Vivera, 2024b). The Thermoselect process has been reported to yield a syngas that can be used in a gas turbine or converted to liquid fuels and chemicals (Ciuta, Tsiamis, & J. Castaldi, 2018; Environment and Climate Change Canada, 2023). However, no public information is available on the performance of Thermoselect facilities to produce syngas for turbines or to produce liquid fuels. All of the Thermoselect facilities in Japan were constructed in the early 2000s and the only facility built outside Japan, located in Germany, closed in 2006.

2.7.3 Summary of Economic & Regulatory Drivers

2.7.3.1 Land Availability

The Japanese government has indicated that the number of landfills is generally decreasing and suitable sites for new landfills are continuously difficult to secure. As of March 2023, the total landfill capacity remaining in the country was estimated at just over 23 years. In Japan, a high priority is placed on conserving remaining landfill space (Government of Japan, 2024).

2.7.3.2 Landfill Tipping Fee

Japan has the highest average landfill tipping fee in the world. In 2018, the average fee was approximately $804 per tonne of waste disposed of in landfills. The prohibitive landfill tipping fee in Japan is a primary factor for the high adoption of waste-to-energy technologies (International Solid Waste Association, 2023b; Honma & Hu, 2021).

2.7.4 Overview – Successes & Challenges

The shortage of landfill sites has been one of the most critical challenges in waste management in Japan due to the difficulty in constructing new ones (limited land availability).

In Japan, the primary waste-to-energy technology is mass burn with some two-stage waste-to-energy facilities. Japan also has a few Thermoselect facilities (combines pyrolysis and gasification) constructed in the early 2000s that have been reported to yield syngas suitable for gas turbine or conversion to liquid fuels and chemicals. However, performance of Thermoselect processes in Japan is not known due to the lack of public information.

2.8 Summary of National and International Practices

The approaches for managing residual waste in Canada, United States, European Union, Japan and Australia were reviewed and presented in this report. In general, these countries/regions align their goals with the waste management hierarchy and make efforts to move waste and related initiatives up the hierarchy. All countries/regions have set goals to reduce, reuse, recycle and decrease the total amount of residual waste to be managed.

The two main residual waste management approaches that have been adopted across the five countries/regions are various forms of mass burn waste-to-energy and landfilling. The level of reliance on these two methods varies from region to region. For instance, in United States, Canada and Australia only a small proportion (20%, 3% and 2% of the residual waste, respectively) is managed through waste-to-energy with mass burn waste-to-energy systems accounting for almost all installed waste-to-energy capacity. Landfilling is used to manage the rest of the residual waste in those countries. Countries like Japan, Sweden and Germany treat most of their residual waste in mass burn waste-to-energy facilities, with landfilling rates being less than 1% of the municipal solid waste generated in some areas. Of the countries/regions reviewed, there seems to be a correlation between available land area and the prevalence of landfills in comparison to mass burn waste-to-energy facilities.

Among the regions reviewed, land availability, low landfill tipping fees and transportation logistics are key drivers with respect to the selected approach to managing residual waste. Other factors impacting the selection of options include the policy and regulatory framework, public perceptions, energy prices/availability and incentives such as subsidies or carbon credits. Japan has the highest average landfill tipping fees in the world due to the limited landfilling capacity left in the country. Similarly, limited space for landfills and policy have been the main drivers of the widespread adoption of mass burn waste-to-energy in Europe. In the United States, where overall landfilling of residual waste is the dominant approach, more mass burn waste-to-energy facilities are used in states with a high population density and limited land available for landfills.

The City of Toronto study on mixed waste processing for green bin organics and high value blue bin recycling material recovery identified a 5.3% diversion rate. The study findings indicated that such a mixed waste processing facility would be unlikely to meet target outcomes of resource recovery and recycling and be less cost-effective than current waste recycling program efforts (City of Toronto, 2021).

The Eunomia study focussed on mixed waste processing for papers, plastics, metals, packaging glass and textiles and identified a 2.9% to 6.1% diversion rate assuming an improvement in the recyclability of these materials (Eunomia, 2023).

3 Key Considerations for Future Options

The literature review presented in the previous section illustrates that a region's overall approach to achieving stated waste management goals and ultimately to managing residual waste is region-specific. What works for one region may not work for another given the significant number of factors that drive regional approaches. Even within broad regions, such as Europe, there are key differences with how waste streams can and should be managed, which depend also on the wants/needs of the public and the overall political direction.

In Canada, landfilling is expected to continue to be the most common approach to managing residual waste for the foreseeable future. Mass burn waste-to-energy is the primary alternative to landfilling around the world with communities choosing mass burn waste-to-energy rather than landfilling based on both local and national circumstances. Technologies such as mixed waste processing appear to be used where the policy or regulatory framework either prohibits or discourages landfilling or treatment and disposal of unprocessed residual waste by waste-to-energy. Two-stage waste-to-energy facilities make up a small component of the international waste-to-energy market, and in some cases serve the dual process of combusting residual waste and vitrifying bottom ash. No evidence supports that there are commercial scale gasification/pyrolysis facilities for residual waste treatment producing syngas suitable for use as liquid fuel or for the generation of electricity in reciprocating or other electricity generators. This conclusion aligns with the Environmental Screening Report for a facility in Ontario, prepared by GHD for Emerald Energy from Waste Inc. It evaluated waste-to-energy technologies, including gasification and pyrolysis, and concluded that mass burn waste-to-energy offers the most economical, most energy efficient, and robust waste-to-energy technology solution (GHD, 2024).

3.1 Provincial Guidelines

Regional districts in British Columbia are mandated to prepare solid waste management plans and the provincial guide is used to navigate the planning process. With respect to residual waste management, regional districts are encouraged to develop programs, policies and facilities that support keeping waste in the upper levels of the waste hierarchy. Disposal, including both waste-to-energy and landfilling, is the least preferred management option (Government of British Columbia, 2024b).

The Ministry of Environment and Parks published an information sheet for Waste-to-Energy and Solid Waste Management Plans in 2018. All regional districts that plan to direct a portion of their municipal solid waste to a waste-to-energy facility must (Ministry of Environment and Climate Change Strategy, 2018):

- Amend their solid waste management plan before considering waste-to-energy and include sufficient details which:
    - Identify a municipal solid waste disposal rate of 350 kg/capita/year with measurable interim targets set and met throughout the planning and implementation process;
    - Highlights that waste-to-energy planning and capacity is conducted only after considering the higher levels of the hierarchy and does not impede efforts to achieve higher levels of the first three levels of hierarchy (reduce, reused and recycle); and
    - Authorizes the waste-to-energy facility to accept municipal solid waste for treatment and/or disposal.

4 Technical Criteria for Evaluating Residual Waste Management Options

Technical criteria have been developed that could be considered during the decision-making process when selecting the most appropriate approach to manage residual waste, through landfilling or waste-to-energy technologies. The table below presents technical criteria for consideration in evaluating residual waste management which covers six different main criteria categories. These are presented alphabetically without any indication that one category is more important than another.

Table 2: Technical Criteria for Evaluating Residual Waste Management Options

Criteria Category	Criteria for Evaluating Residual Waste Management Options
Economic	• Overall cost, including initial capital construction, operational, closure and post closure costs. • Opportunities and risks related to revenue generation through selling recovered materials or energy to markets. • Opportunities for efficient or reduced transport costs (e.g. backhauling). • Potential variability in waste volumes over time. • Opportunity cost in comparison to alternative investment options. • Financial risk from geopolitical or regulatory environment.
Environmental	• Potential to emit pollutant emissions/discharges to air, land and water. • GHG emissions - direct and indirect contributions and offsets (avoided GHGs). • General environmental factors such as dust, odour, litter, noise, vectors etc. • Risk and mitigation potential from climate change and natural disasters. • Geotechnical considerations (e.g. slope failure, flooding risk). • Groundwater, surface water and ambient air quality protection and monitoring systems.
Regulatory Compliance	• Meets or exceeds all current or anticipated environmental and waste management regulations. • Permitting and approval processes required for implementing the system.
Resource Use	• Land requirements for facilities and operations. • Energy generation and use potential and proximity.

	• Opportunities for co-locating complimentary operations, such as public reuse and recycling depot services, processing of specific materials streams.
Social	• Potential impact on public health and safety. • Public perception, cultural considerations, and community acceptance of the system. • Job creation during construction and operation.
Technical Feasibility	• Maturity, reliability, and degree to which the system has been proven on a commercial scale. • Compatibility with residual waste as the feedstock material and ability to adapt to changing waste streams. • Capacity and scalability to handle expected volumes of waste consistently and meet future needs. • Pre-processing requirements. • Percentage of the residual waste stream effectively processed by the system.

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