Point. Advisory

Pathway report

ACT 2050 emissions modelling – waste sector

Prepared for:

ACT Government

23 June 2017

DISCLAIMER

This report has been prepared for the ACT Government as outlined in the Proposal and scope of works. The services provided in connection with this engagement comprise an advisory engagement, which is not subject to Australian Auditing Standards or Australian Standards on Review or Assurance Engagements, and consequently no opinions or conclusions intended to convey assurance have been expressed.

Point Advisory acts in a professional manner and exercises all reasonable skill and care in the provision of its professional services. The reports are commissioned by and prepared for the exclusive use of ACT Government. They are subject to and issued in accordance with the agreement between ACT Government and Point Advisory. Point Advisory is not responsible for any liability and accepts no responsibility arising from the misapplication or misinterpretation by third parties of the contents of its reports.

Except where expressly stated, Point Advisory does not attempt to verify the accuracy, validity or comprehensiveness of any information supplied to Point Advisory for its reports. We have indicated within this report the sources of the information provided. We are under no obligation in any circumstance to update this report, in either oral or written form, for events occurring after the report has been issued in final form.

The findings in this report have been formed on the above basis.

VERSION CONTROL

Version	Date	Author	Project Director
2.0	26 May 2017	Caoilinn Murphy	Charlie Knaggs
3.0	6 June 2017	Caoilinn Murphy	Charlie Knaggs
4.0	8 June 2017	Caoilinn Murphy	Charlie Knaggs
5.0	23 June 2017	Caoilinn Murphy	Charlie Knaggs

EXECUTIVE SUMMARY

The ACT Government has committed to a target of net zero carbon emissions by 2050. This target is enshrined in the *Climate Change and Greenhouse Gas Reduction Act 2010*. Point Advisory was engaged by the ACT Government's Environment, Planning and Sustainable Development Directorate to model emissions reduction pathways within the waste sector to assist the ACT in meeting this target. This report presents the outcomes of Point Advisory's analysis.

Reference scenario

Point Advisory modelled a 'reference scenario' to gain an understanding of the ACT's current emissions trajectory to 2050 based on existing policy settings. The reference scenario provides the basis for modelling emissions reduction actions to set the ACT on a pathway to achieve its net zero target. All assumptions related to population growth are aligned with the assumptions used by Strategy Policy Research in their modelling of the ACT's net zero emissions pathway for stationary energy and buildings.

Reference case modelling involved establishing an emission 'baseline' (derived from the ACT's most recent waste sector greenhouse gas inventory from 2014/15). The ACT's waste sector inventory is based on both solid waste and wastewater data. Solid waste emissions from landfill came from the National Greenhouse and Energy Reporting (NGER) Solid Waste Calculator, provided by the Directorate. ACT-specific waste mix types were used to replace the NGER default values in the calculator. Wastewater emissions were based on the NGER Wastewater (Domestic and Commercial) Calculator.

The impacts of existing and planned policy settings were then modelled onto the baseline to forecast 'business as usual' emissions out to 2050, based on projected population growth, along with a number of other important factors. The major sources of emissions in the waste sector inventory, and the reference case assumptions used, are summarised in Table 1. It should be noted that the analysis is limited to those aspects of the solid waste and wastewater treatment processes that directly release emissions, rather than secondary energy-related emissions or abatement.

Table 1. Summary of reference case emissions to 2050

Emissions sources	Description	Refer (medium reference scenario)
Solid waste - landfill	Solid waste to landfill in the ACT in 2014/15 was equal to 251,487 t. This was composed of 49% municipal solid waste (MSW), 42% commercial and industrial (C&I) waste and 9% construction and demolition (C&D) waste. To estimate waste generation out to 2050: • MSW generation is predicted to increase in line with predicted population growth, and waste generation per capita rates. • C&I waste generation is predicted to increase in line with the ACT's nominal gross state product (GSP) i.e. the economic output of the state. • C&D waste generation is predicted to increase in line with the ACT's private engineering and commercial expenditure. The NGER Solid Waste Calculator was used to predict landfill emissions out to 2050.	Emissions from landfill account for an average of 79% of total emissions from the waste sector out to 2050.
Solid waste - composting	Solid waste (garden organics) to composting in the ACT in 2014/15 was equal to 227,728 t. To estimate waste to composting treatment out to 2050, it was assumed that:	Composting emissions account for an average of 11% of total emissions

Emissions sources	Description	Refer (medium reference scenario)
	• a third bin is provided to all households in the ACT by 2018, for source separation of garden organic waste • the recovery rates from this policy action are relatively high. Composting emissions were based on the methodology provided in the NGER Measurement Determination.	from the waste sector out to 2050.
Wastewater	Wastewater emissions were estimated using the NGER Wastewater (Domestic and Commercial) Calculator, and were approximately 11 kt CO_2-e in 2015.	Wastewater emissions account for an average of 11% of total emissions from the waste sector out to 2050.

As a result of the above sources of emissions, the waste sector in the ACT is predicted to give rise to annual emissions of between 185.4 and 210.7 kt CO_2-e in 2050, mainly depending on population growth out to this time. The reference case emissions trajectory is show in Figure 1 below.

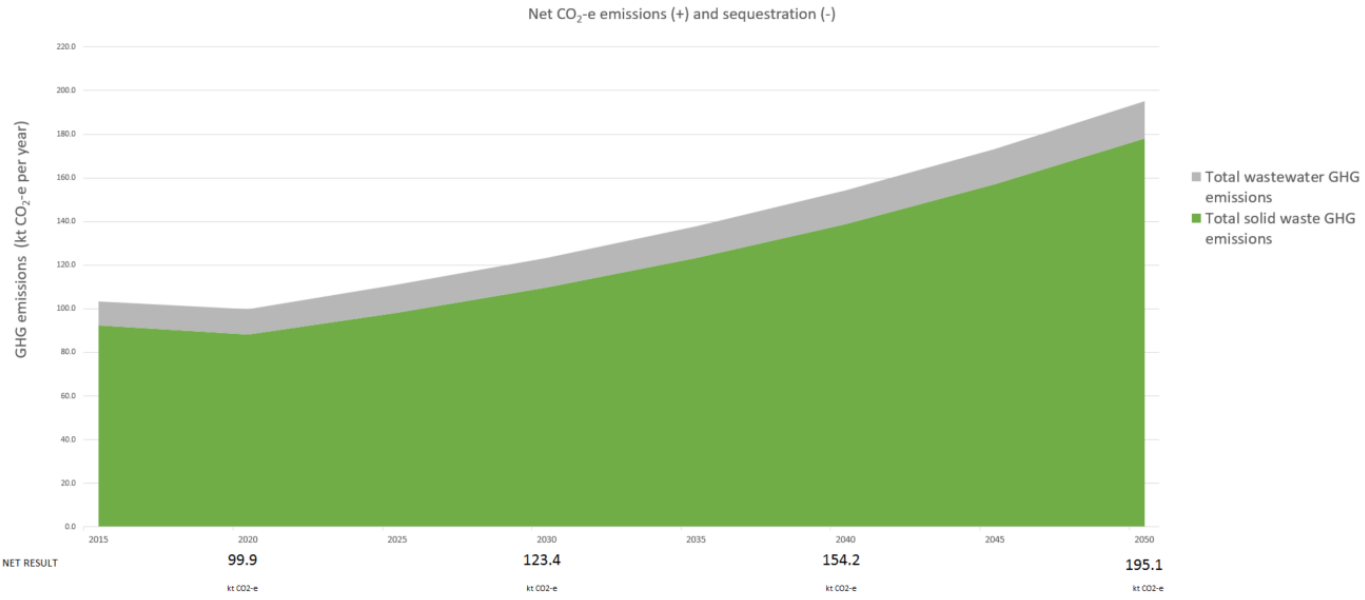


Figure 1. Reference case emissions trajectory for waste sector, 2015 to 2050 (medium scenario)

Options analysis

An options assessment was conducted to assess the range of opportunities for emissions reductions in the ACT's waste sector. A scan was conducted to identify the full range of opportunities available. These opportunities were then screened based on the amount of abatement available, along with other factors including practicality of implementation and technology limitations. Based on this assessment, Table 2 summarises the options that were shortlisted for inclusion in the pathway modelling.

Table 2. Summary of options investigated to reduce emissions

No.	Option	Strengths	Weaknesses
	Solid waste options		
1	SUDs FOGO compost	• Composting of GO, FOGO and other source separated organics is well proven in the Australian context. • In addition, these technology types are generally cheaper and easier to operate and lower risk compared to other waste treatment technologies. • Methane emissions are decreased as organic material is diverted from landfill.	• The quality of the feedstock is dependent on community participation and awareness regarding the organics bin (both GO and FOGO). • If FOGO is to be processed, large buffer distances are required due to odour, in particular for windrow composting as we have assumed for this modelling.
2	MUDS FOGO compost	As above	As above
3	MUDs Commingled Recycling	• Source separation of recyclables (paper, cardboard, plastic, glass etc.) is a proven option in the Australian context. • Low risk option compared with other treatment options • Reduces the reliance on extraction of raw materials for manufacturing, reducing associated GHG emissions • Methane emissions are decreased as organic material (paper and cardboard) is diverted from landfill.	• The quality of the recyclable material is dependent on community participation and awareness regarding the recycling bin
4	C&I FOGO compost	As for SUDs FOGO compost	As for SUDs FOGO compost
5	MSW and C&I FOGO: AD	• High diversion from landfill of biodegradable material • Generated methane gas used for electricity / energy generation • Existing market for compost product • Demonstrated success internationally • Methane emissions are decreased as organic material, e.g. cardboard and paper, is diverted from landfill.	• Technology not proven for treatment of garden waste (GO) mixed with food (FO). The woody lignocelluloses need to be extracted from the waste prior to digestion. This adds cost and reduces diversion. • Digestion process requires a high level of operational control when compared with composting, with associated increased operating costs • Contamination of over 5% leads to operational problems • Costs are higher than with composting facilities
6	C&I Commingled Recycling	As for MUDS Commingled Recycling	As for MUDS Commingled Recycling

No.	Option	Strengths	Weaknesses
7	Banning unsorted MSW to landfill	• Strengths are linked to options 1, 2, 3 and 5. • In addition, this option includes the diversion of even more material from landfill • Residual MSW is used as a feedstock for thermal treatments	• Weaknesses are linked to options 1, 2, 3 and 5
7a	Incineration residual MSW	• Using this option in conjunction with resource recovery and recycling leads to the maximum diversion of MSW from landfill • Well established and effective treatment process • Robust technology that handles multiple heterogeneous streams • Financial benefits as electricity/heat produced can be used to offset site energy consumption, and surplus electricity can be sold to the grid • GHG emissions reductions from diversion of organic waste from landfill and through production of renewable energy (from organic component of waste)	• Higher risks both technologically and economically than other waste treatment options • Approvals for Waste-to-Energy facilities are difficult • Requires pre-gas and residue treatment plants as well as clean-up of emissions to ensure toxics (dioxin, furans) and fly ash particulates control • Risk of 'cannibalising' recycling
7b	Pyrolysis of residual plastics	• Using this option in conjunction with resource recovery and recycling leads to diversion of MSW from landfill • GHG emissions reductions from diversion of organic waste from landfill and through production of renewable energy (from organic component of waste) • Similar to incineration but limits the availability of oxygen – therefore generates less GHG emissions • Road transport fuel produced can be used to offset traditional fossil fuels in vehicles.	• Same weaknesses as for incineration In addition: • Not a proven, reliable technology • Does not offer as much diversion of landfill waste as incineration and gasification as it can only accept waste plastics
8	Banning unsorted C&D to landfill	• Diversion of organic materials from landfill reduces GHG emissions • Residual C&D is used as a feedstock for thermal treatments • Low risk option compared with other treatment options	• There is not a huge amount of additional C&D waste captured for the effort of conducting the additional processing

No.	Option	Strengths	Weaknesses
9	Banning wood waste from landfill	• High diversion from landfill of biodegradable material • Low risk option compared with other treatment options • Well established technologies in Australia	• No extraction and use of energy from wood waste to offset fossil fuel based energy sources
10	BAT landfill gas with energy recovery	• Technology is proven within an ACT context • Generation and sale of ACCUs • Financial benefits as electricity/heat produced can be used to offset site energy consumption, and surplus electricity can be sold to the grid	• The ACT is already recording an average landfill gas capture rate of 67% (NGER2012-2016), therefore the possibility of reaching 75% may be quite difficult. • Moderate costs associated with installing additional equipment to capture landfill gas • As more waste is diverted from landfill, the volume of biogas that can be captured will decrease, meaning additional infrastructure installed now, may not be needed in the future. However, it should be noted that the lagging effect of landfill gas production will mean the impact of this waste diversion, will not be as pronounced to begin with.
	Wastewater options		
11	Wastewater AD CHP	• Well established and effective treatment process • Robust technology • Financial benefits as electricity/heat produced can be used to offset site energy consumption, and surplus electricity can be sold to the grid • Generation and sale of ACCUs • Reduction in fugitive N_2O emissions as there is a change from aerobic to anaerobic conditions • Highly stable digested sludge for agriculture • Significant reduction in treated sludge volume	• Issues with methane leakage from digester • High capital costs • Gas production varies greatly by season

Pathway to zero emissions

The optimal pathway in the waste sector is based on the following key areas of focus:

- A combined approach of high-levels of diversion of organic material from landfill, with anaerobic digestion of the food organics stream, and composting of garden organics.
- MSW that is not suitable for alternative treatment (such as recycling and biological treatment) is transferred to an energy-from-waste facility which produces energy from a suitable feedstock.

- Maximising the landfill gas capture potential of infrastructure at the Mugga Lane landfill.
- The current wastewater treatment system is changed to treat wastewater anaerobically.
- Running parallel with the implementation of all these options is a very active education campaign which raises awareness in the public about the need to reduce waste generation per capita.

The optimal emissions pathway for the waste sector is shown in Figure 2.

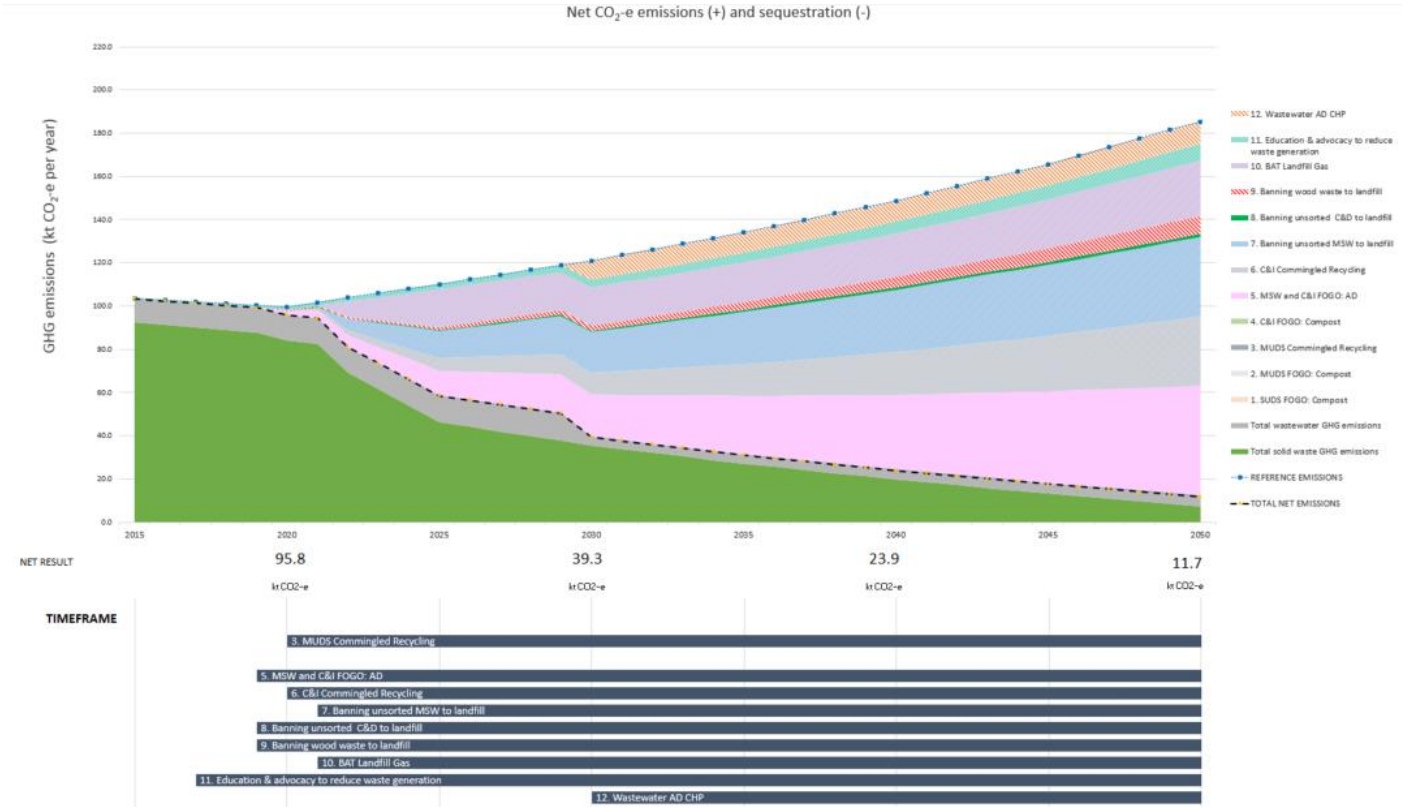


Figure 2. Optimal pathway to net zero emissions for ACT waste sector (dotted line), 2015 to 2050

The bars at the bottom of the chart indicate the implementation timeframes over which the policies have been modelled (refer to Table 4 for more detailed information).

Recommendations

To achieve the optimal pathway and ensure that waste sector emissions are kept within predicted ranges, Point Advisory recommends the following:

- The implementation of many education and advocacy campaigns up to 2050, with a particular focus on waste prevention and minimisation.
- Early engagement with urban planning to assess the feasibility and understand the impacts of developing a purpose-built facility for anaerobic digestion and composting of organic wastes.
- Undertake a feasibility study to assess the resource recovery outcomes of constructing a materials recovery facility (MRF) for dry commercial waste to improve recovery rates.
- Undertake a detailed feasibility study to establish how beneficial it would be to construct an energy-from-waste plant in the ACT, and establish the most appropriate technology. A life cycle assessment of different energy-from-waste options should be considered. In addition, the development of a Residual Waste MRF as part of this option needs to be analysed further.

- Engage with waste specialists to understand how appropriate it is to install additional landfill gas capture infrastructure at Mugga Lane landfill when the ultimate goal of the ACT is stop sending waste to landfill.
- Engage with Icon Water to conduct an in-depth analysis of switching the current wastewater treatment system at the Lower Molonglo Water Quality Control Centre (LMWQCC) to an anaerobic digestion system, and the implication in terms of land footprint required, capital and operating costs.

The ACT Government should also consider the following dependencies relating to waste sector abatement opportunities:

- Large improvements in agricultural land quality can be achieved by the addition of compost and/or anaerobically digested sludge to soil.
- Traditional emissions-intensive fossil fuel energy sources can be displaced through the use of bio-energy from anaerobic digestion or energy-from-waste.

CONTENTS

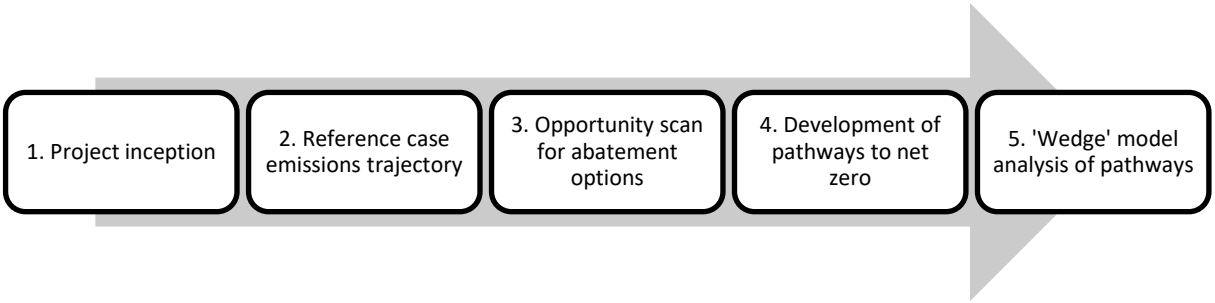
Executive summary iii
Reference scenario iii
Options analysis iv
Pathway to zero emissions vii
Recommendations viii
1 Overview 1
1.1 Background 1
1.2 This report 1
1.3 Modelling 1
1.4 Key assumptions and limitations 2
2 Waste sector emissions assessment 3
2.1 Context 3
2.2 Options to reduce emissions from solid waste 4
2.3 Options to reduce emissions from wastewater treatment 7
3 Reference scenario 9
4 Waste sector abatement options 13
4.1 GHG abatement options investigated 13
4.2 Timelines for implementation of options 20
4.3 Screened options – no further investigation 21
5 Pathway to zero net carbon emissions by 2050 22
5.1 Implementing the pathway 24
References 26
Appendix 1 Glossary 27

1 OVERVIEW

1.1 Background

The ACT Government has committed to a target of net zero carbon emissions by 2050. The target is enshrined in the *Climate Change and Greenhouse Gas Reduction Act 2010*. Point Advisory was engaged by the ACT Government's Environment, Planning and Sustainable Development Directorate (the Directorate) to model emissions reduction pathways for the waste sector to enable the ACT to meet this target.

This engagement involved the following key steps:



This report identifies and provides the abatement potential of different waste management options including garden and organics collections for households and businesses, with treatment using composting or anaerobic digestion, education and awareness campaigns for solid waste reduction, and energy-from-waste technologies for both solid wastes and wastewater.

1.2 This report

This report summarises the outcomes of Point Advisory's modelling of pathways to net zero emissions for the waste sector, and acts as a guide for the associated Emissions Reduction Model – Waste Sector (the model). This report builds on prior work conducted for this engagement as summarised in two reports:

- *ACT 2050 emissions modelling – waste sector reference model*
- *ACT 2050 emissions modelling – waste sector emissions reduction options*.

This report includes the following:

- Key definitions and concepts of terms related to the waste sector
- The reference-case emissions to 2050 (the 'business as usual' emissions trajectory)
- The quantification of options selected for GHG abatement
- The pathways available for the ACT to reach net zero emissions by 2050 for the waste sector.

1.3 Modelling

Three scenarios of modelling were undertaken (low, medium and high) for both the reference case emissions trajectory and each carbon abatement opportunity to account for the inherent uncertainty involved in projecting future emissions. 'High' scenarios are those that result in higher emissions – i.e. those that are pessimistic in terms of climate change mitigation, with relatively low levels of emissions abatement and sequestration from reference case policies and technologies. The 'medium' scenario is considered the most likely under the current settings. The 'low' scenario accounts for elevated levels of ambition, with high levels of abatement and sequestration and low level of emissions.

1.4 Key assumptions and limitations

Waste sector emissions modelling is based on the assumptions provided to Point Advisory, and our project partner, MRA Consulting, by the Directorate following our waste modelling meeting on 8 February 2017. The detailed assumptions are included in our *"ACT 2050 emissions modelling – waste sector reference model"* report, provided to the Directorate on the 16 March 2017. Key assumptions relate to:

- ACT population and growth trends to 2050
- Historical trends in total and per capita solid waste sent to landfill
- Composition of waste sent to landfill e.g. municipal solid waste (MSW), construction and demolition (C&D) waste, commercial and industrial (C&I) waste
- Historical wastewater emissions data.

In addition, the following assumptions apply to the modelling:

- All solid waste options were assumed to commence in 2018.
- Wastewater options were assumed to commence in 2030, because it is not feasible for the current wastewater treatment system to be replaced before this.
- The analysis is limited to those aspects of the solid waste and wastewater treatment processes that directly release emissions, rather than secondary energy-related emissions or abatement.

2 WASTE SECTOR EMISSIONS ASSESSMENT

2.1 Context

When organic waste decomposes anaerobically in landfills, it releases methane and other greenhouse gases, contributing to climate change. Similarly, GHGs can be emitted during the incineration of solid waste; biological treatment (e.g. composting or anaerobic digestion) of solid waste; and treatment of wastewater.

Globally, methane emissions from solid waste disposal and wastewater treatment are equal to around 3% of all GHG emissions (Ecofys, 2013). In 2016, emissions from waste in Australia accounted for 2% of the national inventory, or 12 Mt CO_2-e/year. Approximately 66% of these emissions were from landfill, 33% from wastewater handling and a small proportion from waste incineration and biological treatment of solid waste. From an ACT context, the 2015/16 emissions inventory showed that total emissions from waste were 106 kt CO_2-e or 2.6% of the total GHG inventory. Of this, solid waste emissions accounted for 90%, while wastewater emissions were 10%.

To provide a basis for analysing emissions abatement options in the ACT, it was first necessary to develop an understanding of the current state of play with regards to both solid waste and wastewater management. These are discussed in the following sections.

2.1.1 Current solid waste management system

In the ACT, all single unit dwellings (SUDs) and multi-unit dwellings (MUDs) are currently provided with a green or red lid bin for garbage which is disposed at the Mugga Lane landfill, and a yellow lid bin for recycling of plastic, paper, cardboard, glass, steel, aluminium and cartons which are sorted at the Material Recovery Facility (MRF) in Hume. In addition, all ACT residents can take recyclable materials to one of five recycling drop-off centres. Residents can deliver unwanted reusable items (such as bikes, furniture, and clothes) to the Green Sheds at Mugga Lane and Mitchell Resource Management Centres where items are sold for reuse.

There is no system in place for separate collection of household organic waste, which currently goes to landfill. However, there is a pilot currently underway for the provision of a third bin for household garden waste, and the government has committed to expanding this service to all households in the future. In addition, garden waste may be self-hauled by ACT residents or collected by private contractors and delivered free of charge to one of two open-windrow composting facilities.

Currently, the ACT Government does not provide collection services for C&I waste. The ACT Government runs the free ACTsmart Business Recycling program to support resource recovery of C&I waste. All C&I waste that is not recovered is sent to the Mugga Lane landfill for disposal.

There are two sorting and recycling facilities for C&D waste within the ACT. These facilities recover masonry, concrete, road pavement materials, various timbers and some other materials at very high rates from the construction and demolition industry. All C&D waste that does not get recovered and recycled is treated at the Mugga Lane landfill.

2.1.2 Current wastewater management system

The sewerage system in the ACT consists of a network of approximately 3,100 km of underground pipes to collect sewage from residential, commercial and educational institutions, and transfer it to treatment facilities, with the majority (>80%) being released to the Murrumbidgee River after a high-level of treatment, and the remainder being recycled.

There are three sewage treatment plants within the ACT. The vast majority of Canberra's sewage is treated at the Lower Molonglo Water Quality Control Centre (LMWQCC), a small proportion is treated.at Fyshwick Sewage Treatment Plant (STP) and an even smaller proportion at the water-mining plant at Southwell Park.

This analysis focussed on emissions reduction opportunities at LMWQCC, as it offers the greatest reduction potential.

The wastewater treatment process at LMWQCC is as follows:

1. Raw sewage is screened through three drum screens and the solid screenings are then incinerated.
2. After screening, chemicals are added to improve solids and phosphorus removal. Two grit removal tanks flocculate the suspended solids (creating a sludge) and capture grit from the sewage prior to the primary sedimentation tanks. Lime and phosphorus contained in the sludge makes the residual treated solids attractive to farmers for application to land.
3. The secondary treatment system consists of anoxic reactors to enhance nitrogen removal (Biological Nutrient Removal (BNR) process) followed by aeration tanks and circular secondary clarifiers. It is this aerobic process that produces the high levels of nitrous oxide emissions from wastewater treatment reported by the ACT.
    - The anoxic reactors enable denitrification to occur under zero oxygen conditions.
    - The aeration tanks (secondary reactors) provide biological oxidation of carbonaceous and ammoniacal material with an activated sludge.
    - The secondary clarifiers allow the activated sludge to settle and be returned to the earlier processes, while the clarified effluent flows to the filters.
4. Filters each fitted with a dissolved air flotation (DAF) unit, are used to enhance capture of residual solids.
5. Following filtration, the effluent is disinfected using chlorine.
6. Solids collected in the treatment processes are incinerated in a multiple hearth furnace. The ash from the furnace is rich in phosphorus and is re-used on farms in NSW.

2.2 Options to reduce emissions from solid waste

The ACT Waste Management Strategy 2011-2025 was developed by the Directorate to set a clear direction for the management of solid waste and reduction of associated emissions in the ACT towards 2025. It was adopted in 2011, and has four main outcomes, of which the following are most relevant for our analysis.

- Outcome 1 – Less waste generated. Waste generation has increased over the past 20 years at a greater rate than population growth. Therefore, it is important to introduce measures to promote a reduction in waste generation per capita.
- Outcome 2 – Full resource recovery. The ACT has a target resource recovery rate (solid waste diverted from landfill) of 90% by 2025. Currently the resource recovery rate is at 70%, and has not improved since 2005. Additional actions are required to reach the 2025 target.
- Outcome 4 – A carbon neutral waste sector. One aspect of this is the capture of methane from landfill, however additional work is required to achieve carbon neutrality.

The ACT Waste Management Strategy 2011-2025 is set out in accordance with the waste hierarchy (Figure 3).

Therefore, when seeking to reduce solid waste emissions, some of the most important aspects for consideration are provided below:

- Aim to develop an integrated, whole-of-government approach to waste education within the community and businesses, with a particular focus on reducing waste generation.
    - The report by Zero Waste Europe (Hogg D. and Ballinger A., 2015), found that from a life cycle perspective, the major source of emissions reduction per kg of waste managed is from waste prevention, followed closely by the recycling of dry materials. However, it is noted that separate collection of food wastes, can enhance awareness within households and businesses of what is thrown away, leading to a preventative effect.

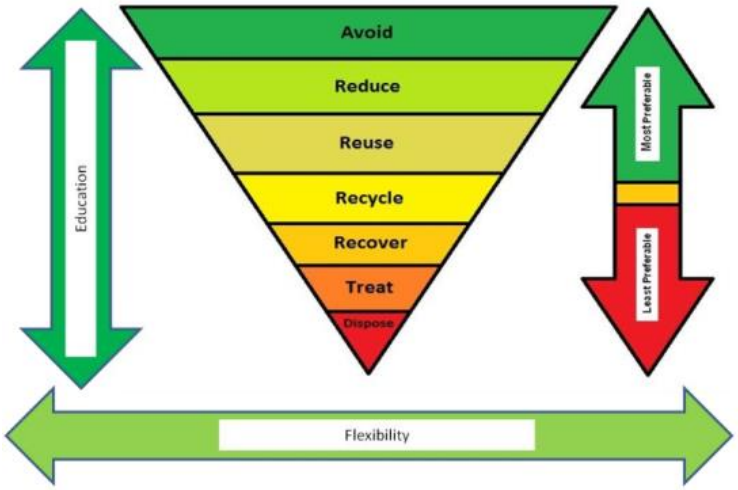


Figure 3. Waste hierarchy

- Aim to eliminate organic waste going to landfill.
  - This can be achieved by separating the organic waste from the solid waste streams and treating it separately. Treatment could include composting or anaerobic digestion (creating biogas to combust for heat or electricity). A report by the Dutch energy and climate consultancy Ecofys, which assessed the feasibility of phasing out all GHG emissions by 2050, states that zero landfilling of organic waste could be implemented in all countries by 2050 (Ecofys, 2013).
- Aim to achieve a carbon neutral waste sector.
  - This aim can be achieved in part by capturing methane released from landfill cells. Currently, this methane capture rate (from both the Mugga Lane and Belconnen landfills) is estimated at 60-70% (ACT Government, 2016), and there is potential for improvement.
  - Another potential option is to implement energy-from-waste technologies. This option could only take place after all prevention, resource recovery and recycling options have been implemented.

Specific options to reduce emissions from solid waste are described below.

2.2.1 Waste education programs

To generate less waste, an integrated, whole of government approach to waste education and community capacity building should be developed. These waste education programs should include a component on reducing waste generation. Waste education not only needs to target households, but also C&I and C&D waste streams.

2.2.2 Composting of organic waste

One of the main advantages composting of organic material has over traditional landfilling is that emissions are significantly reduced. This is because the composting is an aerobic process, and therefore does not give rise to emissions of methane. In addition, composting produces a stable, nutrient rich by-product which can be used as a soil conditioner.

There are several composting technologies that could be applicable in the ACT context, however the ACT currently has windrow composting facilities at West Belconnen and Mugga Lane, operated by independent contractors. Therefore, for this analysis it was assumed that the composting technology used from now until 2050 is open windrow. This choice of composting technology will not impact the quantum of GHG abatement as the ACT's carbon accounting methodology does not differentiate between different composting technologies and hence the emission factors used do not change based on the technology.

Source separated organics (SSO) – usually Garden Organics (GO), Food Organics (FO) or Food and Garden Organics (FOGO) – typically generate the best quality compost as they provide a mostly contamination-free

feedstock. However, there are a number of composting facilities in Australia that have been designed to process mixed residual waste, commonly MSW from kerbside rubbish bins. The compost produced from these facilities is generally lower quality than that produced from SSO, and is used for lower applications such as mine site land rehabilitation. Therefore, for this analysis composting of SSO was deemed the most appropriate in the ACT context.

2.2.3 Anaerobic digestion of organic waste

Anaerobic digestion (AD) involves the biological treatment of waste in an enclosed facility to create biogas (mainly methane) that can be used for generating energy or other thermal uses. In Europe alone, 244 installations dealing with the organic fraction of MSW as a significant portion of the feedstock have been constructed or are permitted and contracted to be constructed as of 2014 (De Baere L. and Mattheeuws B., 2014).

In recent years in Europe, anaerobic digestion has been used to replace the first intensive composting phase in the composting process. This phase is always followed by a dewatering step to produce a digested cake that can be turned into a high-quality compost. Alternatively, AD plants will accept a fraction of the waste (the wetter and most digestible fraction), while the larger woody waste is treated in simple green waste composting plants or is used as a bulking agent for the treatment of the digestate coming from the wetter fraction.

AD offers the opportunity to produce renewable energy, and to reduce the surface area of the composting site. Hybrid composting plants with AD arguably offer a higher quality of organics treatment but at an extra price compared to traditional composting. In addition, AD commonly suffers from methane leakage, and the types of organic feedstock it can process are more limited than for composting. The anaerobic digestion process must be highly controlled and can fail if proper management and controls are not in place.

Therefore, AD is best suited to the processing of source separated organic materials (likely to have a low contamination rate) rather than organic materials extracted from mixed MSW (likely to have a high contamination rate). Therefore, for this analysis anaerobic digestion of SSO with methane capture was deemed the most appropriate in the ACT context.

2.2.4 Landfill gas capture

At a landfill, the amount of putrescible waste accumulates year by year, with waste releasing biogas for several decades, ceasing to release biogas once the waste is fully decayed. Biogas emissions from landfill are composed of approximately 60% methane, which can be captured and combusted to produce electricity or heat. In the ACT, biogas is captured from the operational Mugga Lane landfill, and the closed Belconnen landfill. This biogas capture rate is around 60-70%. The biogas is combusted and is used to produce electricity, at around 3.2 kWh/m^3 biogas captured.

There is potential to increase the rate of biogas capture, through the introduction of additional capture infrastructure. However, the waste hierarchy prioritises waste minimisation and diversion ahead of gas capture, suggesting that this option shouldn't be considered until waste diversion from landfill has been maximised. If the ACT's first action was to build extensive gas capture infrastructure, and then started a major waste diversion from landfill operation, the ACT may find itself with an oversized network of pumps and fans. For this reason, improving landfill gas capture should be dependent on options that maximise diversion from landfill being implemented first.

2.2.5 Thermal treatment of residual waste

Thermal treatments can have greenhouse gas benefits by diverting organic and other material from landfill and displacing high emissions-intensity energy sources with energy-from-waste. Thermal treatment of waste should only be considered once all recyclable and recoverable waste has been extracted from the waste stream, and other avenues relating to influencing behavioural change and education have been considered and fully implemented. In addition, a high-level of energy recovery should be achieved. In addition, a long-term perspective should be used when assessing the need for energy-from-waste facilities, as solid waste available for treatment is expected to reduce significantly as recycling and prevention increases in the future.

To reiterate this point, in January 2017, the European Commission published the "Communication on the role of waste-to-energy" in a circular economy (European Commission, 2017). The report provides clarity for the implementation of the waste management hierarchy and gives guidance for European Union Member States to avoid problems such as incineration overcapacity.

The three energy-from-waste technologies analysed are incineration, gasification and pyrolysis. Incineration is a robust and well-tested technology while gasification and pyrolysis are not as established, have not been proven at as many facilities, and therefore carry higher technology risk.

Gasification has an advantage over incineration in that it produces lower air pollution emissions. In addition, it produces a high-value product called syngas which can be used as a fuel or directly combusted to generate electricity. The syngas combustion process is more efficient than simple combustion of waste.

Similar to gasification, pyrolysis produces syngas, which may be used to fuel engines and gas turbines without modification. Pyrolysis has the added benefit of producing biochar from organic material which can be used to sequester carbon in soil. The sequestration rates and permanence of the sequestration are still the subjects of scientific investigations.

Our "ACT 2050 emissions modelling – waste sector emissions reduction options" report detailed seven proposed energy-from-waste plants in Australia. Of these, three will use gasification when they are completed, two will use incineration and two will use pyrolysis. Feedstocks range from residual MSW, C&I waste, C&D waste, paper pulp, garden organics, wood waste, and end-of-life plastics. One of the pyrolysis plants is proposed for construction in the Hume industrial area in the ACT (Foy Group Ltd., 2017). The proposed facility, which would convert plastics to road transport fuel, is currently being assessed by the ACT Government.

Any move toward these technologies would constitute an increased risk profile for the ACT Government. The Victorian, Western Australian and NSW energy-from-waste guidelines essentially have three controls:

- the thermal treatment must not replace recycling (and be able to prove that it does not);
- it must be a *bona fide* energy-from-waste plant (not just a waste disposal plant); and
- it must ensure that its air emissions conform to European emission standards. Therefore, thermal treatment plants require pre-gas and residue treatment plants as well as clean-up of emissions to ensure toxics (dioxin, furans) and fly ash particulates are not released to the atmosphere.

These points combined effectively rule out mass burn incineration as an option in these states, which is in line with international best practice. Recently, several Australian states (NSW, VIC and WA) have given the green light for energy-from-waste plants. The ACT Government may wish to consider these options as part of this analysis, especially for certain waste materials that are too contaminated to be recovered or recycled.

However, a critical point to consider is that as the electricity grid decarbonises in the future, waste-from-energy technologies will look less attractive. This is because the GHG emissions released from the conversion of energy-from-waste (kg CO_2-e/kWh produced), will be greater than those released from grid electricity production, as more renewable energy sources are used to feed into the grid. As the ACT's grid emissions factor could be reduced as low as 0.085 kg CO_2-e/kWh by 2025 (Pitt & Sherry, 2016), the ACT must consider this when making any decision on implementing energy-from-waste plants in the territory.

2.3 Options to reduce emissions from wastewater treatment

Wastewater contains organic content that produces both methane and nitrous oxide, with the former being the predominant gas produced during anaerobic digestion, and the latter being the predominant gas produced during aerobic treatment.

At the LMWQCC wastewater treatment plant in the ACT, GHG emissions are primarily nitrous oxide emissions that are emitted during the biological nutrient removal (BNR) process. This process also consumes high-levels of fossil-fuel derived energy. Therefore, we have considered the options that could be implemented that

produce bio-energy at the site to offset this energy demand. However, we have not estimated the quantity of bio-energy produced, as this is outside the scope of this analysis.

2.3.1 Anaerobic digestion of wastewater

Anaerobic digestion of municipal wastewater sludge has been widely practiced across the world and in Australia since the early 1900s. Many medium to large wastewater treatment plants use anaerobic digestion for stabilisation of sludge, given the opportunity for beneficial use of digested sludge for pastures and crop growth, as well as the reduction in the volume of the sludge achieved (as some volatile solids and thus total solids are converted to gas). However, the most significant benefit from this process is the production of biogas, which is rich in methane, which can be captured in the reactor, cleaned and then used to offset conventional fossil fuelled energy. This gas can be used in several ways: it can be injected into a city's gas grid, used in a boiler for on-site heat production, burned in a generator to produce electricity, or used in a combined heat and power (CHP) unit to produce electricity and heat.

In 2016, GHD conducted a review on behalf of Icon Water (responsible for providing sewerage and water services in the ACT) to investigate the feasibility of generating biogas at Canberra's main wastewater treatment plant, the Lower Molonglo Water Quality Control Centre (LMWQCC). The report found that this would involve significant changes to infrastructure, which presents a difficulty associated with the site's footprint, space availability and a significant change to operations. This in turn could be quite costly, although some funding could be made available if the Australian Renewable Energy Agency (ARENA) were to invest in the project.

The GHD study determined that if anaerobic digestion was introduced to LMWQCC, potential gas production would be 16,000-20,000 m^3/d (equivalent to up to 475,000 MJ/d) today (increasing by some 33% in 2055). However, the calorific value of biogas is some 30 - 40 % below that of natural gas, and there are a number of contaminants that need to be removed prior to combustion which suggests that the gas would not be a direct substitute for natural gas.

In assessing the feasibility of implementing AD at LMWQCC to generate biogas, the study considered three options for comparison:

1. Anaerobic digestion with biogas refinement and injection of gas into the grid, generation of digested sludge by-product for agricultural use (Class B) and use of existing incineration for screenings / grit only.
2. Anaerobic digestion followed by incineration of the digested solids, with only on-site use of biogas for combined heat and power production, and incinerator fuel (and involving less gas cleaning requirements).
3. Maintaining the status quo – expansion / refurbishment of incineration (I) for biosolids management, and including some heat recovery for existing purposes.

The study estimated that Option 1 was able to offset 8% of Canberra's gas requirements in summer and just 1% in winter. Option 1 presented the greatest capital cost at $72 million, with Option 2 coming in at $68 million. Continuing with the current set-up (Option 3) resulted in capital costs of $20 million. At current energy costs, Options 1 and 2 are not commercially viable. However, potential ARENA funding combined with increasing future energy prices would make these options look more attractive at a later date.

2.3.2 Maximum efficiency aerobic treatment of wastewater

The BNR process at LMWQCC generates considerable amounts of nitrous oxide – up to 7% of the influent nitrogen load, however a large variation in reported emission values exists (Kampschreur. MJ., 2009). Therefore, decreasing the amounts of N_2O emitted from the BNR process presents an opportunity for improvement. There are different operational, treatment and prevention options available to the ACT, however the literature on the subject does not provide clear strategies to reduce emissions, as it still an emerging science.

3 REFERENCE SCENARIO

This section summarises the findings of the reference case assessment compiled for the ACT Government for the waste sector. The reference case trajectory assumes that the ACT Government does not take any **additional** policy action that could have an impact on GHG emissions. ACT policies and planning that have commenced are assumed to continue. In addition, there is one committed policy, the introduction of a garden organics bin for all households, which is assumed to commence in 2018. The reference case can be considered the 'business as usual' emissions trajectory.

Three versions of the reference case were modelled (low, medium and high) to account for the inherent uncertainty involved in projecting future emissions. 'High' scenarios are those that result in higher emissions – i.e. those that are pessimistic in terms of climate change mitigation, with relatively low levels of emissions abatement from reference case policies and technologies. The 'medium' scenario is considered the most likely under the current settings. The 'low' scenario accounts for elevated levels of ambition, with high levels of abatement and low level of emissions.

The reference case assumptions were used to build a model of total waste to landfill across the key waste streams (MSW, C&I and C&D), and the total amount of green waste to biological treatment (composting). This green waste is comprised of self-hauled and privately collected green waste from households and businesses. With the introduction of the garden organics bin in 2018, green waste to biological treatment also includes the portion of garden waste that would have otherwise gone to landfill from the green or red lid bin, and the expected additional garden waste generation that is placed in the organics bin, that otherwise would have been left to decompose in gardens.

Table 3 shows the reference case waste generation forecasts for each waste stream for the ACT for the period 2016 to 2050 for the 'medium' scenario.

Table 3. ACT total waste generation forecasts by waste stream to 2050 (medium scenario)

Solid waste to recycling or biological treatment					
Year	**MSW - recycling**	**C&I - recycling**	**C&D - recycling**	**Green waste - biological treatment**	**Total**
2015	63,565	26,376	404,014	227,728	721,684
2020	68,554	31,859	535,012	266,036	901,461
2025	74,102	38,598	534,010	286,561	933,271
2030	79,449	47,096	594,072	302,328	1,022,945
2035	84,672	57,211	631,938	320,918	1,094,739
2040	89,942	69,596	683,606	339,531	1,182,675
2045	95,362	84,592	736,040	358,555	1,274,549
2050	100,883	102,852	793,774	377,803	1,375,313

Solid waste to landfill				
Year	**MSW – landfill***	**C&I – landfill***	**C&D - landfill**	**Total**
2015	122,511	106,729	22,248	251,487
2020	125,078	128,917	29,461	284,700
2025	135,232	156,185	29,406	322,162
2030	145,021	190,572	32,714	369,736
2035	154,590	231,502	34,799	422,408
2040	164,248	281,616	37,644	485,113
2045	174,184	342,297	40,531	558,708
2050	184,310	416,185	43,711	645,992

*Green waste to landfill is included within these generation forecasts

A breakdown of the total emissions from the waste sector is given below in Figure 4, for the medium reference case. This chart shows that emissions from solid waste dominate the profile, while emissions from wastewater

treatment provides a smaller proportion. Solid waste emissions are mostly methane emissions from landfill, with a smaller amount coming from composting.

The NGER Solid Waste Calculator was used to estimate the landfill emissions. ACT-specific waste mix types for MSW, C&I and C&D waste were used to replace the NGER default values in the calculator.

The reference case trajectory assumes that a high proportion of source separated garden organics is sent for composting. These composting emissions were based on emission factors for nitrous oxide (N_2O) and methane (CH_4) provided in the NGER Measurement Determination.

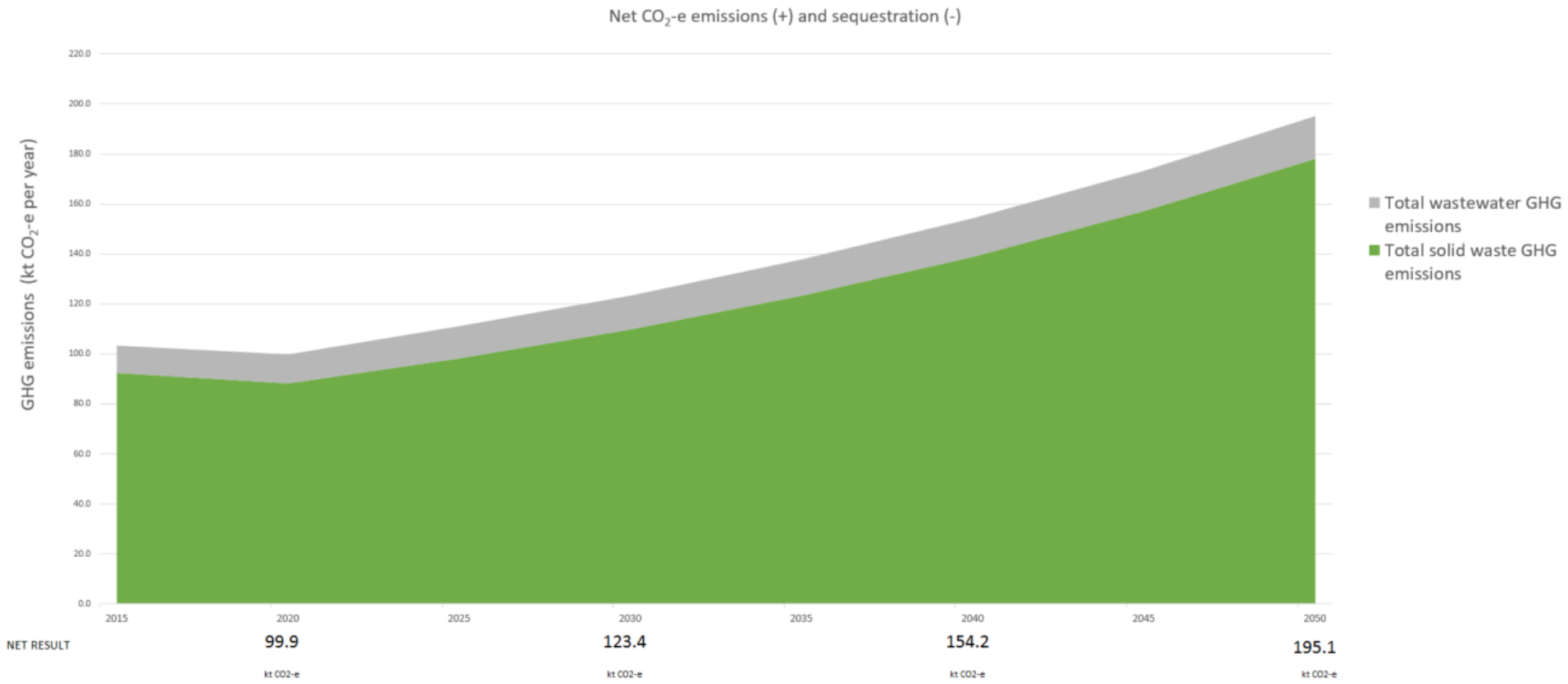


Figure 4. Reference case emissions trajectory for waste sector out to 2050 (medium scenario)

The reference case reveals the following trends out to 2050:

- MSW generation is predicted to increase in line with predicted population growth, and waste generation per capita rates.
- C&I waste generation is predicted to increase in line with the ACT's nominal gross state product (GSP) i.e. the economic output of the state.
- C&D waste generation is predicted to increase in line with the ACT's private engineering and commercial expenditure.
- Green waste generation was expected to increase in line with predicted population growth.
- The reduction in solid waste emissions seen at the 2020 time interval, relative to 2015, is a result of the implementation of the existing 'Third Bin' garden organics recycling policy in 2018. After the implementation of this policy, emissions continue to grow in line with population growth and increasing waste generation rates.
- Wastewater emissions were predicted to increase linearly with population growth.

The following results are evident from the model:

- Under the **low** reference scenario, population growth is relatively small, and there is a high level of ambition within Government for implementing and enforcing policies. The introduction of the garden organics bin is implemented as a mandatory scheme, meaning that 100% of households take it up. Currently, it is estimated that over 90% of household garden/green waste is recovered through community delivery of garden waste to drop-off centres for composting (ACT Government, 2016). Under the **low** reference scenario this recovery rate increases to approximately 93.2%. This combination of factors results in net emissions in 2050 of 185 kt CO_2-e.
- Under the **medium** reference scenario, population growth is moderate, and there is an average level of ambition within Government for implementing and enforcing policies. The introduction of the garden organics bin is implemented as an opt-out scheme, with 85% of households taking it up. Under the **medium** reference scenario, the garden/green organics recovery rate is approximately 92.7%. This combination of factors results in net emissions in 2050 of 195 kt CO_2-e.
- Under the **high** reference scenario, population growth is high, and there is a low level of ambition within Government for implementing and enforcing policies. The introduction of the garden organics bin is implemented as a voluntary opt-in scheme, with just 63% of households taking it up. Under the **high** reference scenario, the garden/green organics recovery rate is approximately 92.0%. This combination of factors results in net emissions net emissions in 2050 of 211 kt CO_2-e.

4 WASTE SECTOR ABATEMENT OPTIONS

Point Advisory developed a list of GHG abatement options that may exist to assist the ACT Government in achieving net zero emissions by 2050.

These options were further refined, and all viable options were modelled to understand the impact they could have on the ACT's waste sector greenhouse gas emissions profile over the period to 2050. Further detail on the modelled options is provided in this section.

4.1 GHG abatement options investigated

4.1.1 Food and garden organics bin for single-unit dwellings

This option explored the introduction of an opt-out (compulsory) household food organic and garden organic (FOGO) waste bin for all single unit dwellings (SUDs) in the ACT. The source separated organic waste is treated at a composting facility, resulting in diversion of organic waste from landfill, resulting in lower emissions. This option is termed "SUDs FOGO compost". The composting of source separated organics is generally cheaper, easier to operate and lower risk compared to other waste treatment technologies, such as anaerobic digestion or energy-from-waste facilities.

Key assumptions and limitations: SUDs FOGO compost

This option relies on the following:

- The recovery rates of food organics for all scenarios, 77% (low), 67% (medium) and 57% (high)
- The additional generation of garden organics (GO) that occurs as a result of the introduction of the third bin. The average of NSW/VIC GO generation rates (based on kg GO/household with GO bin) was used to determine this additional generation that is expected to occur as a result of introducing the third bin. The GO recovery rates were then modelled as opt-out at ~ 85% (medium), opt-in at ~63% (high) and mandatory at ~100% (low)
- Proportion of red-lid (general waste) bin waste that is FOGO, that could be placed in the third bin, following roll-out of the option.
  - GO fraction is 10.9% of bin contents by weight **(APC Waste Consultants, 2014)**
  - FO fraction is 35.2% of bin contents by weight **(APC Waste Consultants, 2014)**

Key risks

- There is a risk that the organic material that is source separated by households may include contaminant materials, which will negatively impact the composting process. Therefore, the quality of the feedstock is highly dependent on community participation and awareness regarding the organics bin.
- There is a risk that communities neighbouring the composting facility may complain of odour issues. If FOGO is to be processed, large buffer distances are required due to odour, in particular for windrow composting as we have assumed for this modelling.

Key co-benefits

- Composting produces a stable, nutrient rich by-product which can be used as a soil conditioner.

4.1.2 Food and garden organics bin for multi-unit dwellings

This option explored the introduction of an opt-out (compulsory) household food organic and garden organic (FOGO) waste bin for all multi-unit dwellings (MUDs) in the ACT. The source separated organic waste is treated at

a composting facility, resulting in diversion of organic waste from landfill, resulting in lower emissions. This option is termed “MUDs FOGO compost”.

Key assumptions and limitations: MUDs FOGO compost
This option relies on the following: • The additional generation of GO as a result of introducing the service, in addition to the recovery rates of FO and GO, were all assumed equal to the SUDs option. • Proportion of red-lid (general waste) bin waste that is FOGO, that could be placed in the third bin, following roll-out of the option. – GO fraction is 6.2% of bin contents by weight **(APC Waste Consultants, 2014)** – FO fraction is 34.1% of bin contents by weight **(APC Waste Consultants, 2014)**
Key risks
Key risks as for SUDs FOGO compost.
Key co-benefits
Key co-benefits as for SUDs FOGO compost.

4.1.3 Recycling of commingled dry waste for MUDs

This option explored the improvement of the current dry recycling bin service for all MUD households. The commingled dry recyclable waste (e.g. paper, cardboard, plastic, aluminium) is then recycled, resulting in diversion of waste from landfill, resulting in lower emissions. Currently, all MUDs in the ACT have access to a dry recycling bin, however this option explores the impacts of improving recovery rates using this service. This option is termed “MUDs Commingled Recycling”.

Key assumptions and limitations: MUDs Commingled Recycling
This option relies on the following: • Average commingled recycling rates for MUDs is 2.05 kg/MUD/week **(APC Waste Consultants, 2014)** • Proportion of MUDS with a recycling service currently is 100% • Assumed capture rate efficiency of MUDS recycling service is 70%
Key risks
• There is a risk that the dry recyclable material that is source separated by households may include contaminant materials, such as food waste, which will be required to be removed prior to the recycling process. Therefore, the quality of the feedstock is highly dependent on community participation and awareness regarding the organics bin.
Key co-benefits
• Reduces the reliance on extraction of raw materials for manufacturing, reducing associated energy consumption and GHG emissions.

4.1.4 Food and garden organics bin for businesses

This option explored the introduction of an opt-out (compulsory) food organic and garden organic (FOGO) waste bin for all businesses in the ACT. The source separated organic waste is treated at a composting facility, resulting in diversion of organic C&I waste from landfill, resulting in lower emissions. This option is termed “C&I FOGO compost”.

Key assumptions and limitations: C&I FOGO compost
This option relies on the following: • The recovery rates of FOGO for all scenarios, 90% (low), 80% (medium) and 70% (high). • Proportion of C&I waste that is FOGO, that could be placed in the organics bin, following roll-out of the option. – GO fraction is 2.3% of total generation by weight (based on landfill audit data provided by Directorate) – FO fraction is 17.6% of total generation by weight (based on landfill audit data provided by Directorate)
Key risks
Key risks are the same as for SUDs and MUDs FOGO compost options
Key co-benefits
Key co-benefits are the same as for SUDs and MUDs FOGO compost options

4.1.5 Recycling of C&I commingled dry waste

This option explored the introduction of a mandatory dry recycling bin service for all businesses. The commingled dry recyclable waste is then recycled, resulting in diversion of waste from landfill, resulting in lower emissions. This option is termed "C&I Commingled Recycling".

Key assumptions and limitations: C&I Commingled Recycling
This option relies on the following: • The recovery rates of C&I recyclables for all scenarios, 90% (low), 71% (medium) and 42% (high) • Proportion of C&I waste that is recyclable, that could be placed in the yellow bin, following roll-out of the option, is 19.3% of total generation by weight (based on landfill audit data provided by Directorate)
Key risks
Key risks are the same as for MUDs Commingled Recycling.
Key co-benefits
Key co-benefits are the same as for MUDs Commingled Recycling.

4.1.6 Food and garden organics bin for all households and businesses with anaerobic digestion and energy recovery

This option explored the introduction of an opt-out (compulsory) food organic and garden organic (FOGO) waste bin for all households and businesses in the ACT. It is similar to options described in Sections 4.1.1, 4.1.2 and 4.1.4, however the source separated organic waste is treated at an anaerobic digestion (AD) facility. The AD facility will only accept the food fraction of the organic waste (the wetter and most digestible fraction), while the larger woody waste (GO) is treated in simple green waste composting plants. At present, the technology is not proven for treatment of garden waste (GO) mixed with food (FO). The woody lignocelluloses need to be extracted from the waste prior to digestion. This adds cost and reduces diversion. This option is termed "MSW and C&I FOGO: AD".

Key assumptions and limitations: MSW and C&I FOGO: AD
This option relies on the following: • All assumptions and limitations are the same as those described in Sections 4.1.1, 4.1.2 and 4.1.4. • Only food organic waste is anaerobically digested, while all garden organics are composted. • It is assumed that all methane emissions produced during the AD process are captured, for combustion to bioenergy.
Key risks
• There is a risk that the anaerobic digestion process could fail if the levels of contamination are not controlled, or if process variables are not monitored and adjusted as required. Therefore, the digestion process requires a high level of operational control when compared with composting, with associated increased operational costs. • There is a risk that biogas may leak from the AD plant.
Key co-benefits
• Generated methane gas captured and combusted for electricity / heat generation • Similar to composting, AD produces a stable, nutrient rich by-product which can be used as a soil conditioner.

4.1.7 Banning unsorted MSW from landfill

This option explored the introduction of a ban on unsorted MSW going to landfill. It cannot occur until all other diversion options are implemented. This ensures that as much commingled recyclables and organic material as possible is recycled. Following the rollout of the preceding diversion options, the residual MSW will be sorted and suitable material with a high calorific content will be separated and transported to an energy-from-waste facility. All remaining MSW, which will be largely inert, will be sent to landfill. Emissions will be dramatically reduced, as organic material remaining in this waste stream will be at a minimum. This option is termed "Banning unsorted MSW to landfill".

Following the implementation of this option, there are two alternate options which will be explored and discussed further in Section 5, but not presented in the "optimal pathway to net zero" model, as they are outside the scope of this analysis.

The first option involves incineration of residual MSW following the banning of MSW to landfill, for the reasons outlined in Section 2.2.5. The residual MSW, which will have a relatively high calorific content (due to the high level of plastics in the stream and organics not being present), will be incinerated in an energy-from-waste facility, to produce electricity which can be used to offset conventional fossil fuelled electricity consumption. It should be noted that in most countries, deriving energy from the non-biomass part of waste is not defined as 'renewable energy' because this waste stream contains plastics and other oil and gas-derived products.

The second alternate option involves the pyrolysis of end-of-life plastics only, for the production of road transport fuel (similar to the Foy Group proposal for the ACT - see Section 2.2.5). These plastics could not be recycled easily and therefore pyrolysis offers an alternative method of treating them. The road transport fuel produced could offset conventional fossil fuels such as diesel and petrol. In comparison with the incineration option, it does not offer as much diversion of waste from landfill, as it can only accept waste plastics.

Key assumptions and limitations: Banning unsorted MSW to landfill

This option relies on the following:

- The roll-out of all preceding MSW diversion from landfill options
- The proportion of residual MSW that is suitable for treatment in an energy-from-waste facility is 81% (low), 59% (medium) and high (38%).
- Incineration option: The calorific value of the residual MSW, and the efficiencies of the incineration process, and electricity generation.
  - Calorific value MSW: 12.5 GJ/tonne **(Garg. A, 2006)**
  - Electrical efficiency CHP unit: 30% **(WSP Environmental Ltd, 2013)**
  - Combustion of non-biomass MSW emission factors (kg CO2-e/GJ energy) from the NGER Measurement Determination 2008
    - CO_2: 87.1
    - CH_4: 0.70
    - N_2O: 1.10
- Pyrolysis option: The calorific value of the plastics within the MSW, and the efficiency of the pyrolysis process.
  - 2017 level of end-of-life plastic that ends up in landfill: 15,000 tonnes (Foy Group Ltd, 2017)
  - Road transport fuel (RTF) production efficiency: 1.06 kL/tonne end-of-life plastic (Foy Group Ltd, 2017)
  - Heating value RTF: 42.8 MJ/kg **(Mochamad Syamsiro et al., 2014)**

Key risks

Key risks are linked to composting and AD options.

For the incineration option:

- Higher risks both technologically and economically than other waste treatment options.
- There is the risk that approval would not be granted for the site, as approvals for Waste-to-Energy facilities are difficult to obtain.
- There is the risk of 'cannibalising' recycling

For the pyrolysis option, key risks are the same as for the incineration option. However additional risks include:

- Higher risk of failure than incineration, due to its less mature and proven status.

Key co-benefits

Key co-benefits are linked to composting and AD options.

For the incineration option:

- Financial co-benefits as electricity/heat produced can be used to offset site energy consumption, and surplus electricity can be sold to the grid.

For the pyrolysis option:

- Road transport fuel produced can be used to offset traditional fossil fuels in vehicles, with the financial co-benefits associated with this.

4.1.8 Banning unsorted C&D from landfill

This option is similar to the previously discussed option, except C&D waste is banned from landfill. However, the additional diverted C&D waste is recycled, as opposed to treated in an energy-from-waste facility. This option is termed "Banning unsorted C&D to landfill".

Key assumptions and limitations: Banning unsorted C&D to landfill
This option relies on the following: • The proportion of residual C&D waste that can be captured for additional processing is 1.6%. This is based on data provided in the Landfill and Transfer Station Waste Audits Report prepared by APC waste consultants in August 2015. Approximately 95% of C&D waste is currently recycled, of the remaining 5% left to be captured, 29.8% is suitable for recycling.
Key risks
• There is a risk that additional processing infrastructure will be installed, and then the amount of additional C&D waste that can be captured is even smaller than predicted, resulting in unnecessary expenditure.
Key co-benefits
• Reduces the reliance on extraction of raw materials for manufacturing, reducing associated energy consumption and GHG emissions.

4.1.9 Banning wood waste from landfill

This option involves banning wood waste to landfill, subsequently followed by burning of this diverted wood waste in an air curtain burner (also called a FireBox). This FireBox significantly reduces the emissions from burning wood and produces ash which can be used as a soil additive. This option is termed "Banning wood waste to landfill".

Key assumptions and limitations: Banning wood waste to landfill
This option relies on the following: • The Proportion of MSW, C&I and C&D waste that is wood and wood waste – MSW: 1.0%, C&I: 12.5% and C&D: 6.0%
Key risks
• Key risks relate to the operation of the air curtain burner: – If the air curtain velocity is too high, the FireBox can become over pressurized and over agitated. The higher pressure will lift the curtain and cause it to become ineffective. The over-agitation will cause embers and ash to be blown out of the FireBox or pit past the ineffective air curtain at a significantly higher rate than normal. – If the mass flow of the curtain is too low then the unburned particles (smoke) will penetrate the curtain on the high velocity of the hot gases being generated from the burning wood.
Key co-benefits
• Process produces ash which can be used as a soil conditioner.

4.1.10 Capture of landfill gas with energy recovery

This option involves increasing the capture rate of landfill gas, once all landfill diversion options have been implemented, for the reasons outlined in Section 2.2.4. The maximum gas capture rate is assumed to be 75%, as per the NGER Technical Guidelines. This is based on the current landfill gas capture rate of 67% which was determined using the solid waste calculator 2015/16 for the ACT provided by the Directorate. This capture rate is based on methane actually captured divided by the theoretical methane emitted if no capture system was in place. This option is termed "BAT Landfill Gas".

Key assumptions and limitations: BAT Landfill Gas
This option relies on the following: • The predicted volume of biogas that is produced at the ACT's landfills up to 2050. • Landfill gas capture efficiencies: – Medium: 70% – Low: 75% – High: 67% (no change)
Key risks
• The ACT is already recording an average landfill gas capture rate of 67% (NGER 2012-2016), therefore the technical possibility of reaching 75% may be quite difficult. • There is the risk that the infrastructure is installed with significant expenditure, and then fails to meet the maximum capture rate. • There is the risk that the infrastructure installed will be oversized for the amount of gas it needs to capture. As more waste is diverted from landfill, the volume of biogas that can be captured will decrease, meaning additional infrastructure installed now, may not be needed in the future. However, it should be noted that the lagging effect of landfill gas production will mean the impact of this waste diversion, will not be as pronounced to begin with.
Key co-benefits
• Financial benefits as electricity/heat produced can be used to offset site energy consumption, and surplus electricity can be sold to the grid. • Generation and sale of ACCUs if operated as a project under the Emissions Reduction Fund.

4.1.11 AD treatment of wastewater with combined heat and power production

This option explored the change of wastewater treatment technology, from aerobic to anaerobic, in approximately 2030. All methane produced from the AD process will be captured and used to produce bio-energy in a combined heat and power (CHP) unit. This energy would be used to offset site energy consumption, including that used for the incineration of digested solids. This option could not be realistically implemented before this, as comments from Icon Water staff indicate that the current system is going through a biosolids furnace upgrade which is expected to last for the next 10-15 years. Therefore, the appetite for completely overhauling the system would be zero currently. This option is termed Wastewater AD CHP.

Key assumptions and limitations: Wastewater AD CHP
This option relies on the following: • The amount of biogas produced using AD for each scenario (Confidential GHD Report for Icon Water in 2016) – Medium: 18,500 – Low: 21,000 – High: 16,000 • The fugitive emissions of biogas from the AD reactors **(IPCC, 2006)**: – Medium: 10% – Low: 5% – High: 15%
Key risks
• There is a risk that the anaerobic digestion process could fail if process variables are not monitored and adjusted as required. Therefore, the digestion process requires a high level of operational control. • There is a risk that biogas may leak from the AD plant. • There is a risk that the amount of energy that can be produced from the system may be overstated as the gas production can vary greatly by season
Key co-benefits
• Generated methane gas captured and combusted for electricity / heat generation • Generation and sale of ACCUs if operated as a project under the Emissions Reduction Fund • Process produces a stable, nutrient rich digested sludge by-product which can be used as a soil conditioner. • Reduction in fugitive N_2O emissions as there is a change from aerobic to anaerobic conditions.

4.2 Timelines for implementation of options

Table 4 provides the estimated years at which planning for each option could begin, and the implementation year for each. Some options can be implemented very rapidly, such as education and advocacy. Others, such as installing AD at the LMWQCC wastewater treatment plant or installing an energy-from-waste facility for the 'Banning unsorted MSW to landfill' option, have longer lead-in times. These timelines are reflected in the pathway model (see Figure 5).

Table 4. Lead in time and effective implementation dates for each waste sector abatement option

No.	Option	Lead-in time (development)	Effective from (emission abatement commences)
1	SUDS FOGO: Compost	2018-2019	2019-2020
2	MUDS FOGO: Compost	2018-2019	2019-2020
3	MUDS Commingled Recycling	2018-19	2019-2020
4	C&I FOGO: Compost	2018-2019	2019-2020
5	MSW & C&I FOGO: AD	2018-2019	2019-2020
6	C&I Commingled Recycling	2018-19	2019-2020
7	Banning unsorted MSW to landfill	2020	2021-2022
8	Banning unsorted C&D to landfill	2019	2019-2020
9	Banning wood waste to landfill	2019	2019-2020
10	BAT Landfill gas capture	2019	2020-2021
11	Education & advocacy to reduce waste generation	Current	Ongoing
12	Wastewater AD CHP	2027-2029	2029-2030

4.3 Screened options – no further investigation

The following options were considered for application in the ACT, but not continued for a variety of reasons including immaterial impact on the inventory, similar impact to other, lower risk options; or low practicality for implementation.

4.3.1 Capture of landfill gas with flaring

Due to the fact that no energy can be recovered as part of this option, and changing to a flaring system will have no impact on the fugitive emissions from the landfill as the methane destruction efficiency of a flare is the same as combustion for electricity generation, this option was not assessed further as a viable GHG abatement option.

4.3.2 AD treatment of wastewater with injection of biogas to grid

Due to the fact that that the emissions abatement is similar to the AD treatment of wastewater with combined heat and power production, and there are very strict gas cleaning requirements for injection back into the grid, this option was not assessed further as a viable GHG abatement option.

4.3.3 Maintaining current wastewater treatment system with additional heat recovery from sludge incineration

Due to the fact that there are significant fugitive N_2O emissions released as part of the current treatment process, the amount of energy produced is minimal compared with the AD process, and the aerobic treatment process consumes relatively high amounts of electricity, this option was not assessed further as a viable GHG abatement option.

4.3.4 Maintaining current wastewater treatment system with maximum efficiency of BNR process

Due to the fact that the aerobic treatment process consumes relatively high amounts of electricity, compared with anaerobic digestion, and the lack of proven strategies currently available in the literature on the subject, this option was not assessed further as a viable GHG abatement option.

5 PATHWAY TO ZERO NET CARBON EMISSIONS BY 2050

An interactive model was created to enable users to plot the reference case emissions for the waste sector in the ACT out to 2050, and to visualise the impact of the different abatement opportunities on the territory's emissions trajectory. The 'optimal' pathway, as determined by Point Advisory in consultation with the ACT Government, is shown in Figure 5. It is seen that the waste sector does not achieve net zero emissions, but can potentially reduce emissions from 103.4 kt CO_2-e in 2015, to 11.7 kt CO_2-e in 2050, despite an increase in population of 54% over the same period.

This pathway occurs when the ACT's population growth is low out to 2050. It includes a combined approach of high levels of diversion of organic material from landfill, with anaerobic digestion of the food organic stream, and composting of garden organics. MSW that is not suitable for alternative treatment (such as recycling and biological treatment) is transferred to an energy-from-waste facility which produces energy from a suitable feedstock. Contaminated wood waste is burnt in an air curtain burner, which produces very low emissions. All wastewater is treated anaerobically, with high levels of methane production and capture, and low fugitive emissions. Running in parallel with the implementation of all these options is a very active education campaign which encourages behaviour change to reduce waste generation per capita.

Specifically, the optimal pathway includes:

- Maximising the recovery rates of both commingled recyclables and organics from households and businesses.
- Limiting the amount of waste that can go to landfill to largely inert materials with low calorific values.
- Running an education and behaviour change program to reduce waste generation per capita.
- Maximising the capture of landfill gas at the Mugga Lane landfill.
- Reducing fugitive emissions from anaerobic digestion of wastewater to as low as possible.

The optimal pathway implements policies that reflect the following criteria:

- Favour technologies that are readily available and relatively easy to implement.
- Favour technologies that have been technically and economically proven in Australia and internationally.
- Where the technology has not been proven to be cost-effective in an Australian context, e.g. pyrolysis of end-of-life plastics for the production of road transport fuel, then the implementation is dependent on political will.
- Favour technologies with a long expected life (for the purposes of modelling, all options are assumed to operate to 2050 and beyond).

The timing of implementation of the policies identified for the pathway is largely at the discretion of the ACT Government's Waste Policy team. Timing will be informed by any feasibility studies the Waste Policy team conducts as part of the recommendations provided in this report. The pathways analysis is based on the timelines provided in Table 4.

The impact of bringing forward or delaying the implementation of any identified policies is partly captured in the uncertainty band provided by the difference in the 'high', 'medium' and 'low' scenarios (that can be modelled using the interactive pathways model tool developed by Point Advisory).

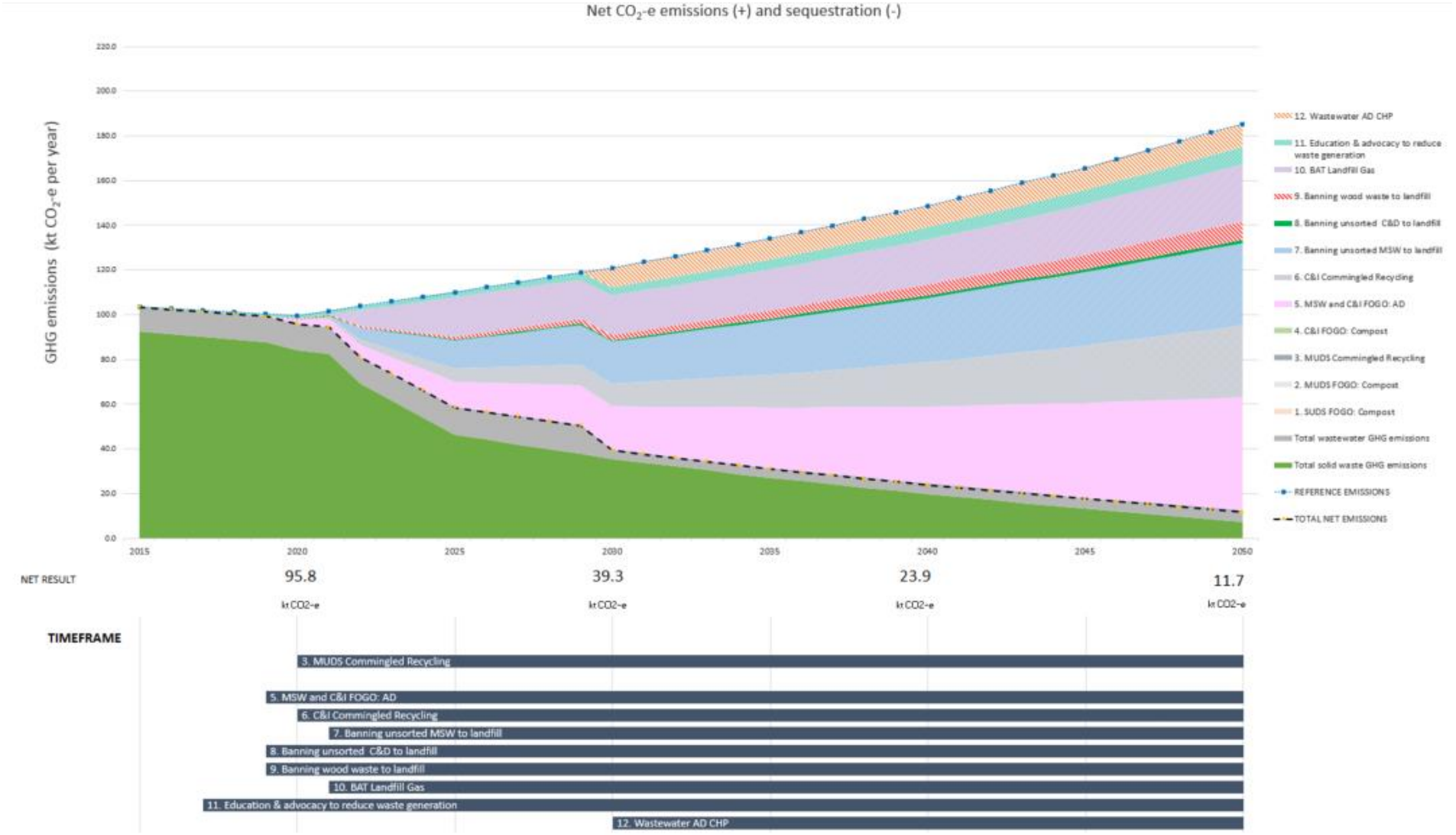


Figure 5. Optimal pathway to net zero for ACT, 2014 to 2050

5.1 Implementing the pathway

An in-depth examination of the options required to achieve the optimal pathway is given below.

5.1.1 Solid waste

Education and advocacy to reduce waste generation

This option is contingent on the implementation of many education and advocacy campaigns up to 2050, as it has been shown that the effects of these campaigns often do not endure. Therefore, soon after the campaign ends, waste generation rates may well return to their original levels. As this option directly impacts the amount of waste generated, it could potentially lead to a reduction in landfill gas emissions of roughly 4% compared with reference case emissions. However, when considering this option from a life cycle emissions perspective, the impacts on emissions may be more far-reaching. For example, activities that reduce the amount of material consumed without increasing the consumption of another type of material, such as avoiding the wastage of food, will lead to large GHG abatement across the whole economy. The benefits of not wasting food can be considered through the negation of GHG impacts associated with the production of the food product. Therefore, the GHG abatement extend far wider than just the end-of-life emissions investigated for this analysis.

To implement this measure the whole-of-government Waste Education Working Group, recently established by the ACT Government, must continue to ensure a consistent and effective approach to waste education is promoted across the territory. In addition, information about waste prevention and reduction per capita should be made available on the ACT NOWaste website. Any presentation and tours provided by ACT NOWaste should incorporate these aspects also. Communication channels such as public advertisements should also be considered to spread the message.

Diversion of organic waste from landfill

The combination of these options offers a large quantum of emissions abatement as organic material is diverted from landfill, with subsequent reductions in methane emissions. This results in about 30% reductions in solid waste emissions compared with the reference case, in 2050. For the anaerobic digestion option, additional GHG abatement will be seen throughout the wider economy as the impacts associated with replacing conventional fossil fuelled electricity with bioenergy will be seen.

To implement this measure, all organic waste collected from households and businesses would be biologically treated in a purpose-built facility (anaerobic digestion and composting). Contamination from organics bins (non-recyclable and mostly inert) would be sent to landfill.

Diversion of commingled recyclables from landfill

The combination of these options offers a large quantum of emissions abatement as materials such as paper and cardboard are diverted from landfill, with subsequent reductions in methane emissions. This results in about 19% reductions in solid waste emissions compared with the reference case, in 2050. Additional GHG abatement will be seen throughout the wider economy as the impacts associated with manufacturing the item from entirely primary sources, are reduced, as the same item can be produced from recycled materials instead.

To implement this measure, additional infrastructure will be required to increase the recovery rate of dry recyclables in the territory.

Banning unsorted waste from landfill

This option offers a large quantum of emissions abatement as all remaining biodegradable wastes are diverted from landfill, with subsequent reductions in methane emissions. This results in about 21% reductions in solid waste emissions compared with the reference case, in 2050.

This option assumes that there will be the development of an energy-from-waste facility in the territory, either an incineration or a pyrolysis plant.

An analysis of the incineration option with electricity production shows that when the emissions from this process are compared with conventional fossil fuelled electricity production (grid emission factor is assumed to be 0.6 kg CO_2-e/kWh), the emissions from energy-from-waste are actually higher. This trend will continue as the grid continues to decarbonise over time. For the pyrolysis of residual plastics, the GHG abatement offered by the option compared with the use of gasoline are just 5%. As electric and hybrid vehicles gain more popularity in the

future, this advantage will also decrease. It is important to state that this energy-from-waste option is likely to appear more attractive from a life cycle perspective, however this was not included in the scope of this analysis.

To implement this measure, all residual waste following the diversion of organics and commingled recyclables would need to be sorted at a new Residual Waste MRF. Contamination materials (e.g. non-recyclables and mostly inert) would be sent to landfill.

Improving landfill gas capture technologies

This option offers a moderate quantum of emissions abatement, as more methane is captured from landfill. This results in about 15% reductions in solid waste emissions, compared with the reference case, in 2050.

To implement this measure additional landfill gas capture infrastructure will need to be developed. It should be noted as more waste is diverted from landfill, the volume of biogas that can be captured will decrease, meaning additional infrastructure installed now may not be needed in the future. However, the lagging effect of landfill gas production will mean the impact of this will not be as pronounced to begin with.

5.1.2 Wastewater

Wastewater AD with CHP

This option offers a large quantum of emissions abatement from the wastewater sector – a 70% reduction in emissions compared with the reference case, in 2050. However, when looking at the waste sector collectively, this option reduces total emissions by just 6%. In addition, GHG abatement will be seen throughout the wider economy as conventional fossil fuelled electricity and heat will be replaced with bioenergy.

To implement this measure the wastewater infrastructure currently in place in the ACT at LMWQCC will need to be completely overhauled, and the site's physical footprint will increase significantly.

REFERENCES

ACT Government. (2016). *ACT Waste Feasibility Study,.* Canberra, ACT: ACT Waste Feasibility Program Office.

APC Waste Consultants. (2014). *ACT NOWaste Domestic Waste Audit Report.* Canberra, ACT: ACT NOWaste.

De Baere L. and Mattheeuws B. (2014). *Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe.* Belgium: OWS.

Department of Environment & Climate Change NSW. (2007). *Report into the Construction and Demolition Waste Stream Audit 2000-2005.* Sydney, NSW: Department of Environment & Climate Change NSW.

Ecofys. (2013). *Feasibility of GHG emissions phase-out by mid-century.* Global Call for Climate Action (GCCA).

European Commission. (2017). *The role of waste-to-energy in the circular economy.* Brussels: European Commission.

Foy Group Ltd. (2017). *Environmental Impact Statement - Public Enquiry. Non-recyclable plastic to liquid fuel processing facility.* Canberra, ACT: FOY Group Ltd.

Foy Group Ltd. (2017). *Environmental Impact Statement - Public Enquiry. Non-recyclable plastic to liquid fuel processing facility.* Canberra, ACT: FOY Group Ltd.

Foy Group Ltd. (2017). *Environmental Impact Statement - Public Enquiry. Non-recyclable plastic to liquid fuel processing facility.* Canberra, ACT: FOY Group Ltd.

Foy Group Ltd. (2017). *Road ready fuel from end-of-life non-recyclable plastics.* Canberra, ACT: Foy Group Ltd.

FullCAM and Agriculture Inventory Expert Advisory Panel. (2016). *New emissions estimation methods for the 2016 National Inventory Report submission unde rthe UN Framework Convention on Climate Change.*

Garg. A, K. K. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2: Energy.* Intergovernmental Panel on Climate Change.

Hogg D. and Ballinger A. (2015). *The Potential Contribution of Waste Management to a Low Carbon Economy.* Bristol, UK: Zero Waste Europe and Eunomia Research & Consulting.

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.* Intergovernmental Panel on Climate Change.

Kampschreur. MJ., T. H. (2009). Nitrous oxide emission during wastewater treatment. *Water Research*, 4093-4103.

Mochamad Syamsiro et al. (2014). Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors. *Energy Procedia*, 180 – 188.

MRA Consulting Group. (2016). *Alternative waste treatment facilities: Experience in Australia and abroad.* Sydney, NSW: MRA Consulting Group.

Pitt & Sherry. (2016). *Past and projected future components of electricity supply to the ACT, and resultant emissions intensity.* Canberra, ACT: ACT Government.

RTI International. (2012). *Environmental and Economic Analysis of Emerging Plastics Conversion Technologies.* New York.

Wiedemann. S. et al. (2015). Resource use and environmental impacts from beef production in eastern Australia. *Animal Production Science*.

WSP Environmental Ltd. (2013). *Waste technologies: Waste to energy facilities.* Perth, WA: Government of Western Australia, Department of Environment and Conservation.

APPENDIX 1 GLOSSARY

Term	Definition
Anaerobic Digestion (AD)	Involves a series of biological processes in which microorganisms break down organic material under anaerobic conditions (without oxygen). The breakdown of organic material results in the production of biogas, which is a mixture of methane and carbon dioxide. The biogas can be used an alternative source of energy (essentially as a replacement to natural gas) or can be flared to reduce its global warming potency. AD also results in the production of "digestate", a nutrient rich slurry which can be further processed to produce compost or soil conditioner.
Commercial and Industrial (C&I) Waste	Comprises solid waste arising from the activities within commercial and industrial sites, including but not limited to offices, retail outlets, restaurants, factories and institutions.
Combined Heat and Power (CHP)	Also known as cogeneration. Systems that generate electricity and useful thermal energy in a single, integrated system.
CO_2-e	Carbon dioxide equivalent.
Calorific Value (CV)	The energy contained in a fuel, food or waste, determined by measuring the heat produced by the complete combustion of a specified quantity of it. Expressed in joules per kilogram.
Emissions Reduction Fund (ERF)	The Commonwealth Government's scheme to enable participants to create and then sell carbon credits related to emissions reduction projects across a variety of sectors.
FO	Food organics.
Fugitive wastewater emissions	Emissions that occur throughout the wastewater treatment process as a result of chemical reactions e.g. the emission of methane gas during anaerobic digestion.
Gasification	A process that transforms a carbon-based material, such as MSW or biomass, into other forms of energy without actually burning it. Instead, gasification converts the solid and liquid waste materials into a gas (syngas) which can be used to produce energy.
GHG	Greenhouse gas.
GO	Garden organics.
GWP	Global Warming Potential
Incineration	A waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration of waste materials converts the waste into ash, flue gas and heat.
Landfill Gas (LFG)	A natural by-product of the decomposition of organic material in landfills. LFG is composed of roughly 50% methane (the primary component of natural gas), 50% carbon dioxide and a small amount of non-methane organic compounds.
Mechanical Biological Treatment (MBT)	The use of mechanical and biological processes to transform waste into valuable outputs. The broad technology types include Composting and Anaerobic Digestion.
Materials Recovery Facility (MRF)	A facility where recyclable materials that are collected from homes and businesses are taken to be sorted into different "streams" such as paper, plastics, glass, aluminium or organics.
Municipal Solid Waste (MSW)	Primarily waste collected from households and councils, such as through kerbside waste collections. It includes biodegradable material, recyclable materials such as bottles, paper, cardboard and aluminium cans, and a wide range of non-degradable material including paint, appliances, old furniture and household lighting
Multi-Unit Dwellings (MUDs)	A classification of housing where multiple separate housing units for residential inhabitants are contained within one building or several buildings within one complex. A common form is an apartment building.
Operational wastewater emissions	Emissions resulting from the consumption of energy to operate a wastewater treatment plant.
Organic waste	Organic material such as food, garden and lawn clippings. Can also include animal and plant-based material and degradable carbon such as paper, cardboard and timber.

Term	Definition
Pyrolysis	A thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. In general, pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content, char.
Source Separated Organics (SSO)	Activities which separate organic material from waste at the point of generation and divert it away from landfill.
Single Unit Dwellings (SUDS)	Attached/detached units on individual freehold titles, whereas multi-unit dwellings are subject to 'community title'. Most commonly, freestanding houses.
Thermal treatment	Incineration and other high-temperature waste treatment systems are described as "thermal treatment".