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# Alternative Residual Waste Treatment

## Biostabilisation

Report for Zero Waste Scotland

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# Executive summary

### Background

A ban on the landfill of biodegradable municipal waste (BMW) will come into force in Scotland on 31 December 2025. On that basis, local authorities in Scotland will need to review options for processing residual municipal solid waste (MSW) (residual waste[1]) to ensure future compliance with the ban.

The project documented in this report was commissioned to review the practice of biostabilising residual waste, principally with consideration to its subsequent disposal in landfill, rather than as part of a treatment process that produces refuse derived fuel (RDF) or solid recovered fuel (SRF) for energy recovery.

Residual waste can be biostabilised utilising mechanical biological treatment (MBT) technologies and the level of biostability necessary to allow the treated waste to be landfilled under the ban is detailed within Scottish legislation.

As the name suggests, MBT is the treatment of waste by both mechanical and biological means. Biological treatment of waste degrades complex organic compounds into simpler compounds. If the treated waste is then landfilled, it is more stable and will degrade less within the landfill and so will generate less landfill gas than it would without prior biological treatment. Landfill gas is a mixture that includes gases with global warming potential (GWP). The more organic material that is degraded in the MBT process, the more stable the waste becomes (biostabilisation).

The project scope did not include comparison to be made with any other form of residual waste treatment, nor any recommendation to be made on whether MBT should be employed in Scotland. There are advantages and disadvantages to all forms of residual waste treatment. This study set out to explain whether MBT is feasible for meeting the BMW landfill ban criteria and to explain the advantages and disadvantages of employing MBT, in the Scottish context, to help local authorities and policy makers make informed decisions.

The high-level project scope was to:

- Set out what biostabilisation of residual waste involves.
- Review how techniques have been implemented in Britain (high level summary) and, via case studies, in selected EU countries.
- Undertake a carbon lifecycle assessment (LCA) for the biostabilisation of residual waste.
- Consider the balance and interaction of technical, economic, policy and environmental factors that influence the implementation of biostabilisation techniques in practice.

The carbon LCA undertaken is bespoke to the MBT process, and the approach used shares some similarities to a carbon LCA, for energy from waste (EfW), previously undertaken by Zero Waste Scotland. Within the agreed scope of work, there are some limitations to the carbon LCA undertaken; for example, it does not consider future changes in waste composition and it utilises a single approach to allocating carbon emissions, in line with the prior Zero Waste Scotland EfW carbon LCA.

### Types of MBT technology

Various MBT technologies are described below, and throughout this report, and specific MBT facilities in Great Britain (23 no.) and in the EU (6 no.) are discussed. None of the specific facilities discussed have been confirmed to meet all the modes of operation of most interest to this study, which are listed below.

- No RDF production.
- Main output is destined for landfill.
- Achieves a level of biostability that will comply with the Scottish ban criteria.

The mechanical processing that takes place at MBT facilities involves size reduction and sorting of the residual waste into different components. Typically, materials are separated into recyclable fractions, RDF, contaminants and an organic rich fraction. The organic rich fraction is then processed

[1] Residual waste is the waste that has not been placed in containers provided to allow collection of recyclable materials.

utilising an aerobic composting or an anaerobic digestion (AD) process, which are both biological processes. The output of the biological process is generally either a compost like output (CLO) or, for AD processes, digestate and biogas. Biogas is used as a fuel for energy generation or vehicle propulsion.

Mechanical separation techniques can involve a wide array of technologies, most of which are well proven and commonplace in waste management processes. However, as waste is separated into different streams, each stream has different properties, such as moisture content, bulk density, particle size and particle shape. A change in input waste composition can have a notable affect upon facility performance, especially in terms of blockage and spillage at equipment in mechanical pre-treatment but also in terms of the residence time in the biological process and the throughput capacity of the whole facility. The more complex the mechanical process, the greater the potential for issues as the input waste composition changes.

The biological process can comprise:

- In-vessel composting (IVC).
- Biological drying (Biodrying).
- Anaerobic digestion (AD).

Of the above biological processes, IVC and dry-AD (a form of AD) followed by IVC can be designed and operated to allow various extents of biostability, including to meet the Scottish ban criteria. Biodrying will not achieve a high level of biostability and wet-AD (another form of AD) output is not practicably amenable to the necessary subsequent IVC process required to achieve a high level of biostability.

Ricardo has not established the level of biostabilisation achieved at British MBT facilities, nor for the six case study sites reviewed in other countries. In Britain, there is currently no legislative requirement to meet a specific threshold of biostability prior to landfill. The focus of most MBT facilities, in Britain and the EU, is not to biostabilise waste prior to landfill; to the contrary, the focus is often to divert as much waste as possible away from landfill. Nonetheless, it is Ricardo's conviction that IVC can, subject to design and mode of operation, achieve levels of biostability in residual waste that will comply with the Scottish ban criteria.

Organic materials present within residual waste are amenable to composting and composting can be managed, including duration and extent of maturation[2], to achieve a high level of biostability. Proposed biostability thresholds for EU Ecolabel (for growing media, soil improvers and mulch) and EU end of waste criteria include values that are more stringent than the Scottish ban criteria, demonstrating that composting can achieve high levels of biostability.

Furthermore, Ricardo has contacted technology providers that have confirmed that they can design facilities capable of achieving the Scottish ban criteria. Reference facilities were mentioned, although none that only process residual waste.

Biodrying involves aeration of waste to commence the composting process to raise the waste's temperature to drive off moisture. However, the composting process is cut-short once the waste has dried to the desired level and, unlike a full composting process, water is not added. A humus like composted output is not produced in biodrying. Biodrying will not stabilise residual waste to the level necessary to allow its landfill in Scotland.

Anaerobic digestion alone will not meet the Scottish biostabilisation criteria. Anaerobic digestion can be undertaken on a dry or wet basis. Unlike wet AD, dry AD digestate is more amenable to subsequent IVC processing. As such, dry AD and IVC combined can be used to meet the Scottish biostabilisation criteria.

Whilst wet AD cannot, in a practical manner, meet the Scottish biostabilisation criteria, it is a popular MBT option within Europe, including in Britain, where it typically accompanies processes to generate

[2] Maturation is sometimes employed after the main composting process. During maturation, there is minimal active management of the process and the temperature and rate of degradation gradually reduce, and the compost becomes 'matured'. Matured compost has a greater level of biostability than un-matured compost.

RDF rather than outputs for landfill. As such, some case study examples of wet AD have been included in this study for information purposes.

A comparative summary of the main strengths and limitations of each biostabilisation technique employed at MBT facilities is detailed in the table below.

| MBT option | Can be designed to meet BMW landfill ban criteria? | Technology complexity for biological process | Advantages (relative to other MBT options) | Disadvantages (relative to other MBT options) |
|---|---|---|---|---|
| IVC | Yes | Less complex than AD | IVC technology alone can achieve the ban criteria (if designed and operated to do so).<br><br>Easier to control/more stable process than AD. | IVC does not allow for energy recovery from organic materials. |
| Wet AD | Not in a practical manner | Complex | Easier to control and optimise than dry AD- substrate can be mixed, heated and transferred with greater ease.<br><br>AD allows for energy recovery- IVC does not. | AD will not biostabilise enough to meet the ban- needs to be followed by IVC. However, the liquid nature of wet AD digestate output is unsuitable for IVC without drying and mixing with material with structure- i.e. not a practical option even if technically possible (likely to require mixing non-source separated MSW with source separated material).<br><br>Requires greater footprint area than dry AD. |
| Dry AD | Only when combined with IVC and must have prior RDF removal | Less complex than wet AD but less easy to mix and maintain steady operation | AD allows for energy recovery- IVC does not.<br><br>Dry AD output can be suitable for IVC, whereas IVC is not practical for the output from wet AD. | AD will not biostabilise enough to meet the ban- needs to be followed by IVC. Batch processes are not practicable for high throughput facilities and semi-continuous flow processes require some 'contaminant' (RDF materials) removal prior to AD. |
| Biodrying | No | Least complex of all | Fast, easier to optimise than other options and relatively low footprint area compared to IVC. | Biodrying does not allow for energy recovery from organic materials.<br><br>Will not allow enough biostabilisation to meet the ban criteria. |

A change in the organic content of residual waste will have a significant impact upon the function and utilisation of the biological process. That is evident from some of the case study facilities reviewed, where facility modification or closure to residual MSW treatment has occurred. Introducing source segregated organics collection is likely to be significant and the impact is likely to be greatest at an

AD facility, whose design and anticipated performance involve electricity, heat or biomethane production.

### MBT in Britain

In theory, if not always in practice, MBT offers several benefits over landfill and incineration. Benefits might include a reduction in material sent to landfill, or incineration, resulting from biological process losses and, potentially, the removal of higher quantities of recyclable materials. Nonetheless, energy from waste (EfW) by thermal treatment (generally combustion- incineration) is more popular, in terms of the number of facilities and tonnage treated, than MBT in Britain.

Twenty-three British MBT facilities have been identified in this study, comprising one in Wales, two in Scotland and 20 in England. MBT facilities that are integral to onsite EfW facilities (thermal treatment of waste) have not been included in the list, except for one facility because it is in Scotland.

All but one British MBT facility (an English IVC facility) generated RDF in 2019. The operators of the facility that did not generate RDF wish to construct an EfW facility at the site.

Of the 23 British MBT facilities, the biological processes undertaken include:

- 8 Biodrying (including the one Welsh facility and one of the two Scottish facilities)
- 9 Wet AD (including the one Scottish MBT/EfW facility)
- 1 Dry AD with IVC
- 5 IVC

There is currently no limit on the biostability of waste that can be landfilled in Britain and Ricardo is not aware of any British MBT facility that biostabilises waste to the level required by the forthcoming Scottish ban.

British MBT facilities are focussed upon landfill diversion by removal of recyclable materials, production of RDF and mass loss via biological treatment.

Based on the experiences of Ricardo staff, the quality of recyclable materials separated at MBT facilities can be poor and market prices highly variable.

The British experience has shown that securing outlets for CLO is particularly problematic, and it is often landfilled until other opportunities arise. However, if residual waste was subject to removal of recyclable materials, biostabilisation and landfill, without RDF production, there would be no need to find an outlet for CLO.

### Scottish MBT facilities

Scotland has two MBT facilities, which are the Glasgow Recycling and Renewable Energy Centre (GRREC) and Lochar Moss in Dumfries and Galloway.

At GRREC, mechanical processing is followed by wet AD and a gasification[3] EfW process is integrated with the residual waste MBT process. English MBT facilities with on-site thermal EfW processes have not been included within this report; the exception was made for GRREC as it is in Scotland.

Irrespective of the production of RDF to be input into the gasification process, the GRREC facility utilises wet AD and, therefore, does not biostabilise waste such that it could be landfilled following the 2025 ban. However, the process will avoid the landfilling of BMW if the total organic carbon in the solid residue (char) from the thermal process is below the required limit such that it can be landfilled to comply with the requirements of the BMW landfill ban.

The Lochar Moss facility is a biodrying/RDF facility (Ecodeco technology) and in 2019 the single largest output fraction was RDF. Whilst the facility may potentially be able to meet the requirements of the ban, through EfW and landfill of ash, it will not do so by biostabilisation.

[3] Gasification is a thermal process that partially oxides waste in a low oxygen environment.

### Case study countries and facilities

France, Germany, Italy and Spain were selected as countries known to have established experience of MBT. The main influences of legislation and policy, compost standards, biostabilisation criteria and landfill tax were reviewed and six MBT facilities, located in France (x1), Germany (x3) and Spain (x2) were researched and feature as case studies in this report.

The case study facilities broadly reflect the current variety of MBT processes typically employed in Europe.

Five of the case study facilities produce RDF, and the situation at the sixth is unclear. The prevalence of RDF production encountered when selecting the six case study facilities reflects the same situation that exists in Britain, where RDF production is the norm. The prevalence of RDF production is primarily the result of policies to divert waste from landfill and the waste hierarchy, which places energy recovery above landfill.

Two of the case study facilities no longer process residual waste, influenced by the introduction of source segregated biowaste collections and, in one instance, due to EfW being a cheaper option. A third facility will be significantly impacted by a change in legislation that will significantly impact the mode of operation, potentially threatening its future.

Although France, Germany, Italy, Spain and Scotland share the high-level desire to divert waste from landfill and to apply the waste hierarchy, the policies, legislation and regulation applied to achieve those ambitions vary considerably. In turn, there are different conditions in each country that can impact upon the development of MBT facilities. A summary of some of the main differences is provided in the table below.

| Policy/ legislation/ regulation | Country | Impact on MBT viability | Applicability to Scotland |
|---|---|---|---|
| Allow CLO application to agricultural land | France and Spain (if compost standards met)<br>(Does not apply to Germany and Italy) | Significant advantage to an MBT operator (no landfill or EfW gate fees) | No end of waste status for CLO (so not an option) |
| No specific biostabilisation criteria for the landfill of BMW | France and Spain (only some regions in Spain have banned BMW going to landfill)<br>(Germany and Italy have criteria) | Advantage to an MBT operator as a high level of biostability is not necessary, and biostability does not need to be consistent. An operator may design a process with less retention time than it would if biostability criteria applies (reduced capital and operational costs and smaller facility footprint area) | Ban on BMW to landfill, with biostabilisation criteria, to apply from 2025 |
| Minimum energy recovery mandated (70% of material unsuitable for material recovery must go to energy recovery) | France | Significant advantage to MBT with RDF production (and direct EfW also has an advantage over landfill) because landfill of such material is not possible | Scotland does not have a comparable policy |

| Policy/ legislation/ regulation | Country | Impact on MBT viability | Applicability to Scotland |
|---|---|---|---|
| Waste not recycled that has a calorific value over a certain threshold cannot be landfilled | Germany | Significant advantage to MBT with RDF production (and direct EfW also has an advantage over landfill) because landfill of such material is not possible | Scotland does not have a comparable policy |
| Mandatory separate collection of organic waste | Germany (widespread and a requirement)<br>France (to apply from end of 2023)<br>(Does not apply to Spain and Italy) | Disadvantage to an MBT operator because mass loss from the biological process is a central focus for most MBT facilities (particularly problematic if separate collection introduced during the operation of an existing facility) | Will apply to Scotland if there is an increase in separate collection |
| Polluter Pays principle (payment for specific amount of residual waste collected) | Germany | Disadvantage to an MBT operator if quantity of residual waste diminishes | Scotland does not have a comparable policy |
| Landfill tax and incineration tax but with discounts for most operators limiting tax effect | France | Unlikely to significantly impact an MBT operator in this instance due to discounts | Landfill tax but no incineration tax |
| High landfill tax rate | Spain (Catalonia) | Significant advantage to MBT (if RDF produced) and for EfW operators over direct landfill. MBT (biostabilisation and landfill) will fare better than direct landfill due to a reduction in material landfilled, but EfW will fare best | Applies in Scotland |

The review of policy and case study facilities in other countries, and facilities in Britain, highlights several points of interest to the possible future landfill of biostabilised residual waste in Scotland, as listed below.

- The landfill of biostabilised waste, without prior RDF production, in Scotland would not reflect a typical MBT operation in Britain and the EU. The experiences, benefits and difficulties encountered elsewhere should be considered in that context.
- The prevalence of RDF production and minimisation of waste to landfill are common themes within Britain and the EU, informed by the waste hierarchy. If MBT with biostabilisation and landfill, without RDF production, is to be promoted in Scotland, it may be beneficial to review the provisions of the waste hierarchy from a carbon perspective.

- There are many differences in policy, legislation and regulation between France, Spain, Italy, Germany and Scotland. Some policies in other countries are not relevant to Scotland or are unlikely to apply in future; that includes the application of CLO to agricultural land, and restrictions on the landfill of some waste that could be utilised for energy recovery. Such policies will influence the economic viability of MBT.
- Fast moving changes in policy and the regulatory landscape increases uncertainty and investment risk. In Scotland, as is common elsewhere in Britain and the EU, waste policy and practices are being developed and refined on an ongoing basis. Policy changes, such as measures to increase the source segregation of waste, can lead to changes in waste composition. A change in waste composition, especially from an increase in the source segregation of food waste, can have a significant impact upon the continued viability of an MBT facility.

### Carbon lifecycle assessment

All scenarios modelled in the carbon lifecycle assessment (LCA) showed a calculated carbon impact (not benefit), per tonne of residual waste treated, as shown below.

- IVC only, without RDF production: 12kg $CO_2$eq/t
- Dry-AD+IVC (must involve RDF production): 66kg $CO_2$eq/t
- IVC only, with RDF production: 115kg $CO_2$eq/t

The greatest influences on the carbon balance are whether RDF is produced, and subsequently combusted elsewhere for energy recovery, and whether materials are recycled. The former unfavourably impacts the carbon balance whereas the latter benefits it.

The combustion of RDF has a net impact (not benefit) of high significance to the overall carbon balance, as is evident from the difference between the two IVC only scenarios considered (see above). That is due to the combustion of fossil carbon, which is 'stored' if landfilled under an MBT scenario wherein RDF is not generated and the MBT output is landfilled.

Dry-AD+IVC has the benefit that biogas, of biogenic origin, is produced and combusted to generate electricity, but that advantage comes with a need to remove RDF and the impact associated with RDF combustion.

In future years, the mix of the supply of electricity to the grid in Britain is expected to decarbonise substantially to meet legally binding targets. A grid mix with lower carbon intensity will entail lower carbon emissions from the production of electricity consumed at MBT facilities, as well as lower carbon benefits associated with electricity generation at Dry AD facilities or generated from the combustion of RDF separated at MBT facilities. Overall, this is likely to make IVC without RDF production even more advantageous, from a carbon performance perspective, compared to Dry-AD with IVC and IVC with RDF production.

Carbon impacts are not the only aspect that needs to be considered. Any solution must be sustainable, in all senses of the word, for the anticipated lifetime of a waste facility.

### Balance and interaction of factors affecting MBT viability

The balance and interaction of factors affecting MBT viability are complex, especially because MBT covers a range of possible equipment configurations and technologies, with a variety of output materials that can be utilised in different ways. MBT processes vary significantly in terms of technology, complexity, scale and cost.

As described above, MBT of residual waste, with landfill of biostabilised output material, is technically possible and there are potential environmental (carbon) benefits that could be realised if such an MBT operation can be sustained in the long-term. There are also various policy measures that could be implemented that may or may not benefit an organisation considering developing an MBT facility.

However, to be sustainable over the long-term, an MBT facility must be financially viable. Financial viability is influenced by how stable technical performance, policy and regulation and market conditions are. However, policy and regulation can change considerably and relatively quickly, and market conditions, such as recyclate markets and the presence of competing facilities, are variable and unpredictable.

A change in policy, or general economic conditions, can bring about a change in waste composition. A change in waste composition can cause technical issues at an MBT facility and can impact upon the quality of the facility outputs. In turn, that can affect the possible end use of facility outputs and the revenue from energy or material sales.

Local authority contracts are generally in place for several years, and many British MBT facilities have been developed under public-private partnerships (PPP) and private finance initiative (PFI) agreements, with complex contractual terms that often include wider waste management services. Determining a cost for MBT, and then making comparisons with other technology options is therefore problematic at the national scale. It is difficult to arrive at a typical gate fee for British MBT. However, there is no evidence to suggest that it is a cheaper option than EfW and, in some instances, it may prove to be the more expensive option per tonne of waste treated.

An important aspect of such complex long-term contracts is how risk is shared between the contracting parties.

Under a long-term contract, a local authority will sometimes be prepared to pay ‘a bit more’ to limit its exposure to fluctuations in market conditions. The contractor will assume the risk but is hopefully compensated by receiving a good payment per tonne of waste treated, as determined by the payment mechanism. Such contracts are typically in place for around 20 years, and a lot can change in a short space of time. Irrespective of cause, whether technical error in facility design, change in waste composition, or change in market conditions, there is plenty of scope for one or more parties to a contract to become dissatisfied.

The complex interaction between the influencing factors described above is a negative aspect of MBT facilities. Other residual waste management techniques, EfW for example, are typically less sensitive to the types of interactions described above.

### Recommendations

Some MBT technologies can treat BMW to a level of biostability that will meet the Scottish ban criteria, and it performs well from a carbon emissions perspective. However, MBT can take many forms and its implementation can be problematic.

To employ MBT in Scotland, with landfill of most of the facility outputs, would require a step-change in attitude and approach by many involved, in whatever manner, in waste management. That approach is not currently practiced in Scotland, and only one English facility has been identified that does so.

If employed, the result would be unlikely to cause a decrease in waste landfilled, it would most likely increase, and this would not be in keeping with the waste hierarchy wherein energy recovery is deemed preferable to landfill.

If further consideration is to be given to MBT development in Scotland, Ricardo’s recommendations for future consideration are summarised below.

1. Priority should always be given to minimising waste generation, and to collection of source segregated waste wherever practicable. Recycling has carbon benefits but recovering and recycling components of residual waste is more difficult than for source segregated materials. Furthermore, unlike organic materials in residual waste, source segregated organics can be processed to gain end of waste status in Scotland. If successful source separation of recyclable materials and organic waste in Scotland limits opportunities for MBT in Scotland, then that must be considered a good outcome so long as residual waste generation is minimised as much as possible.
2. If MBT was to be promoted in Scotland, it is likely that policy or financial instruments would need to be developed to allow it to become the favoured option. If MBT aimed at landfill and not RDF production was to be promoted, then a review could be undertaken into how landfill tax might be applied to support such practice.
3. A review could be made of the waste hierarchy and whether it requires amendment, in a time when the carbon balance of waste management is becoming ever more prominent in decision making. The carbon LCA undertaken in this study demonstrates a marked difference in incinerating RDF versus its landfill, if that material is biostabilised prior to landfill.

4. A review could be made of the experience of MBT implementation in England. That might include liaison with UK waste management companies and local authorities that have experience of MBT implementation.
5. A review could be made of the remaining landfill capacity in Scotland and changes in the tonnage and volume inputs to Scottish landfills that might result from the landfilling of biostabilised residual waste in Scotland.
6. A review could be made of the practice of producing mixed polymer pellets from materials separated at MBT facilities. To begin with, that could involve liaison with Zero Waste Europe to understand the evidence base informing statements it made in a report it published[4].
7. Because most designers and operators of MBT facilities are familiar with RDF production, greater due diligence will be needed if selecting MBT-IVC technologies that do not involve RDF production. The suitability of MBT will have to be assessed on a case by case basis and with consideration to the local authority specific residual waste composition and any forecast future variation.

[4] Building a bridge strategy for residual waste- Material Recovery and Biological Treatment to manage residual waste within a circular economy- Policy Briefing, June 2020, Zero Waste Europe

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# Glossary

| Abbreviation | Definition |
|---|---|
| AD | Anaerobic digestion |
| BMW | Biodegradable municipal waste |
| CIC | Consorzio Italiano Compostatori<br>The Italian composting and biogas association |
| CHP | Combined heat and power |
| CLO | Compost like output<br>This term is used to describe the output from a residual waste composting process, in recognition that it cannot lose its waste status and simply become a compost product. Sometimes known as stabilised organic material (SOM) or 'stabilite'. |
| CV | Calorific value |
| DM | Dry matter<br>Often expressed in terms of weight percentage, this describes what portion of the waste or product is not comprised of moisture. |
| EF | Emission factor |
| EfW | Energy from waste |
| EPC | Engineering, procurement and construction |
| EPR | Extended producer responsibility |
| EWC | European Waste Catalogue<br>Also referred to as LoW (List of Waste). |
| GDP | Gross domestic product |
| GWP | Global warming potential |
| HDPE | High-density polyethylene |
| HWRC | Household waste recycling centre |
| IVC | In vessel composting |
| LAS | Landfill allowance scheme<br>No longer in force, this was the name for schemes that applied in Scotland and Wales that were focussed on reducing the landfill of BMW. |
| LATS | Landfill allowance trading scheme<br>No longer in force, this scheme applied in England and was focussed on reducing the landfill of BMW. |
| MBT | Mechanical biological treatment |
| MRF | Material recovery facility |
| MSW | Municipal solid waste |

| Abbreviation | Definition |
|---|---|
| PAS | Publicly available specification<br>PAS100 applies to compost and PAS110 applies to digestate. |
| PET | Polyethylene terephthalate<br>Also abbreviated to PETE, this is the chemical name for polyester. |
| PFI | Private finance initiative |
| PPP | Public-private partnership |
| RAL | Reichs-Ausschuß für Lieferbedingungen und Gütesicherung<br>This is the committee for delivery and quality assurance in Germany. |
| RDF | Refuse derived fuel |
| SCM | Scottish carbon metric |
| SEPA | Scottish Environment Protection Agency |
| SOM | Stabilised organic material<br>Sometimes known as compost like output (CLO) or ‘stabilite’ (see CLO above). |
| SRF | Solid recovered fuel<br>The term SRF is sometimes used interchangeably with RDF, but SRF generally refers to a fuel that is more consistent in quality and that has been produced to stricter quality criteria. |
| TGAP | Taxe Générale sur les Activités Polluantes<br>In France, landfilling and incineration activities are subject to this general tax on polluting activities. |
| WRATE | The Waste and Resources Assessment Tool for the Environment |
| WTS | Waste transfer station |

# 1 Introduction

## 1.1 Background

A ban on the landfill of biodegradable municipal waste (BMW) (the ban) will come into force in Scotland on 31 December 2025. On that basis, local authorities in Scotland will need to review options for processing of residual municipal solid waste (MSW) (residual waste) to ensure future compliance with the ban.

A key objective of the ban is to help reduce Scotland's carbon emissions on a carbon dioxide ($CO_2$) equivalent basis.

In order to address the ban, there are two ways to treat residual waste prior to its landfill. These are energy from waste (EfW), with resultant landfill of any ash that is not recycled, and biostabilisation in mechanical biological treatment (MBT) facilities. The treatment of organic matter to increase its stability is known as 'biostabilisation' and requires the use of either an aerobic or anaerobic biological process.

The project documented in this report was commissioned to consider biostabilisation as a means of meeting the ban, principally with consideration to the subsequent disposal of treated waste in landfill.

MBT processes are also employed to produce compost like output (CLO) for application to land and as part of a treatment process that produces refuse derived fuel (RDF) or solid recovered fuel (SRF) for energy recovery. However, such processes are not the primary focus of this study. Where RDF/SRF is produced in MBT processes, it is sent for combustion and energy recovery rather than landfill and can typically comprise around 50%, sometimes much more if the output of the biological process is what forms the RDF/SRF, of the input residual MSW. As such, an MBT facility with RDF or SRF production is not predominantly aimed at 'biostabilisation', but largely on producing fuel for EfW.

Organic material present in residual waste will degrade under aerobic or anaerobic conditions, generating carbon dioxide and, in the case of anaerobic processes, methane. Both gases have a global warming potential (GWP), and that of methane is 28 times[5] greater than carbon dioxide over a 100-year period.

When waste is landfilled it is subjected to anaerobic conditions and generates landfill gas, which contains high levels of both methane and carbon dioxide. Paragraph 4 of Schedule 3 of The Landfill (Scotland) Regulations 2003 (as amended) (the 'Landfill Regulations') requires that landfill gas must be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and, to the extent possible, used. These regulations also require that landfill gas which cannot be used to produce energy must be flared. However, even in a well-designed and operated landfill, where landfill gas is generated it is not possible to fully capture it all and the emission of landfill gas to atmosphere is a significant source of global warming gases. In 2019, emissions of methane from waste management in Scotland amounted to 1.4Mt $CO_2$eq (Scotland's total emissions of greenhouse gases amounted to 47.8Mt $CO_2$eq in 2019, of which 9.2 Mt $CO_2$eq were methane emissions)[6].

The landfill of biostabilised residual waste will generate significantly less landfill gas, and global warming impact from methane, than the landfill of residual waste that has not first been biostabilised, thus meeting the main objective of the ban.

## 1.2 Aim and approach

The project aims were to understand the potential role of biostabilisation as an approach for meeting the ban in Scotland, and to establish the carbon balance associated with MBT in Scotland.

From project inception, the approach utilised in this study was refined and developed in collaborative discussion with Zero Waste Scotland.

[5] IPCC Fifth Assessment Report
[6] https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-1990-2019/pages/3/

The high-level approach to fulfilling the project aims was to set out what biostabilisation of residual waste involves, to review how techniques have been implemented in Britain and selected EU countries and to undertake a carbon lifecycle assessment for the biostabilisation of residual waste. This information allows a summary to be made of factors, such as technical, economic, policy and environmental, that might influence the success, or otherwise, of MBT facilities in the Scottish context.

The main activities that were undertaken for this study are listed below.

- Identification of the methods of biostabilising residual waste, which all involve mechanical biological treatment (MBT) technologies, and their respective benefits and limitation, including in the context of the Scottish BMW landfill ban.
- Identification, through desk-based study and Ricardo knowledge, of how many MBT facilities exist in Britain and what processes are employed at each facility.
- Desk study review of how and why MBT has been employed in France, Spain, Italy and Germany, as countries that have an established track record in MBT development. This includes six case studies that were selected from a list of 28, in collaboration with Zero Waste Scotland to ensure coverage of a range of technologies and facility configurations. The main area of interest for this project is removal of recyclable materials and biostabilisation of the remaining residual waste, without RDF production, and with subsequent landfill of the biostabilised output. That is not a typical approach employed by MBT facilities and so the case study sites instead present a range of facility and output scenarios, with elements that might be applicable in the Scottish context.
- Undertaking of a carbon life cycle assessment for biostabilisation processes that could be employed in Scotland to meet the biostabilisation criteria for the landfill of residual waste. This includes processes with and without RDF production.

Some of the discussion in this report has been informed by the experiences of Ricardo staff, whether gained at Ricardo or not, that have collectively worked on many MBT facility projects in the UK. For confidentiality reasons, it is not possible to elaborate on where and when that experience was gained.

# 2 Policy and legislation in Scotland

## 2.1 Making Things Last: A Circular Economy Strategy for Scotland 2016[7]

Scotland's strategy focuses on four main areas: food and drink, remanufacture, construction, and energy infrastructure. It seeks to encourage circular business models across Scotland though funding and investment, such as hire and leasing systems and performance-service systems. As with the other circular economy strategies, there is also discussion of the need to reform producer responsibility and incentivise reuse and repair services. The drive of this strategy is to move resources up the waste hierarchy as much as possible, limiting the amount of residual waste produced.

The strategy sets out Scotland's waste targets, which include:

- A ban on biodegradable municipal waste going to landfill from 1 January 2021 (revised to 31 December 2025[8]).
- No more than 5% of all waste sent to landfill by 2025 (following the BMW to landfill ban).
- Reduce all food waste arisings in Scotland by 33% by 2025 and work with industry to reduce on-farm losses of edible produce.
- Reduce waste arisings by 15% against the 2011 baseline of 13.2 million tonnes by 2025.
- 70% recycling, composting and preparing for reuse of all waste by 2025.

The BMW landfill ban was revised from 2021 to 2025 due to '….*concerns that Scottish residual waste would be sent across the border to be landfilled in England, as some local authorities and commercial operators had not made sufficient progress towards complying with the ban*[8]'.

The implication of these waste targets is that Scotland's residual waste will continue to change in quantity and composition. The quantity of waste arising should reduce and an increase in composting and recycling will most likely involve increased source segregation and, therefore, less recyclable and organic materials within the residual waste stream.

If residual waste is to be biostabilised and subsequently landfilled without production of RDF, there may be an implication to the achievement of the target of not landfilling more than 5% of all waste. Where RDF is removed, it can typically comprise around half of the input residual waste. If residual waste is to be sent direct to EfW, the resultant bottom ash, much of which can be recycled, and air pollution control residue, will represent a lower mass of waste to be landfilled than by the biostabilisation and landfill approach to residual waste management.

## 2.2 Landfill tax

Landfill tax is a tax paid by landfill operators on the disposal of material at a landfill site[9]. The tax was introduced in 1996 to incentivise the diversion of waste from landfill and to promote waste reduction and recycling.

From April 2015, the Scottish Landfill Tax is being administered by Revenue Scotland and receipts/declarations are no longer included in HMRC figures.

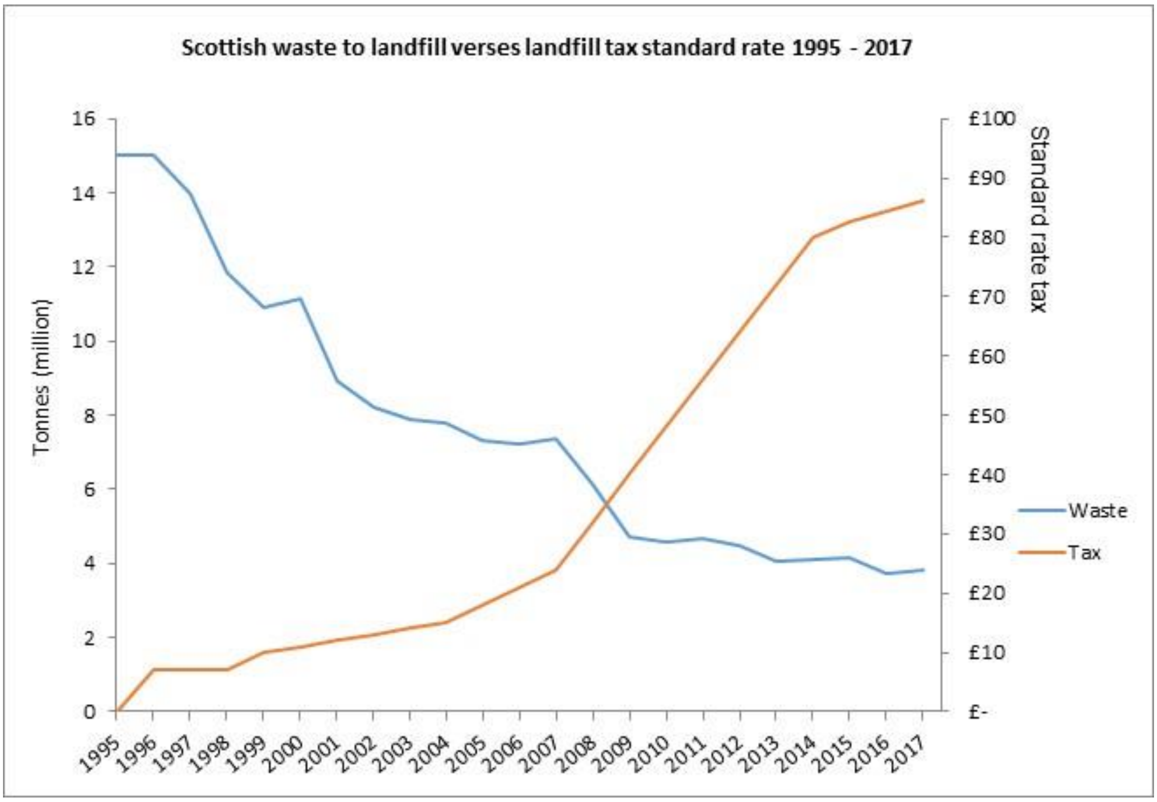
The tax is charged on a weight basis, but there are two rates depending on the type of waste. Non-hazardous and low-polluting waste, such as non-biodegradable wastes that have low organic content or do not break down under the anaerobic conditions that prevail in landfill sites to produce methane are charged at a lower rate, while all other taxable materials are charged with the standard rate. In 2021, the lower rate in Scotland was £3.10 per tonne and the standard rate was £96.70 per tonne[10].

[7] https://www.gov.scot/publications/making-things-last-circular-economy-strategy-scotland/pages/17/
[8] https://www.letsrecycle.com/news/latest-news/scotland-reluctantly-pushes-landfill-ban-to-2025/
[9] https://www.gov.uk/government/statistics/landfill-tax-bulletin/october-2020-commentary
[10] https://revenue.scot/taxes/scottish-landfill-tax/slft-rates-accounting-periods

Landfill tax has been a key factor in the changing of attitudes leading to the diversion of waste from landfill. As seen in Figure 1, the rate of landfill tax has been increasing since it was introduced, whilst the quantity of waste sent to landfill has reduced.

By diverting waste from landfill, the landfill tax has promoted other waste management routes, primarily incineration, and those other routes increased by 199% between 2011 and 2019[11].

Figure 1: The reduction of waste landfilled in Scotland against the rising landfill tax[12]




## 2.3 Compost and digestate standards

SEPA's 'Regulation of Outputs from Composting Processes'[13] specifies the requirements for the output from a composting process for it to cease to be waste.

In order for it to achieve product status and no longer be subject to waste regulatory controls, the treatment process and any compost produced must be certified to conform to the standards contained in BSI PAS100:2018 Specification for Composted Materials (Publicly Available Specification, PAS). In addition, there are 'Additional Scheme Rules for Scotland' that must be adhered to as well as limitations on plastic content that are more stringent than the PAS100 requirements.

Pertinently, the PAS100 Specification requires that input materials to the composting process shall be source segregated biowastes and/or source segregated biodegradable materials. This requirement means that outputs from the composting of residual waste cannot conform to PAS100 and must remain regulated as waste, which prevents opportunities for its use as a non-waste product. Other requirements preclude the use of sewage sludge or its derivatives and preclude the blending of outputs with other materials in order to meet the required quality criteria.

For similar reasons, the outputs of digestate from anaerobic digestion plants treating residual waste cannot conform to BSI PAS110:2014 (Specification for whole digestate, separated liquor and separated

[11] https://www.sepa.org.uk/media/527075/2019-waste-incinerated-commentary.pdf
[12] https://www.sepa.org.uk/regulations/waste/scottish-landfill-tax/
[13] https://www.sepa.org.uk/media/219843/wst-g-050-regulation-of-outputs-from-composting-processes.pdf

fibre derived from the anaerobic digestion of source-segregated biodegradable materials) and must remain regulated as waste.

## 2.4 Biostabilisation criteria

The forthcoming ban on the landfill of BMW is detailed within The Waste (Scotland) Regulations 2012 ('the Regulations'), which amends regulation 11 of The Landfill (Scotland) Regulations 2003 (the 'Landfill Regulations'). Regulation 11 is concerned with the prohibition of acceptance of certain wastes at landfill and the amendment adds biodegradable municipal waste to the wastes types to be prohibited. The date of prohibition is detailed as 1st January 2021, but that was subsequently amended to 31 December 2025. The amendment includes a definition of biodegradable municipal waste as follows:

> *For the purposes of this regulation, waste is–*
>
> *….*
>
> *""biodegradable municipal waste" if it consists of municipal waste that is also biodegradable waste, but does not include waste—*
>
> *(i) that is treated, and either—*
>
> > *(aa) respiration activity after a static respiration test is less than 10 milligrams of oxygen for each gram of dry material; or*
> >
> > *(bb) dynamic respiration over one hour is less than 1000 milligrams of oxygen for each kilogram of volatile solids;*
>
> *(ii) that is incinerated, and the total organic carbon content is less than 5%"*

As such, to landfill biodegradable municipal waste, it must either be incinerated and contain no more than the permissible level of organic carbon content, or it must be treated such that it meets the stability criteria under 'aa' or 'bb', i.e. through biostabilisation.

Biodegradable waste is defined in Regulation 2 (1) of the Landfill Regulations as follows:

> *"biodegradable waste" means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food, garden waste, paper and cardboard.*

SEPA Guidance[14] (WST-G-55, version 1, April 2018) provides more detail relating to the requirements of the Regulations:

> *BMW includes biodegradable household waste together with biodegradable waste which is similar to household waste such as, for example, waste from the retail and hospitality sectors. It includes residual ('black bag') waste and other mixed municipal wastes collected from households and commercial businesses coded as 20 03 01. In 2016, 1,223,587 tonnes of waste coded as 20 03 01 was landfilled in Scotland.*
>
> *BMW also includes sorting residues from processing mixed municipal waste often coded as 19 12 12. In 2016, 779,521 tonnes of 19 12 12 waste was landfilled in Scotland although not all of this was from municipal sources. It is important to distinguish between sorting residues from different sources so that sorting residues from BMW are not landfilled. Mixed sorting residues derived from sources which include municipal waste will be assumed to be wholly municipal waste for the purpose of the ban.*
>
> *….*
>
> *The Regulations provide two ways to demonstrate that treated BMW is no longer biodegradable and can, therefore, be landfilled. The tests set out in the Regulations are linked to two types of treatment – Mechanical Biological Treatment (MBT) and Incineration (Energy from Waste (EfW)).*

[14] https://www.sepa.org.uk/media/352595/sepa_bmw_landfill_ban_guidance_note.pdf

> *If the waste undergoes a mechanical biological treatment, any residues destined for landfill must achieve either;*
>
> *• a Respiration Activity after four days (AT4) below 10 mg $O_2$/g dm; or*
>
> *• a Dynamic Respiration Index below 1,000 mg $O_2$/kg VS/h*
>
> *If the waste is incinerated, any residues destined for landfill must achieve a Total Organic Carbon value of less than 5%.*

The amended Landfill Regulations mean that when municipal waste that is biodegradable is treated to meet the required criteria it is not then, for the purposes of the regulations, '*biodegradable municipal waste*'. That means that the waste is not '*capable of undergoing anaerobic or aerobic decomposition*'.

From a technical perspective, that waste treated to such levels exhibits respiratory activity when tested in a laboratory implies that it is undergoing decomposition. However, such treated waste will be more stable compared to untreated BMW. Waste being subject to MBT processes, or if it is landfilled, degrades exponentially and so a substantial increase in stability can be achieved in a short period of time relative to the period required for full decomposition.

Although the landfill ban criteria relate to the landfill of treated waste and not to the application of material to land, it is useful to consider criteria for the application to land to provide context.

- In a 2014 EC Joint Research Centre (JRC) report[15], the following limits were proposed as potential end of waste stability criteria (numbers and units changed to equate to the Scottish ban units):
  - ≤ 800 mg $O_2$/kg VS/h (for compost)
  - ≤ 1,600 mg $O_2$/kg VS/h (for digestate)

  The proposed stability criteria are part of wider proposed end of waste criteria, and are proposed '*to protect the market against insufficiently treated materials which may cause adverse environmental impacts during storage, transportation and application….A minimum stability should avoid unwanted emissions during transport and storage and prevent materials from entering the market without proper treatment*'.
- A 2015 EC commission decision[16] is concerned with '*establishing the ecological criteria for the award of the EU Ecolabel for growing media, soil improvers and mulch*' and contains the following provisions for stability (numbers and units changed to equate to the Scottish ban units):
  - Stability requirements of soil improvers and mulch intended for non-professional applications and growing media intended for all applications: ≤ 480 mg $O_2$/kg VS/h
  - Stability requirements of soil improvers and mulch intended for professional applications: ≤ 800 mg $O_2$/kg VS/h

The EU Ecolabel criteria were proposed in a 2015 JRC report[17], which notes that the proposed limit for professional applications is based upon the 2014 JRC report on end of waste. The report also refers to the end of waste stability limit for digestate, albeit that does not feature in the Commission Decision. The report notes:

> *The minimum stability for professional uses proposed in the EU Ecolabel criterion is meant to ensure a sufficient level of stability, while preventing the introduction of materials that have hardly undergone any treatment (e.g. so-called "shred-and-spread" compost), despite the fact that these untreated materials might be used in agriculture. The figure proposed ensures that the materials were processed to get a reasonable level of stabilization by means of aerobic stabilization. In the case of digestates, a post-composting process would be needed, to overcome the market barriers identified and to improve the perception of the waste-derived products. This aims to avoiding methane and odour emissions, while it suffices to comply with*

[15] End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals, JRC scientific and policy reports, European Commission, 2014

[16] Commission decision (EU) 2015/2099 of 18 November 2015

[17] Revision of the EU Ecolabel Criteria for Soil Improvers and Growing Media, Technical report and draft criteria proposal, JRC scientific and policy reports, European Commission, 2015

*the market expectations for professional purposes, which often use active compost, for soil improvers or mulch, according to the feedback received from the stakeholder.*

The 2015 JRC report quotes work undertaken by others[18] in which proposals are put forward for categorisation of compost product stability for biowaste and green waste compost. The categorisation is copied as Table 1.

Table 1. Proposals for categories of compost stabilisation (2015 JRC report)

| Category of compost product | Oxygen uptake rate (mg $O_2$/kg VS/h) |
|---|---|
| Very unstable | > 960 |
| Unstable | 480 – 960 |
| Stable | 160 – 480 |
| Very stable | < 160 |

Whilst some of the values discussed above are below the Scottish ban criteria, i.e. more stringent, the Scottish ban criteria is for treated BMW to be disposed to landfill and represents significant improvement in stability compared to untreated BMW. The EU Ecolabel and end of waste values illustrate that BMW treated to the Scottish ban limits will still generate some landfill gas when landfilled.

The generation of landfill gas from the landfill of biostabilised MSW has been considered in the carbon lifecycle assessment (carbon LCA) undertaken for this study.

[18] Veeken A.H.M., de Wilde V., Hamelers H.V.M., Moolenar S.W. and Postma R. (2003) OxiTop measuring system for standardised determination of the respiration rate and N-mineralisation rate of organic matter in waste material, compost and soil. Wageningen University, Netherlands.

# 3 Mechanical biological treatment and biostabilisation

## 3.1 Overview of MBT processes

As the name suggests, MBT is the treatment of waste by both mechanical and biological means. Biological treatment of waste degrades the organic compounds within it, meaning that if it is then landfilled it will generate less landfill gas than it would have without treatment. The more organic material that is degraded, the more stable the waste becomes, and the less landfill gas will be generated if the waste is subsequently landfilled. The biostabilisation of residual waste takes place in a controlled manner in an MBT facility.

Whilst treatment of source segregated food waste at an anaerobic digestion facility, or an in-vessel composting facility, involves both mechanical and biological processing, such a facility is not referred to as an 'MBT' facility. Instead, MBT processes typically refer to the treatment of whole 'black bag' or residual waste of domestic or commercial origin and there are typically several main material output streams (see section 3.5).

The biological process employed at an MBT facility most commonly involves one or more of the following:

- In-vessel composting (IVC).
- Biological drying (Biodrying).
- Anaerobic digestion (AD).

In some instances, such as at the Glasgow Recycling and Renewable Energy Centre, MBT facilities are integral to a thermal treatment processes, i.e. incineration or gasification (gasification is utilised in Glasgow).

In most instances, other than for biodrying, the biological process is preceded by a mechanical pre-treatment process.

## 3.2 Mechanical pre-treatment processes

An MBT process typically commences with the removal of contaminants, RDF and recyclable materials and size reduction. Contaminants may include items that might damage equipment, such as hazardous or oversize waste, grit, and materials unsuitable for recycling or energy recovery. Manual sorting by operatives sometimes accompanies the mechanical processing stages.

A greater degree of mechanical pre-treatment tends to take place at MBT wet-AD facilities (see section 3.3.3). However, metal recovery and size reduction, as a minimum, are found at the majority of MBT facilities.

Obtaining the best quality RDF, recyclable material or organic fraction for subsequent biological processing can require extensive mechanical processing, entailing high capital and operational expenditure. MBT facility pre-treatment processes can be relatively complex and can require a lot of effort to clean and maintain and a lot of power to operate. With knowledge of the composition and quality of the input waste, a decision must be made about what level of performance is desired and whether a high level of performance is worth the investment required. Potential future changes in waste composition must also be considered, although unless a planned change is known about, predicting future composition will produce uncertain results.

The impact of input waste composition not only influences the quality of outputs, but it can also influence facility throughput, and blockage and downtime events. As the input waste is separated by equipment into what can be numerous separate and interconnecting processing lines, the composition affects the amount of waste on each line and its bulk density. As waste composition changes over time, bottlenecks in the process may appear, subject to the equipment size margin employed at facility design.

The more waste is processed into different fractions, the greater the potential for loss of small fraction organic material to the other output streams, i.e. to RDF, recyclable materials and 'rejects' sent to landfill. However, the more the residual waste is processed, the better the quality of the different output material streams.

Municipal residual waste is, by definition, what remains when materials of greatest value are separated at source and, therefore, it is a relatively poor-quality waste stream. Whilst some recyclable materials and organic waste will be present, it will be of lower quality than would be expected if it was source separated. Food and liquids present will soak into paper, card and textiles and adhere to them and all wastes will be intermixed and require separation, which cannot be realistically achieved with absolute success.

Whatever form of residual waste treatment is employed, wherever practicable, source segregation of materials and waste minimisation should be the priority.

A large proportion, often around half, of residual waste can comprise materials suitable for use as RDF. This is likely to include a lot of materials, such as mixed plastic film, which has a low potential to be recycled. Therefore, RDF production is common at many MBT facilities.

Metals are relatively easy to remove and generally attract a revenue.

Size reduction aids material handling and homogeneity.

Where input waste, or output digestate, requires pasteurising, or other heat treatment such as pressure sterilisation, prior size reduction is also necessary to comply with animal by-product legislation. Whether such heat treatment is necessary, depends upon the intended use of the facility's organic stream output material. If the intention is for it to be landfilled or incinerated, heat treatment is not normally required. Owing to different temperatures achieved in the biological process, the particle size requirements are different for IVC than for AD.

Residual waste that is processed in an MBT facility, prior to being landfilled, should not require pasteurising or pressure sterilisation, because it will not become exposed to the food chain when landfilled.

The design of an MBT facility can vary significantly subject to the nature of the waste being processed, the desired facility outputs and simply because there are many ways of achieving the same result.

A wide range of equipment and configurations are available. Mechanical pre-treatment equipment commonly found at residual waste MBT facilities is described in Appendix A1.

## 3.3 Biological processes

### 3.3.1 IVC

Composting is where aerobic microorganisms in the environment, and present on the organic matter, utilise oxygen present in air to oxidise organic matter, and in so doing generate carbon dioxide, water, heat and compost. The process degrades and stabilises the waste.

Where organic materials from residual waste are processed, the composted material is often called 'compost like output' (CLO), in recognition of its poorer quality compared to compost from source segregated organics. The term CLO is generally only used when the stabilised waste is refined to remove physical contaminants prior to land application, e.g. for land restoration.

In industrial composting processes, methods are employed to optimise conditions to allow efficient composting. Such processes fall into two main categories, outdoor open windrow composting and IVC. Within Europe, including the UK, IVC is the only composting process used to treat organic materials separated from residual waste, as IVC processes are contained processes that can be managed to meet the requirements of animal by-product legislation. There are many forms of IVC technology from small-scale packaged units to largescale processes undertaken within buildings.

The active phase of composting, during which temperatures are thermophilic (around 50 to 70°C), typically takes around 6 to 12 weeks and most of the degradation of organic material takes place in that time. When conditions are optimised, the temperature rises quickly in the early stages of active composting.

Many composting processes are followed by a period of maturation, during which active management of the process is minimal. Generally, limited active air input and no water are added, and only occasional turning takes place. During maturation, the temperature and rate of degradation gradually reduce, and the compost becomes ‘matured’. Matured compost has a greater level of biostability than un-matured compost.

Composting duration is dependent upon the type of organic matter being composted, the design of the process, the operating conditions and the intended use of the compost.

Effective composting requires a careful balance of carbon and nitrogen within the waste feedstock and the presence of ‘structure’ materials within the waste mass, for example twigs and branches within green waste. Besides potentially compromising the biological process, a sub-optimal balance between carbon and nitrogen can cause odour issues. A feedstock with poor structure does not allow adequate air flow and can give rise to anaerobic zones within the waste mass, especially in liquid saturated zones.

Source segregated food waste generally has a high nitrogen content and poor structure, with high moisture content and a slop-like consistency. IVC of such feedstock typically requires addition of higher carbon content, higher structure materials such as green waste, woodchip or cardboard. However, organic feedstock separated from residual waste in an MBT-IVC facility typically has a lower moisture content, higher carbon content, principally resulting from paper and card, and improved structure due to the presence of plastics etc, when compared to source segregated food waste. There are examples, including in the UK, of the IVC of such residual waste organic feedstock without the addition of other materials.

Composting does not generate any usable energy and the heat generated typically rises to around 60 to 70$^{o}$C, which over a sustained period (e.g. one week at >60$^{o}$C) will beneficially kill pathogens and seeds.

With careful design and optimised operation, it is possible for residual waste to achieve the required Scottish biostabilisation criteria when treated in this way (see section 2.4 for criteria).

With enough retention time in the process and with appropriate control of operating conditions, the biological process will continue until such time as the organic material present is insufficient to sustain the process further. An MBT facility must be designed to allow the required retention time and conditions necessary to meet the required level of biostabilisation.

The end of waste criteria, and compost stability criteria, described in section 2.4 show that composting processes can biostabilise to a greater extent than necessary for the Scottish BMW landfill ban. Furthermore, Ricardo corresponded with two technology providers that confirmed that their processes can be designed to achieve the Scottish biostabilisation criteria.

### 3.3.2 Biodrying

Biodrying is a biological process with similarities to IVC, but the process is aimed at moisture reduction rather than biostabilisation.

Biodrying involves forced airflow through the waste mass, but no water is added, and the process typically takes only one to two weeks. The composting process commences during this time and the waste temperature rises, which, along with the air flow, drives off moisture. However, degradation of organic material will be limited over such a short time and a humus like composted material will not be produced.

Biodrying is often undertaken with a view to increasing the calorific value of the MSW for its use as RDF/SRF.

If undertaken prior to separation of waste components, as is common, biodrying can improve separation performance and recyclate quality as dry waste is less cohesive than wet waste.

Biodrying does not biostabilise organic components of residual waste to a level that would meet the requirements that would allow subsequent landfill of residual waste in Scotland from 2025 onwards.

### 3.3.3 Anaerobic digestion

The biological process in AD is very different to composting and utilises different microbes under very different environmental conditions, notably the absence of air. In AD, plant and animal organic matter is decomposed by microorganisms in the absence of air, to produce a methane-rich biogas and a solid or liquid known as digestate.

The main constituent gases present in biogas are methane (typically 50 to 60%) and carbon dioxide (typically 40 to 50%), with other gases generally only present at concentrations around 1 to 2%.

Industrial waste management AD can be undertaken using a wide variety of technology designs and variants. One fundamental consideration is whether the process is a wet or dry process.

In wastewater treatment, very low dry matter (e.g. 0.5% DM) feedstock can be treated in AD. Dry matter is the amount of solid material within the waste, measured with laboratory oven drying. However, where feedstocks are solid, perhaps with DM in the range of 35% up to 55%, reflecting source segregated food waste and residual waste organic fines respectively, they can be digested with (wet AD) or without (dry AD) addition of water or liquid waste.

Solid waste wet AD processes typically involve preparing a substrate to be input to the digesters (tanks where the AD process takes place) within the 5 to 15% DM range (a material with a DM of 15% contains 85% moisture). Above 15%/20% DM the process should be considered dry AD, which is a process that is designed and operated in a different manner to wet AD.

In Britain, wet AD is more commonplace than dry AD, although dry AD processes do exist. In continental Europe, dry AD is utilised more than in the UK, often at agricultural AD plants.

As water, or liquid waste, is often added to feedstocks to prepare them for wet-AD, the AD feedstock increases in volume, requiring larger digesters and greater heat input where pasteurisation is undertaken and for maintaining digester temperature at optimum levels (typically 37 to 40$^{o}$C for mesophilic processes and 50 to 55$^{o}$C for thermophilic processes[19]). However, the advantages are that wet AD digesters are relatively easy to mix and substrate and digestate transport through pumps and pipework is relatively straight forward. Mixing of wet-AD is necessary to prevent stratification of tank contents, into floating and settling material, and serves to distribute microorganisms and organic material throughout the digester.

The biological process in AD is more sensitive to disruption than composting. The process takes longer to establish and a sudden change in feedstock type or quantity, the presence of two incompatible feedstocks or a change in environmental conditions within the digester, can easily cause problems and slow down and hinder the biological process. A disrupted AD process can take a while to recover. In the worst case, an AD process will need to be restarted from scratch, which may take around three months, subject to feedstock type and size of the digesters. This period must not be confused with the normal retention time of substrate within the digester.

Substrate retention time, in normal operation, will vary subject to the size of the digesters and facility throughput, because increasing the rate of waste feedstock input requires taking more digestate out. Furthermore, different feedstock types require different retention periods for the organic material to break-down. The facility design, especially the size of the digesters, must be matched to the type of feedstock and volume throughput of the facility. A wet-AD process will typically have a retention time of between 20 and 60 days. Retention time is a consideration that affects the size of plant, whether AD or IVC, but is not a critical factor to consider when comparing the relative merits of technologies.

In contrast, composting processes will be initiated within a day and the process is far less susceptible to disruption.

Conditions should be maintained as near optimum and steady as possible, unless a dry batch AD process is employed. This is because dry batch AD involves processing waste in batches, such that conditions do not remain constant with time. In most instances other than dry batch AD, feedstock is input on a 'little and often' basis and digestate is removed in a similar manner such that digester

[19] Mesophilic and thermophilic are terms used to describe bacteria that grow and thrive within certain temperature bands.

contents remain at broadly steady volume. This manner of operation does, however, mean that AD does not biostabilise feedstocks to such a level as can be achieved with IVC. That is because leaving the substrate in the digester to exhaust as much of the organic matter as possible would lead to microorganism stress and harm to the biological process. A greater degree of degradation might be possible with batch dry-AD processes, although batch processes are less suitable for high throughput facilities and are less efficient at producing biogas.

If AD is utilised, then it must be followed by IVC in order to achieve the level of biostabilisation necessary for it to be landfilled in Scotland. That is more problematic for digestate from wet AD than for digestate from dry AD, as explained below.

In an MBT-wet AD process, the organic substrate entering the digester must be as free as possible from contaminant materials such as grit and plastics, both of which can sink and float in the digester, and cause blockage and wear of pumps and pipework. These materials must be removed to a high level during dry and wet processing of the feedstock prior to entering the AD process. Where residual waste is processed, it is typical for much of the material removed to be utilised as RDF. The digestate exits with a low DM as a liquid, which is often separated out into a liquid fraction that can be treated for reuse in the process, and a solid cake, which can be further dried. The digestate cake has no structure and must be mixed with structural material for it to be processed in IVC.

The need to remove a large portion of the residual waste prior to wet AD, followed by the need to dewater and mix the digestate cake with a waste with more structure, e.g. green waste, means that wet AD is not a desirable technique to biostabilise waste prior to landfill.

In dry AD there is no need to remove material to such an extent prior to AD. In batch dry-AD processes, there is no need to remove any material. However, batch AD is not well suited to high capacity facilities and the process is less efficient than semi-continuous flow dry-AD. In semi-continuous flow dry-AD, there is a requirement to first remove RDF type materials to minimise contaminants, thus allowing better material handling, but it is not necessary to remove as much material as is necessary for wet-AD. The resultant digestate, which is relatively high in DM, will have much more structure than digestate from a wet AD process.

Dry-AD followed by IVC could potentially be used to biostabilise residual waste prior to it being landfilled, although the residual waste would need to be pre-treated to first remove RDF type materials.

The advantage that dry AD followed by IVC, versus IVC only, brings is that it produces biogas, which can be utilised as a fuel from which energy can be gained. That energy can be used to support facility operation and potentially for third party offsite use. The energy produced will be from a biogenic source and will potentially prevent or minimise use of energy from other sources, which may include some fossil-based carbon burning.

The disadvantage of dry-AD followed by IVC, versus IVC only, is that it adds to facility complexity, capital costs and maintenance demands and a facility needs to be designed to suit the quantity of organic material within the residual waste. If the organic content then reduces, for example due to the introduction of source segregation of domestic food waste, the financial viability of dry AD may then be compromised. Any waste facility needs to be designed around the intended input waste quantity and composition. However, the biogas and energy produced in an AD process is a key parameter in the facility energy balance and financial model and, therefore, contract/ performance expectations.

That an AD facility generates methane should not be viewed negatively from a carbon balance perspective. The subsequent combustion of the biogas or biomethane will result in carbon dioxide emission and AD facilities are designed to contain biogas and prevent air ingress. However, it is possible for an AD facility to emit methane to the environment in the following circumstances:

- Tanks containing biogas are fitted with pressure relief valves, which can emit biogas at times of undesirable high pressure within the tank headspace. This is a safety feature and pressure instrumentation on the tanks will identify that such an event has taken place. An operator should identify the cause of the over-pressure incident and should resolve it. Such emissions should be limited in frequency and quantity of gas escape such that they are negligible in environmental impact.

- Gas pipework and points where features, such as instrumentation, mixers and hatches, penetrate or attach to the digester can be sources of leaks. Such leaks might be evident from pressure records and should be identifiable during daily inspection activities. Biogas is odorous and corrosive, both of which can allow identification of even a small leak.
- A sudden loss of biogas can occur in the event of damage to a tank, gas holder or pipework. Such an event will be immediately evident to the operator who should take immediate measures to rectify the problem.

Biogas is a valuable fuel and its release can have safety implications, noting that it is both an asphyxiant and explosive gas when present in air at specific concentrations. Whilst biogas might escape in certain circumstances, as described above, it is an operator's interest to investigate and remedy such an event as an immediate priority. From an environmental impact perspective, emissions of methane from an AD facility should generally be negligible. The largest routine source of methane emission should be from engine exhausts (typically 99% methane destruction efficiency) or from 'methane slip' in the biomethane production process (this term and the treatment and use of biogas is discussed in section 3.5).

A summary of the comparison of dry and wet AD processes is provided in Table 2.

Table 2. Comparison of dry AD and wet AD

| Aspect | Dry AD | Wet AD |
|---|---|---|
| Ability to meet Scotland's landfill ban biostabilisation criteria | Criteria can be met because the digestate has enough structure for subsequent treatment by IVC. | Low likelihood of suitability because the digestate would need to be dewatered and mixed with other materials to allow treatment in IVC in order to meet the criteria.<br><br><u>This is the main factor making wet AD a contender of low interest if the intention is to biostabilise waste prior to landfill.</u> |
| Extent of waste pre-treatment required (in addition to removal of recyclable materials) | Batch AD should require very little pre-treatment.<br><br>Semi-continuous dry AD requires some removal of non-organic materials ('contaminants'- maximum level of contaminants in waste entering the digesters should be around 20% w/w), most commonly as RDF. | Requires a very high level of contaminant removal in pre-treatment. This is a significant disadvantage versus semi-continuous dry AD. |
| Ability to deal with high throughput of waste | <u>Batch dry AD is not well suited to high throughput facilities.</u> Although possible, it requires multiple reactors to prevent fluctuations in volumes of biogas production. Batch dry AD also requires considerable operator intervention to fill and empty reactors.<br><br>Semi-continuous dry AD is suitable for high waste throughput. | Wet AD is suitable for high waste throughput. |

| Aspect | Dry AD | Wet AD |
|---|---|---|
| Ability to produce biogas (biogenic source of energy production) | Produces biogas.<br>Unlike batch dry-AD, semi-continuous dry AD produces biogas more efficiently and with a more stable output. | Produces biogas.<br>Produces biogas more efficiently than dry-AD because conditions (mixed state and temperature) are easier to control. |
| Ease of management | Harder to transfer and mix substrate and digestate than wet AD. | Greater ease of substrate and digestate handling than dry AD and with greater ease of maintaining optimal process conditions. |
| Main differences | Little or no water addition and little or no post AD digestate treatment (excluding the necessary IVC process) required.<br>Requires a lower footprint area than wet AD and less pre-treatment (wet AD requires solid feedstock to be prepared into a homogenous slurry) | The opposite to what is stated for dry AD. |

## 3.4 Facility flexibility

MBT is sometimes promoted by technology providers and waste management companies as being flexible to change in input waste composition. Certainly, a facility should be designed with some flexibility, but there are inherent limitations to that flexibility.

A Zero Waste Europe report[20] claims that an MRBT facility (material recovery and biological treatment) is '*inherently flexible*' since its processes may also be used for clean materials derived from separate collection. In this regard, the report refers to organic waste as well as different metals, different polymers and different paper grades. The report claims that MBT facilities that produce RDF cannot be adapted to process such clean materials.

The main distinction Zero Waste Europe makes between an MBT facility and an MRBT facility is that the latter does not generate RDF and is geared towards recovery of recyclable materials from residual waste, with biostabilisation of the remaining fraction prior to its landfill. It claims intensive use of equipment can allow recovery of very high percentages of recyclable material, albeit it acknowledges that the quality of recovered material will not be the same as for source segregated recyclable materials.

The Zero Waste Europe report references the possible use of plastic extruders for making low grade mixed polymer pellets. These are not typically found at MBT facilities. Extrusion of mixed polymers, bound to contain contaminants when sourced from residual waste, and making products from the resulting pellets, is a difficult process that often produces a low-grade product.

Ricardo disagrees with Zero Waste Europe's statements on facility flexibility, for the reasons listed below.

- If an MBT facility produces RDF, it does not mean that it cannot remove recyclable materials as well. There are examples of this amongst Britain's MBT facilities, and in two of the case studies discussed later in this report (both in Spain).

[20] Building a bridge strategy for residual waste- Material Recovery and Biological Treatment to manage residual waste within a circular economy- Policy Briefing, June 2020, Zero Waste Europe

- Whether or not an MBT facility produces RDF, a facility cannot simply be switched from processing residual waste to the processing of source segregated waste streams without considerable modification or process replacement. Residual waste and different source segregated waste streams have very different properties. Irrespective of the capacity of the main items of equipment, storage bays and conveyors would have to be of a size capable of handling different materials, and that is unlikely to be the case.

## 3.5 MBT outputs

Outputs from MBT facilities can include:

- Recyclable materials (wide range possible).
- A refuse derived fuel (RDF) or solid recovered fuel (SRF).
- Contaminants separated, that are unsuitable for the process, or cannot be recovered as a fuel or recycled and so must be landfilled.
- Processed organic material.
- Biogas or biomethane (AD only), and possibly heat and power generated from the gas.

Residual waste, input to an MBT facility, mostly contains materials for which there are no specific source segregation collection methods in place. It will, nonetheless, contain some materials for which there are other arrangements because source segregation measures are not always utilised correctly or by all service users.

Recyclable materials separated from residual waste are typically of low quality. In simple MBT processes, the only recyclables removed might be ferrous and non-ferrous metals, but all materials in MSW that are commonly recycled can be recovered in MBT processes.

- Food and drink waste, and other liquid waste, will adhere to and soak into other materials within the waste stream. That hinders the separation of food waste and reduces the quality of other materials streams.
- No separation process is perfect and non-target materials will be entrained and removed with target materials, and some target material will evade capture.
- The lower the proportion of a target material within residual waste, the harder it is to remove that material on a percentage recovered basis. Put another way, it is generally easier to recover 90% of a material that comprises a large portion of the input waste than to recover 90% of a material that comprises a small proportion of the input waste.
- To capture a large percentage of a material can sometimes require setting of equipment to ‘over recover’, wherein a high amount of the material is removed but, in so doing, a large amount of non-target material is also removed, which impacts quality. It is possible, for example, to over recover a greater mass of non-ferrous metal and contaminants than there is non-ferrous metal present within the incoming residual waste.
- If the operator’s priority is to recover material of high quality, it might have to set equipment to under-recover, wherein some of the target material remains uncaptured but the captured material is of reasonable quality.

In a similar manner, separating organic material from residual waste is more problematic when it is only present at low levels, and quality can be poor in such instances.

Processed organic material can be managed in several ways. The output from IVC processes is sometimes known as compost like output (CLO), stabilised organic material (SOM) and ‘stabilite’ is a term commonly used in continental Europe. The output from AD processes is known as digestate.

As it is not from a segregated source, CLO or digestate cannot comply with the requirements of PAS100 (publicly available specification for composted materials) or PAS110 (publicly available specification for whole digestate, separated liquor and separated fibre derived from anaerobic digestion), nor the Quality Protocols employed in England, Wales and Northern Ireland or the Additional Scheme Rules for Scotland. As such, it remains a waste following treatment and subject to continued regulation as a waste. Due to the quality of CLO and its regulation as waste, there is effectively no possibility for it to be utilised in agriculture where food production is involved.

For CLO or digestate to be applied to other (non-food production) land, where it is used in place of non-waste material to perform a particular function i.e. for land restoration purposes, regulator approval is required in each case to ensure that the waste recovery test is met for each particular scheme. This poses a problem for operators because MBT facilities are typically constructed with a 25-year life, and each land restoration project will have limited demand for the CLO or digestate. The experience of UK MBT operators has been one of difficulty finding such outlets for digestate and CLO, and sometimes difficulty in securing approval from the regulator.

- IVC output and dried digestate can be used as an RDF, used as landfill daily cover, landfill restoration layers or it can simply be landfilled.
- With regulator approval, CLO can be used for land reclamation, but not on land used for food production.
- Wet AD digestate can be dewatered with water treatment and water reuse or disposal. The solid cake can be used in a similar manner to CLO.
- Dry AD digestate can be subject to IVC processing to further biostabilise it. It can be used in a similar manner to CLO and wet digestate.

Biogas is commonly combusted on site, to produce heat and electricity, often in combined heat and power (CHP) engines or upgraded on site to biomethane. Biomethane has properties like natural gas, and can be injected to the mains gas network, compressed and used as a vehicle fuel or it can be compressed and transported by road.

Biomethane production has become increasingly popular at UK AD facilities in recent years. Upgrading biogas to biomethane can be undertaken using several processes, and the main process stage is the removal of other gases, the greatest of which in percentage terms is carbon dioxide ($CO_2$). The stripped $CO_2$ is often vented to atmosphere, but there are some examples of it being captured, purified and bottled for industrial use, albeit not at British MBT facilities.

The overwhelming majority of MBT facilities in the UK and continental Europe generate RDF/ SRF, which can be a significant portion of the total of all output materials, often around 50%. Both RDF and SRF can be subject to conventional incineration or advanced thermal technologies such as gasification. SRF is a more consistent and higher quality RDF and is often used at cement kilns.

# 4 British MBT facilities

## 4.1 Data reviewed

Ricardo identified existing British MBT facilities utilising its in-house facilities database (FALCON) and through internet research and review of waste return data for 2019, to establish information for each MBT facility. Much of the information discussed below reflects the situation with British MBT facilities in 2019, and some change may have occurred since then.

For each facility, Ricardo sought to establish whether it utilises biodrying, IVC, dry AD or wet AD as the biological stage of the MBT process and to determine whether RDF is produced.

Where waste returns data is discussed, it should be borne in mind that:

- Some sites report sitewide data rather than data at a process by process level, which means the data will not always accurately reflect outputs from the MBT facility. Many sites are integrated facilities that might, for example, include household waste recycling centres (HWRC), composting of source segregated organics, residual waste MBT etc. However, where the data and internet review indicate that an MBT process involves production of RDF/SRF, this is detailed within the discussion in this report.
- There is generally a difference in input and output tonnages that is due to process loss, principally the result of moisture loss and breakdown of organic material, but it can also reflect an onsite landfill or onsite incineration/gasification process. Where percentage outputs are detailed (Appendix A2), they reflect the percentage of all solid material outputs, i.e. no account is taken for process loss or onsite thermal treatment or landfill.
- Waste returns data obtained from Waste Data Interrogator[21] describes the fate of facility outputs as one of the following:
    - Incinerator[22]
    - Landfill
    - Recovery
    - Transfer (typically a small amount of total waste outputs from a facility)
    - Treatment (typically a small amount of total waste outputs from a facility)

  'Recovery' mostly refers to materials separated for recycling and outputs from biological processes (AD and composting) that qualify as 'recovery' (not likely in relation to biological processing of residual waste). In the context of Waste Data Interrogator, the term 'recovery' should not be confused with 'energy recovery', which in many other contexts is often simply called 'recovery'. However, it is evident that some operators, on occasion, include RDF in the 'recovery' category when submitting waste returns. The tonnages are comparatively low compared to the RDF included under 'Incineration'. Waste returns are not always submitted in correct or consistent form, but anomalies are not significant for the purposes of this report.
- Waste return data may not reflect 'normal' operation in instances where facility operation is disrupted such that waste is not processed in the normal manner. A snapshot (for 2019) has been presented.

Even with consideration to the above points, the data is useful in informing whether RDF is produced within the MBT process and to show the typical split in solid outputs.

## 4.2 Scottish MBT facilities

Scotland has two MBT facilities, which are the Glasgow Recycling and Renewable Energy Centre (GRREC) and Lochar Moss in Dumfries and Galloway.

At GRREC, mechanical processing is followed by wet AD (BTA international GmbH technology) and a gasification (Energos energy from waste) process is integrated with the residual waste MBT process.

[21] https://data.gov.uk/dataset/d409b2ba-796c-4436-82c7-eb1831a9ef25/2019-waste-data-interrogator
[22] In frequency and tonnage, this mostly refers to 'R1' recovery, but also includes some 'D10' disposal operations (codes from the EU Waste Framework Directive).

As such, the MBT facility is RDF and wet-AD focussed and, therefore, cannot biostabilise waste such that it could be landfilled following the 2025 ban. However, the process avoids the landfilling of BMW and so, assuming its waste is processed in the facility as intended and the total organic carbon in the ash is below the required limit, waste processed at the facility will be able to comply with the requirements of the biodegradable waste landfill ban.

The Lochar Moss facility is a biodrying/RDF facility (Ecodeco technology). Waste return data for 2019 shows that the single largest output fraction was RDF. Whilst the facility may potentially be able to meet the requirements of the ban, it will not do so by biostabilisation, as the MBT process employed is biodrying and RDF production.

There are three facilities in Argyll and Bute which some sources, including documents from Argyll and Bute council, describe as MBT. These facilities are Dalinlongart, Lingerton and Moleigh. However, it appears[23] that these facilities comprise landfill, HWRC, composting (non-residual) and transfer station i.e. not residual waste MBT. Waste return data for 2019 also supports that position.

Argyll and Bute Council is considering how to address the forthcoming ban on landfill of BMW and the operator of the above mentioned facilities (Renewi- under a public-private partnership, PPP, arrangement) has proposed replacing the facilities with MBT-IVC, with RDF production, as an option (with assumed 60% RDF production and 40% treated in IVC)[24]. The strategy for the council addressing the ban was still under development towards the end of 2020 although the MBT-IVC solution remained a key consideration, as was a ‘Total Transfer Solution’[25].

Avondale Landfill (Falkirk) is home to an RDF production plant (material recovery facility- MRF), which opened in 2012 and then shut shortly afterwards, owing to financial considerations and is understood to now be operational again[26]. Around 2007 there was talk of the construction of an MBT facility on the site[27], although it is understood that did not progress further.

## 4.3 Welsh MBT facilities

Wales has one MBT facility, which is a biodrying facility that was commissioned in 2015 and is known as Wrexham Recycling Park (Phase 2)[28].

Waste return data for 2019 shows material outputs as comprising 81% destined for incineration and 19% destined for recovery, i.e. recycling.

## 4.4 English MBT facilities

Twenty MBT facilities have been identified in England and the split between organic processing type is detailed below.

- 6 Biodrying (all produce RDF/SRF)
- 8 Wet AD (all produce RDF/SRF in pre-treatment mechanical processing)
- 1 Dry AD with IVC (produces RDF)
- 5 IVC (four out of the five produced RDF in 2019)

The only English MBT facility that does not produce RDF is the Waterbeach MBT-IVC facility in Cambridgeshire, which is operated by AmeyCespa (East) Limited (Amey).

Waste return data shows that the composted output from the Waterbeach facility was landfilled in 2019. However, Amey is keen to develop an energy from waste facility at the site. A planning appeal for the energy from waste facility was rejected in June 2020[29].

[23] https://www.sepa.org.uk/media/286895/waste_sites_capacity_2015.xlsx
[24] https://www.argyll-bute.gov.uk/sites/default/files/draft_waste_strategy_document.pdf
[25] https://www.argyll-bute.gov.uk/moderngov/documents/s166133/Waste%20Management%20Strategy%20Update.pdf
[26] http://www.avondalelandfill.co.uk/
[27] https://www.letsrecycle.com/news/latest-news/18m-mbt-plant-set-for-scotland/?nowprocket=1
[28] https://www.fccenvironment.co.uk/wrexham/recycling-park-phase-2/
[29] https://www.letsrecycle.com/news/latest-news/planning-inspectorate-rejects-ameys-waterbeach-efw/

The authors of this report have not established what level of biostabilisation is being achieved at the Waterbeach facility, which will be influenced by the waste input, the facility design and manner of operation. IVC technology can, subject to design and operation, achieve a level of biostabilisation that can meet the criteria associated with the forthcoming landfill ban in Scotland, but that criteria does not exist in England.

Details for the English MBT facilities, including 2019 waste return summary data for outputs, are provided in Appendix A2. A small number of the facilities are residual waste MRF only, as the organic fraction is sent to a biological processing facility operated by the same organisation but on another site. Where that is known to be the case, it is mentioned in Appendix A2 but still classed as an MBT facility, as the overall process is MBT, even if not undertaken at one site.

## 4.5 Britain’s experience with MBT

Some of the discussion below has been informed by the experiences of Ricardo staff, whether gained at Ricardo or not, that have collectively worked on many MBT facility projects in the UK. For confidentiality reasons, it is not possible to elaborate on where and when that experience was gained.

There is only one British MBT facility (Waterbeach in Cambridgeshire) that was designed, and is operated, with the intention of not producing any RDF, but instead to remove recyclable material and to biostabilise the remainder for subsequent landfill. The remaining 22 British MBT facilities identified in this report all produce RDF, thus reducing the amount of material that might be landfilled.

The prevalence of RDF production and the desire to limit the amount of waste landfilled reflects the impact of policies and instruments in place, and some MBT facility designs benefit from prior removal of RDF materials that would otherwise prevent or hinder effective biological processing of the waste.

Policies and instruments include the landfill tax, the discontinued landfill allowance trading scheme (LATS) in England and discontinued landfill allowance scheme (LAS) in Scotland and Wales, both of which aimed to limit the landfill of BMW, the ban on certain wastes being landfilled (stemming from the Landfill Directive) and the waste hierarchy. The waste hierarchy involves disposal to landfill being the least favoured of all options and energy recovery sits above it in the hierarchy.

In its ‘Waste Strategy for England 2007’ document, Defra wrote:

> *‘…markets are developed for secondary recovered fuel, of which England is expected to produce some 2 million tonnes a year from existing and planned mechanical biological treatment plant from 2009 onwards. Developing such markets has the potential for big benefits for the UK’s most energy-intensive industries, protecting jobs and with benefits to social cohesion…’*

MBT has been discussed further by Defra in a detailed report, which includes positive comment of how MBT can help contribute to meeting national targets, first issued in 2007 and updated in 2013[30].

In excess of 20 MBT facilities have been constructed in Britain. Some of these facilities have been in operation for a notable number of years, and the construction of some has been informed by negative attitudes towards thermal treatment. However, there have been reports in trade press of issues at some British MBT facilities, including issues with technology design, under-performance against contract targets, poor financial performance, contractual disputes, contract termination and some facility closures. Such issues have also occurred with other residual MSW technologies and contracts, but it is nonetheless useful to be aware of the issues encountered with MBT implementation in Britain to date. The British experience has also often included difficulty in securing outlets for CLO/digestate and issues with the quality of recyclable material affecting the revenue, or cost, it attracts.

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[30] https://webarchive.nationalarchives.gov.uk/ukgwa/20130403153720/http://archive.defra.gov.uk/environment/waste/residual/newtech/documents/mbt.pdf

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

In a 2017 briefing report on MBT[31], Tolvik Consulting considered the cost of waste management across 29 waste disposal authorities. The report notes that the five most expensive, per tonne of residual waste treated, primarily relied upon MBT, whereas only seven of the 29 primarily rely upon MBT. The authors noted that the analysis was '*not necessarily the most robust*' but that their findings were '*unlikely to be a co-incidence*'.

MBT processes vary significantly in terms of technology, complexity, scale and cost. Local authority contracts are generally in place for several years, and many MBT facilities have been developed under PPP and PFI agreements, with complex contractual terms, that include wider waste management services. Determining a cost for MBT, and then making comparisons with other technology options is therefore problematic at the national scale.

WRAP gate fee report information has been reviewed, with comparison between EfW and MBT, and is reported in Appendix A3.

The WRAP gate fee data for MBT contains limitations, as stated in its reports, and since 2018 WRAP no longer reports information for MBT. As such, the information should be treated with caution.

The WRAP gate fee data does not show a significant difference between reported gate fees for MBT and energy from waste facilities. However, the data for MBT facilities is only presented up until the 2017 WRAP report, which reports data for the 2016 calendar year.

For reasons explained above, it is difficult to arrive at a typical gate fee for British MBT. However, there is no evidence to suggest that it is a cheaper option than energy from waste and, in some instances, it may prove to be the more expensive option per tonne of waste treated.

Another factor that has influenced the experience of MBT in Britain has been the nature of the contractual arrangements between the parties involved in facility development and operation. This has often been long-term, complex, bespoke PPP/PFI, or similar, contracts between local authorities, waste management companies and lenders, with similar engineer, procure and construct (EPC) contracts between the main contractor and sub-contractors.

Some aspects of such contracts are associated with risk share, such as the payment mechanism, performance guarantees, performance deductions and liquidated damages. A local authority will sometimes be prepared to pay 'a bit more' to limit its exposure to fluctuations in market conditions. That might include fluctuations in downstream treatment and disposal costs and revenues from sale of materials and energy. The contractor will assume the risk but is hopefully compensated by receiving a good payment per tonne of waste treated, as determined by the payment mechanism. It is the contactor that factors in the risk when calculating its desired gate fee in contract negotiations. Similarly, the contract will typically make provisions for facility unavailability, or under-performance, wherein the local authority is afforded some protection. Again, the contractor will assume much of the risk alongside receipt of a good payment per tonne.

The risk share described above has merit and rationale. However, such contracts are typically in place for around 20 years, and a lot can change in a short space of time. Irrespective of cause, whether technical error in facility design, change in waste composition, or change in market conditions, there is plenty of scope for one or more parties to a contract to become dissatisfied. That might be a local authority paying a premium price when it sees that other, cheaper, options have become available, or it might be a contractor paying high penalties and liquidated damages. Sometimes the pain can be mutual. Complicating the picture is fast changing waste and resource policy and legislation. Quite often, disputes between parties involve discussion of waste composition.

The result of some contractual situations in the UK has been contract termination, companies going into administration, high insurance pay-outs and, on occasion, facility closure or significant modification. That situation can, and does, occur with any type of waste management facility and contract type. However, the technical complexity of MBT, its sensitivity to waste composition changes and its numerous material outputs lends itself to such problems.

[31] https://www.tolvik.com/wp-content/uploads/2017/09/Tolvik-2017-Briefing-Report-Mechanical-Biological-Treatment.pdf

A technical performance problem might, at face value, seem straight forward and relatively cheap to fix in capital expenditure terms, but the damages associated with facility downtime or landfill of waste that should be treated, can be quite the opposite. Similarly, the impact of a small change in waste composition might be limited in terms of physical facility performance but might have significant financial implications if damages are triggered under the contract, or contract provisions rendered void by out of specification waste; and that can be in the favour of either party.

# 5 France

## 5.1 Legislation and policy

Although France is a unitary state, some waste management responsibilities are delegated to the regions (départements) and that gives rise to differences in implementation. Whilst national requirements must be met, priorities vary at the regional level. Local authorities are responsible for the household waste management services. They are also responsible for the rules that apply to the finance of these services, such as taxes and duties. Commercial and industrial waste streams are the responsibility of the companies that generate them.

The first Grenelle law was implemented in 2009[32] and it introduced measures and specific, time-bound, targets such as:

- 7% reduction of the production of household waste and similar waste between 2009 and 2014.
- 15% reduction of waste sent to landfill or incineration between 2009 and 2012.
- Recycling rate, including organics, of 35% in 2012 from 24% in 2004.
- Introduction of economic instruments, including a variable payment scheme for collection, such as pay as you throw, between 2009 and 2014.
- Implementation of municipality level waste prevention plans.

In addition to the above targets, producers of significant quantities of organic waste were required to set up separate collection and treatment for their waste by 2012, aiming to reduce the greenhouse gas emissions impact and to return nutrients to the soil[33]. Householders are also expected to have access to separation at source for organic waste by 2025, either through home composting or collection by local authorities.

The extended producer responsibility (EPR), mostly implemented between 2001 and 2010, applies to tyres, printed/graphic paper, textiles and shoes, furniture, household healthcare products, chemicals from households and household natural gas cylinders, increasing the amount of materials separately collected.

In April 2018, the French government issued the French Circular Economy Roadmap[34] (feuille de route de l'économie circulaire), which set targets to:

- Reduce natural resource use associated with French consumption, in relation to gross domestic product (GDP), by 30% of 2010 levels by 2030.
- Reduce the amount of non-hazardous waste landfilled by 50% of 2010 levels by 2025.
- Reduce food waste by 50% between 2013 and 2025.

The "Programme national de prevention des déchets 2014-2020"[35] also set out several new waste prevention targets and revised the ones set in the, above mentioned, first Grenelle law. These targets, as well as targets reported by the government to the European Commission (EC)[36], are:

- A 10% decrease, between 2010 and 2020, in household and similar waste.
- 55% recycling of non-hazardous, non-inert, waste in 2020 and 65% in 2025.
- 50% collection target of textiles and shoes from households for the quantities placed on the market by 2019.
- 35-90% collection target of packaging and plastic waste for agricultural supplies in 2020.
- Reduction per unit of value in the quantity of waste from economic activities in 2020 compared with 2010.

[32] https://www.eea.europa.eu/publications/managing-municipal-solid-waste/france-municipal-waste-management
[33] https://www.municipalwasteeurope.eu/sites/default/files/FR%20National%20factsheet.pdf
[34] https://www.ecologie.gouv.fr/sites/default/files/FREC%20anglais.pdf
[35] https://www.ecologie.gouv.fr/sites/default/files/Programme_national_prevention_dechets_2014-2020.pdf
[36] https://www.eea.europa.eu/publications/even-more-from-less

- 60% reused or recycled building waste materials in road construction materials purchased by national and local authorities in 2020.

Act No. 2020-105 (Act 2020-2015), issued in February 2020, set a specific target, under Article L. 541-1 of the Environment Code, that 100% of plastic will be recycled by 1 January 2025. The Environment Code[37] introduced into national legislation the national strategy concerning waste regulation, as well as some EU directives. It also includes uplifts of several targets mentioned above and introduces new stricter ones:

- The decrease of 10% in household and similar waste between 2010 and 2020 is extended to 2030 and is now 15%.
- The quantities of household and similar waste sent to landfills in 2035 must be reduced to 10%.
- Energy recovery of at least 70% of waste that cannot be subject to material recovery by 2025.
- Separate collection of organic waste by 31 December 2023.
- As of 1 January 2027, it is prohibited to use organic waste treated in MBT facilities as compost.

All the above targets, which reflect the waste hierarchy and will have implications for existing MBT facilities in France, point to a reduction in residual waste tonnages and significant changes to its composition. Source segregation of organic wastes and the prohibition on the use of CLO on land as a compost will have notable impact on some MBT facilities, including the case study facility discussed in section 5.5.

## 5.2 Compost standard

For a material to be marketed as a compost product in France, it needs to meet the statutory NFU 44-051 standard[38]. The standard includes limit values for concentrations of trace metals, some organic compounds, contaminant materials (glass and plastic), pathogens and agronomic parameters. If the material complies with the requirements, it can be considered a product and not waste, irrespectively of its origin or whether it is formed by mixing materials. This does not apply to sewage sludge, which has a separate standard.

The CLO generated at MBT facilities in France can, therefore, be used in agriculture if the criteria of the standard are met. However, as detailed in section 5.1, this practice will only continue until 2027, as then any material that originates from non-source segregated waste will not be allowed to be used as a compost product that is not subject to regulation as a waste.

## 5.3 Biostabilisation criteria

The criteria and procedures for admitting waste to landfills in France are outlined in a document that transposes Council Decision 2003/33/EC[39]. On 1 July 2002, a ban on landfilling of untreated waste was imposed[40]. However, no degree of biodegradation was established. Thus, the main driver to biostabilise waste prior to landfill has been the requirement of the EU Landfill Directive to *'landfill a maximum of 75% of the total biodegradable municipal waste generated in 1995 by 2006, 50% by 2009 and 35% by 2016'*[32].

## 5.4 Landfill tax and gate fees

In France, landfilling and incineration activities are subject to the general tax on polluting activities (Taxe Générale sur les Activités Polluantes, TGAP)[32]. The landfill tax was first imposed at EUR 9.15 per tonne and did not change between 2001 and 2008. At landfills where the operators held environmental certification, such as ISO14001 or EMAS, there was a discount (EUR 7.5/t). A reform of the TGAP resulted in an increase of the tax by four times between 2009 and 2015 and an incineration tax was implemented between 2009 (EUR 7/t) and 2015 (EUR 14/t). However, a tax discount is allowed for

[37] https://www.legifrance.gouv.fr/codes/id/LEGITEXT000006074220/
[38] https://nord-pas-de-calais.chambre-agriculture.fr/fileadmin/user_upload/Hauts-de-France/028_Inst-Nord-Pas-de-Calais/Telechargements/Recyclage/fiche2-seuils-reglementaires-fixes-par-les-normes.pdf
[39] https://aida.ineris.fr/consultation_document/1595
[40] https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000000345400

incineration with energy recovery and high energy efficiency (EUR 1.5/t in 2009 to EUR 3/t in 2015). The efficacy of the tax is potentially reduced by the fact that more than 90% of all operators subject to the taxes benefit from the discount. The taxes apply to all types of waste and not specifically to MSW.

At present, the gate fee for an authorised landfill with 75% energy recovery from the captured biogas is EUR 37 per tonne, increasing to EUR 54 per tonne if no energy recovery takes places and to EUR 152 per tonne if the landfill is not authorised[41].

The ban on untreated waste to landfill appears to have influenced the rate of landfilling to a higher degree than the landfill tax.

## 5.5 Case study 1: ECOCEA, Chagny, France

A summary of this case study is provided in Table 3. Further detail is provided in Appendix A4.

Table 3. Case study 1 summary details

<table>
<tr><th>Facility</th><th>Technology</th><th>Inputs</th><th>Outputs</th></tr>
<tr><td>ECOCEA, Chagny, France<br><br>Commissioned in 2015</td><td>Dry AD and tunnel IVC</td><td>Residual MSW (73,000 tpa) with addition of green waste (8,000 tpa) prior to tunnel IVC.<br><br>Only the <10mm fraction is processed in AD.</td><td>RDF<br><br>Ferrous and non-ferrous metals<br><br>Compost for use in agriculture<br><br>Biogas upgraded to biomethane</td></tr>
<tr><td colspan="4">The organic fraction in MSW is typically concentrated in the smaller fractions and <10mm is a very fine fraction. That probably reflects the desire to ensure a good quality CLO for land application.<br><br>Addition of green waste prior to IVC provides material structure and assists meeting current French compost standards. In Scotland, CLO from non-source separated materials cannot gain end of waste status, limiting options for land application, whilst composted green waste can get end of waste status. In Scotland, it would not make sense to mix green waste with the AD digestate, including if the intention was to landfill the output. A larger particle size fraction (from MSW) would need to be subject to dry AD and IVC to ensure structural materials are present.<br><br>From 2027, CLO will no longer be classed as a compost product in France. This is likely to have notable implications for the facility.<br><br>At present there is no source separation of food waste in the area, whereas there is a push in France to do so. If that happens in the area, there will be a notable implication on the economics of the facility unless its mode of operation is changed, i.e. to treat source separated feedstock. Biomethane upgrading involves high capex and gas sales will be central to the facility's financial model.<br><br>This facility is quite new and the changes in legislation and potential changes to input waste composition will have serious implications to the mode of operation, and financial performance, in future.<br><br>Whilst it is unknown if the current facility biostabilises to the level of the Scottish ban (unlikely with 2 weeks of IVC), IVC processes can be designed to meet the criteria.</td></tr>
</table>

[41] https://www.cewep.eu/wp-content/uploads/2021/08/Landfill-taxes-and-bans-overview.pdf

# 6 Germany

## 6.1 Legislation and policy

Waste control, disposal and management in Germany are defined in the Circular Economy Act (Kreislaufwirtschaftsgesetz, KrWG) [42]. The act came into force on 1 June 2012 to transpose the Waste Framework Directive into national legislation and set out the fundamental principles of the circular economy, which include the polluter-pays principle, the waste hierarchy and the principle of shared public and private responsibility for waste management. The shared responsibility means that municipal waste management companies are responsible for organic and residual household waste, while private waste management companies are responsible for the recycling of household, commercial and industrial waste. The act aims to promote the circular economy to conserve natural resources and to protect human health and the environment from the impacts arising from the generation and management of waste.

In addition, the expanded Waste Prevention Programme required proper care in the management of goods and waste prevention measures to be taken by distributors and traders, as well as the preparation of products for reuse and recycling, which resulted in the obligation for separate collection of waste streams to be extended and further specified.

In 2010, 76 of 402 rural districts and urban municipalities, with a population of 10.8 million, did not collect organic waste separately. Section 11 (1) of the Circular Economy Act required that separate collections for organic waste must be set up from 1 January 2015. However, the law has not yet been implemented across the whole of Germany. Paper, metal, plastic and glass waste were also required to be collected separately. The new Commercial Wastes Ordinance, which came into force on 1 August 2017, expanded the obligation, to include cardboard, wood, textiles and other production-specific waste fractions.

The German resource efficiency programme was also issued in 2012 (ProgRess I) and updated in 2016 (ProgRess II)[36]. Among the action areas considered are the development of a resource-efficient circular economy and the support of policies on resource efficiency both on local and regional levels. The programme set a specific target to increase the quantity of separately collected organic waste by 50% and recycle and recover the same waste stream with high quality by 2020 relative to 2010.

Since mid-2005, under the Closed Cycle Management Act[43], organic waste was required to be treated prior to landfill, either in MBT or thermal treatment facilities, so that it could be specified as stabilised and not release significant amounts of leachate and landfill gas. The same applies to residual waste, from which any recoverable substances must be separated before landfilling and the energy from the materials must be utilised, unless the separation is shown to be technically impossible or economically unreasonable. Moreover, since 1 January 2019 sorting facilities must fulfil specific technical requirements, achieving a sorting rate of at least 85% and a recycling rate of at least 30%. The introduction of separate collection of organic materials and packaging waste has increased the recycling rate, which was 67% in 2020, and the volume of residual waste, which declined from 239 kg/capita/year in 1985 to 128 kg/capita/year in 2018.

In 2017, 45 MBT plants with a capacity of five million tonnes treated 4.5 million tonnes of waste, from which only around half a million tonnes was landfilled[42]. This can be attributed to the strict landfill requirements combined with the fact that most of the MBT facilities in Germany produce RDF.

## 6.2 Compost standard

The RAL quality assurance for compost was established in Germany in 1991 and, in recent years, approximately 70% of compost is labelled with the quality label RAL-GZ 251[44]. The utilisation of organic

[42] https://www.bmu.de/en/publication/waste-management-in-germany-2020/
[43] Nelles, M., Gruenes, J., & Morscheck, G. (2016). Waste management in Germany–development to a sustainable circular economy?. Procedia Environmental Sciences, 35, 6-14.
[44] https://www.kompost.de/uploads/media/Compost_Course_gesamt_01.pdf

waste on land used for agricultural, silvicultural and horticultural purposes is regulated via the Ordinance on Biowastes – BioAbfV 1998, which specifies the requirements on:

- The process.
- The hygienic and precautionary environmental aspects of the material.
- The requirements for application.

The requirements only apply to source-segregated organic waste and, thus, CLO cannot be applied on land used for food production.

## 6.3 Biostabilisation criteria

The requirements for waste landfilled in Germany are set out in the Landfill Ordinance (Deponieverordnung - DepV)[45]. More specifically, in Annex 3: Admissibility and assignment criteria, a set of parameters and their limits are set for each type of landfill. In addition, for outputs from MBT the following requirements also apply:

a) *The organic fraction of the dry residue of the original substance shall be deemed to be complied with if a TOC of 18% by mass or a calorific value of 6,000 kJ/kg DM is not exceeded;*
b) *A maximum DOC of 300 mg/l applies; and*
c) *the biodegradability of the dry residue of the original substance of 5mg/g (determined as respiration – $AT_4$) or 20 l/kg (determined as gas formation rate in the fermentation test – $GB_{21}$) is not exceeded.*

The respiration limit as set by the third criterion is stricter than the one set by the Scottish Government for the landfill ban which will be introduced in 2025. In addition, the criterion on the calorific value of the waste indicates that materials with a higher calorific value are considered suitable for incineration and should be diverted from landfill.

## 6.4 Landfill tax and gate fees

Germany hasn't imposed a landfill tax[41]. However, a landfill ban on untreated waste with TOC higher than 3% was introduced with an administrative regulation (TASi) in 1993 but was not fully implemented until mid-2005. The exceptions to this ban can be found in the previous section.

The German waste management system is financed by fees, applying the "polluter-pays" principle, where the producer has to pay for waste treatment or disposal[43].

## 6.5 Case study 2: Freienhufen, Germany

A summary of this case study is provided in Table 4. Further detail is provided in Appendix A4.

Table 4. Case study 2 summary details

| Facility | Technology | Inputs | Outputs |
|---|---|---|---|
| Freienhufen, Germany<br><br>Commissioned in 2007 | Wet AD | Residual MSW<br><br>Facility capacity was 50,000 tpa which includes a separate bulky waste process.<br><br>In 2012, 27,327 tonnes of residual MSW was processed in the MBT facility, excluding around 7,000 to 8,000 tpa of bulky waste which was processed separately. | RDF (in 2012, this was 56.6% of total input waste)<br><br>Ferrous and non-ferrous metals<br><br>Dried digestate was landfilled (29% of input waste landfilled as dried digestate in 2012- meaning the input waste was rich in organics). |

[45] https://www.gesetze-im-internet.de/depv_2009/index.html#BJNR090010009BJNE000401310

A facility upgrade took place in 2011/12 and further modifications were recently (since 2018) made to allow the facility to operate for the sole processing of source segregated biowaste (principally kitchen waste and green waste), i.e. residual MSW is no longer treated. This was the result of the mandatory introduction of source segregation of biowaste in the area. The changes required modifications including the addition of tunnel IVC with four-week retention time in order to process 20% kitchen waste with 80% green waste.

For the digestate from this facility to have been landfilled, it must have been deposited as a landfill restoration material, or it may have been used as daily cover material at the landfill. The facility was commissioned prior to the introduction of biostability criteria for waste to be landfilled in Germany.

This case study is an example of how changes in policy and legislation, reflecting a change in waste composition, can have significant impact upon the operation of an existing MBT facility.

Wet AD is not suitable to meet the Scottish biostabilisation for landfill criteria as it will not be possible to achieve the required level of biostabilisation without drying and IVC, and the dried digestate will have insufficient structure for IVC without mixing with other materials.

## 6.6 Case study 3: Lübeck, Germany

A summary of this case study is provided in Table 5. Further detail is provided in Appendix A4.

Table 5. Case study 3 summary details

| Facility | Technology | Inputs | Outputs |
|---|---|---|---|
| Lübeck, Germany<br>Commissioned in 2006/7 | Wet AD | Residual MSW<br>120,000 tpa of residual waste and 26,000 tpa of sewage sludge.<br>(The MBT has three lines, one for biowaste (source segregated organic waste) and sewage sludge, one for doorstep household residual waste and one for bulky waste, and there is some interaction between the residual waste line and the bulky and commercial waste line) | RDF<br>Ferrous and non-ferrous metals<br>Dried digestate is landfilled |

The MBT facility forms part of wider waste treatment infrastructure at the Lübeck Waste Management Centre.

The area is served with separate biowaste collection and there is also a separate 'biomass facility' which receives green waste as well as woody material and digestate from the source segregated organics line from the MBT facility. The biomass facility utilises tunnel IVC (12 no.) technology followed by open windrow composting. The residual MSW does not go to the biomass facility.

The facility was developed as a result of a ban on untreated waste being landfilled, which came into force in Germany in 2005.

Ricardo's research has not identified any issues with this facility. The facility has the benefit of being designed in the knowledge that biowaste is to be collected separately. As an integrated facility, including wet-AD of MSW organic fine fraction and source separated organics in separate digesters, the facility has a degree of flexibility to variation in organic content of the doorstep residual MSW. The biogas at the facility is combusted in CHP engines. If the organic fine fraction in the residual MSW reduces, it is likely to be alongside an increase in the source segregated food waste collected and so there will be no loss in overall biogas production.

Wet AD is not suitable to meet the Scottish biostabilisation for landfill criteria as it will not be possible to achieve the required level of biostabilisation without drying and IVC, and the dried digestate will have insufficient structure for IVC without mixing with other materials. For the digestate from this facility to have been landfilled, it must have been deposited as a landfill restoration material, or it may have been used as daily cover material at the landfill. The facility was commissioned prior to the introduction of biostability criteria for waste to be landfilled in Germany.

## 6.7 Case study 4: Vorketzin, Germany

A summary of this case study is provided in Table 6. Further detail is provided in Appendix A4.

Table 6. Case study 4 summary details

| Facility | Technology | Inputs | Outputs |
|---|---|---|---|
| Vorketzin, Germany<br>Commissioned in 2005 | IVC | Residual MSW<br>180,000 tpa capacity | RDF<br>Ferrous and non-ferrous metals<br>CLO landfilled |

The site was built as a response to the 2005 ban on landfilling untreated waste. However, the biological treatment process was stopped in 2012 and operations ceased altogether at the end of 2015. It is possible that the plant was affected by the introduction of separate organic waste collections in the catchment. Additionally, other residual waste reduction and diversion policies, such as the separate collection of recyclable streams, resulted in the reduction of the overall residual waste stream.

The districts that provided the facility with residual waste decided to send it to EfW plants because the gate fees were lower and that is the principal reason for the facility closure.

Whilst it is unknown if the facility biostabilised to the level of the Scottish ban, IVC processes can be designed to meet the criteria. The facility was commissioned prior to the introduction of biostability criteria for waste to be landfilled in Germany. It is possible that the introduction of the criteria had an influence on the viability of the facility.

# 7 Italy

## 7.1 Legislation and policy

The national programme for waste prevention[46,47] for Italy (2013 to 2020) was aimed at reducing organic, construction and demolition, hazardous, paper, packaging, batteries, electrical and electronic equipment waste. The programme set the following targets to be achieved by 2020, based on 2010 levels:

- Reduction of 5% in municipal solid waste relative to GDP unit.
- Reduction of 5% in special non-hazardous waste relative to GDP unit.
- Reduction of 10% in special hazardous waste relative to GDP unit.

Furthermore, the Report on Circular Economy in Italy[48] sets ten proposals for the Italian economy to move away from the linear economy model. With regards to waste, the aim is the *"rapid and effective implementation of the new European directives on waste and circular economy"* while taking into consideration the realities of the Italian system. The document includes targets on the preparation for reuse and recycling of municipal waste, which is set at 55% until 2025, 60% until 2030 and 65% until 2035, with specific targets per material, and a maximum of 10% of municipal waste sent to landfill. Waste prevention measures, such as food donations and repair and reuse of products, are also planned.

There are substantial differences among regions in Italy[36]. For instance, the Emilia Romagna region set targets for separate waste collection to reach 73% by 2020, the per-capita waste generation to decrease by 25% by 2020 relative to 2011 and recycling to increase to 70% by 2020, while the Lazio region only set a separate waste collection target of 65% by 2020. In addition, landfilling is higher in the southern regions, due to a shortfall in recycling facilities.

There is no clear national requirement for the separate collection of organic waste for the purposes of bio-treatment, although the practice is common[49].

## 7.2 Compost standard

The Italian Compost Association (CIC) is the national association for the compost industry. In 2016, 33% of Italy's total compost production was labelled with CIC's quality label for compost (CQL). The label is based on the limit values on the most important environmental parameters set by the National Law, D.Lgs 75/2010[50] and subsequent amendments, for use of source segregated organic waste as fertilisers or soil improvers.

CLO is used as landfill cover in some regions, based on the old regulation on "mixed MSW compost" (DCI 27/7/84)[51]. Older documents also outline the need for more specific guidelines and terms for the organic outputs of MBT facilities[52]. The latest guidance on compost from mixed waste was from 1984. The need to differentiate between the compost that derives from mixed waste and compost that derives from source segregated waste is emphasised by the Agency for the Protection of the Environment and for Technical Services (Agenzia per la protezione dell'ambiente e per i servizi tecnici, APAT), as the quality of the latter is much better.

[46] https://www.mite.gov.it/sites/default/files/archivio/normativa/dm_07_10_2013_programma.pdf
[47] https://www.eea.europa.eu/themes/waste/waste-prevention/countries/italy-waste-prevention-fact-sheet
[48] https://circulareconomynetwork.it/wp-content/uploads/2019/02/Rapporto-sulleconomia-circolare-in-Italia-2019.pdf
[49] https://www.municipalwasteeurope.eu/sites/default/files/IT%20National%20factsheet.pdf
[50] https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/10087
[51] https://www.aora.org.au/sites/default/files/uploaded-content/website-content/International_Comparison_AS4454_Final.pdf
[52] https://www.isprambiente.gov.it/contentfiles/00004100/4160-rapporto-biostabilizzato.pdf/

## 7.3 Biostabilisation criteria

The Ministerial Decree of 1 December 2010 defined the landfill waste acceptance criteria[53]. A parameter of interest to MBT outputs is the DOC, for which the limit is set at 100 mg/kg. However, this limit does not apply to:

- *"Outputs of mechanical or biological treatment that are characterised with the European Waste Catalogue (EWC) codes of 190501, 191210 and 191212;*
- *Outputs of biological treatment that are characterised with the EWC of 190503, 190604 and 190606, provided it is compliant with the programmes referred in article 5 of Legislative Decree 36/2003 and the dynamic breathing indicator, determined according to UNI/TS 11184, not greater than 1,000 $mgO_2$/ kg VS/h".*

The first exclusion refers to the 'non-composted fraction of municipal and similar wastes', while the second one refers to digestate and off-specification compost. This indicates that the outputs of the biological treatment of MBT facilities in Italy may be landfilled if the biodegradability of the CLO is below 1,000 $mgO_2$/ kg VS/h. This level of biostabilisation is equal to one of the two Scottish biostabilisation requirements, noting that the Scottish requirement is that either one or the other biostabilisation criteria must be met.

## 7.4 Landfill tax and gate fees

Italy introduced a landfill tax in 1996. Even though it contributed to the diversion of waste from landfill, the tax is low and no longer provides enough incentives for alternative treatment[54]. The Law 549/1995, which imposed the landfill tax, is applied at a regional level and the tax is directly paid to the regions by landfill operators.

Landfill tax varies between regions, from EUR 5.3 per tonne to EUR 25.82 per tonne, which is the maximum tax allowed from national legislation[41]. The tax also varies if the waste is pre-treated.

Italy has no ban on waste sent to landfill. A ban on waste with calorific value higher than 13,000 kJ / kg was introduced in the 2003 landfill law, for implementation by 2007, but the implementation was delayed six times, until 2016/2017 when the ban was abrogated[41].

[53] https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2010-12-01&atto.codiceRedazionale=10A14538&elenco30giorni=false
[54] https://www.eea.europa.eu/publications/managing-municipal-solid-waste/italy-municipal-waste-management/at_download/file

# 8 Spain

## 8.1 Legislation and policy

The State Programme for Waste Prevention 2014-2020[55] has four strategic objectives to:

- *"Reduce the quantity of waste.*
- *Reuse products and extend their life.*
- *Reduce the content of harmful substances in materials and products.*
- *Reduce the environmental impacts of waste, as well as its impact on human health".*

The target on waste reduction aims at reducing waste generation by 10% by 2020, relative to the amount generated in 2010. Additionally, Spain aims at reducing construction and demolition waste by 10% by 2020 relative to 2010 levels and to recycle, at least 50% by weight, paper, glass, plastic, organic waste and other recyclables of household and commercial origin[36].

Separate collection of organic waste is not a requirement in Spain, although it is undertaken in some regions[56].

## 8.2 Compost standard

The Royal Decree 506/2013[57] on fertiliser products specifies the requirements for any compost used on land. For Class C compost, which is the compost that derives from mixed waste, there is an annual limit of 5 tonnes of dry matter per hectare. No other limitation is applied on compost from mixed waste.

## 8.3 Biostabilisation criteria

There is no requirement for waste sent to landfill to meet any criteria on biostabilisation. However, some regions have implemented a ban on biodegradable or non-treated waste[41].

## 8.4 Landfill tax and gate fees

The landfill tax in Spain varies from zero in some regions to EUR 53.1 per tonne in Catalonia. The different rates across the country affect the degree to which each region acts upon waste reduction and recycling.

## 8.5 Case study 5: Barcelona Ecoparc 4, Spain

A summary of this case study is provided in Table 7. Further detail is provided in Appendix A4.

Table 7. Case study 5 summary details

<table>
<tr><th>Facility</th><th>Technology</th><th>Inputs</th><th>Outputs</th></tr>
<tr><td>Ecoparc 4, Barcelona, Spain<br><br>Commissioned in 2010/11</td><td>IVC</td><td>Residual MSW<br><br>285,000 tpa capacity<br><br>(the facility also has a separate process for treatment of source separated organics at 75,000 tpa capacity)</td><td>SRF<br><br>Ferrous metal, non-ferrous metal, paper, HDPE plastic, PET plastic, brick and plastic film are sent for recycling.<br><br>CLO (around 8% of the input waste mass)</td></tr>
<tr><td colspan="4">A range of materials within the area are subject to separate collection, including Organics (small garden and food waste) (introduced in 2010).</td></tr>
</table>

[55] https://www.eea.europa.eu/themes/waste/waste-prevention/countries/spain-waste-prevention-fact-sheet
[56] https://www.nature.com/articles/s41598-021-90957-2
[57] https://www.boe.es/boe/dias/2013/07/10/pdfs/BOE-A-2013-7540.pdf

This facility was selected as a case study owing to its large capacity and sophisticated mechanical processing stage, which removes a range of recyclable materials. This does, however, come at a capex and opex cost. Some British MBT facilities have also been designed to remove a range of recyclable materials, often with use of manual hand-sorting.

Other than odour issues, which are not uncommon at MBT facilities, no issues were identified in Ricardo's desk study review.

Whilst it is unknown if the facility biostabilised to the level of the Scottish ban, IVC processes can be designed to meet the criteria.

## 8.6 Case study 6: CTR Vallès Occidental, Vacarisses, Barcelona, Spain

A summary of this case study is provided in Table 8. Further detail is provided in Appendix A4.

Table 8. Case study 6 summary details

| Facility | Technology | Inputs | Outputs |
|---|---|---|---|
| CTR Vallès Occidental, Spain<br>Commissioned in 2010 | IVC | Residual MSW<br>245,000 tpa capacity | Recyclable materials (paper, metals, packaging, etc.)<br>CLO, which is reported to meet European Standards and to be suitable for landscaping or gardening. However, some data sources state that it is either used for restoration of quarries and landfills or it is packed in shrink-wrapped bales with a very small percentage of biodegradability, which suggests it is landfilled. |

This facility utilises power generated from landfill gas from an adjacent landfill.

As with the Ecoparc 4 facility, organic waste is collected separately in the area, the facility has a high annual capacity and a range of recyclable materials are removed in the MBT process.

Available information suggests that RDF/SRF is not produced but the situation regarding facility outputs is unclear, including whether CLO is utilised or landfilled. The presence of conflicting information suggests that it is possible, but unconfirmed, that material is being landfilled which was originally anticipated would be used as CLO. The experience in Britain has been that finding outlets for CLO is problematic, which has sometimes led to it being landfilled.

A 2017 audit report, produced by the audit office of Catalonia, highlights a range of issues with this facility, some of which include:

- The cost of sending waste to the MBT facility was so high that some municipalities decided to take their waste to other MBT facilities in the area.
- Construction and commissioning were both delayed, and the latter was held-up by performance issues.
- The MBT facility was 'definitively received', which means the client accepted it (taken over), despite not having the necessary environmental licence and not passing the performance tests for the biostabilisation system and the quality of the biostabilised material, nor of the air treatment system performance and emissions.
- In 2016 it was announced that adjacent landfill would shortly close and disposal costs for MBT facility outputs would rise owing to a need to send them further afield.

It is evident from the audit report that there were irregularities in what took place, from a contractual and financial perspective, and that technical performance of the facility was problematic such that performance tests could not be achieved. It is unclear if those issues were ever resolved. These issues, combined with the conflicting information on fate of outputs, suggest the facility has not performed as anticipated. It appears that the facility was designed with CLO production and without RDF production. The issues may be linked, in part, to those decisions.

# 9 Comparative analysis of country and case study information

## 9.1 Country information

Some differences exist between waste policies in France, Germany, Italy, Spain and Scotland. However, at a high-level, waste reduction and diversion from landfill are common themes.

- Unlike Germany and Italy, France and Spain both allow CLO to be applied to land for agricultural purposes, i.e. as compost, if national compost standards are met. In Scotland, CLO cannot gain end of waste status, because it is not from source segregated organics, and so its application to land will be restricted. The ability to apply CLO to land with relative ease is a significant advantage to an MBT operator because it avoids landfill or EfW gate fees. However, from 2027 onwards, the practice of applying CLO of residual waste origin to agricultural land in France will cease. That is likely to make MBT less favourable in France, and will have a financial implication, if not an existential implication, for some existing French MBT facilities.
- All five countries, including Scotland, have developed policies and legislation aimed at reducing waste, diverting waste from landfill, and increasing recycling. However, the approach has not been consistent between the countries:
  - France and Spain do not have specific biostabilisation criteria for the landfill of BMW, whereas Germany and Italy do. Some regions in Spain have, however, banned the landfill of BMW or untreated BMW.
  - France and Germany have measures in place to encourage EfW over landfill. In France, 70% of material unsuitable for material recovery must be subject to energy recovery. In Germany, material that is not recycled and has calorific value over a certain threshold cannot be landfilled, meaning it must instead be sent for EfW. Italy considered a ban on the landfill of high calorific value waste, but the proposal has now been dropped.
  - Separate collection of organics is widespread in Germany, which was a requirement to be met by January 2015, albeit it had not been fully enacted in all regions by that point. It is considered likely that was one influencing factor affecting modification or closure of German case study MBT facilities reviewed in this report. From the end of 2023, it will become a requirement in France. Italy does not have robust requirements in place that make separate collection for bio-treatment mandatory, although it is common practice in some areas. It is not a requirement in Spain, although it is implemented in some regions. Of these countries, Spain has the lowest proportion of separately collected organic waste, which is something in favour of MBT.
  - There is no landfill tax in Germany, but there is a strong emphasis on the polluter pays principal. One German case study local authority cited charges for residual waste at the doorstep as having a notable influence within its area. France has both landfill tax and an incineration tax, but there are discounts available for some circumstances and they apply to most operators, which limits the potential influence of the tax. Italy has a very low landfill tax which is reported to have little influence on diverting waste from landfill. Landfill tax in Spain varies by region, with some regions not applying a tax. Catalonia has the highest rate of landfill tax in Spain, and it has a relatively high amount of MBT facilities.

## 9.2 Case study information

Of the six case study sites (one in France, three in Germany and two in Spain):

- Five case study sites produce RDF and are heavily focused at minimising the amount of waste landfilled, as opposed to biostabilisation prior to landfill. This is also the case for almost all UK MBT facilities (see section 4) and reflects common policies that promote energy recovery above landfill.
- A ban on energy from waste is explicitly cited as one of the drivers for MBT facility development in one of the case studies. Ricardo is aware of several UK MBT facilities that

were developed alongside local authority decisions to rule out EfW development, based upon opposition to EfW expressed by residents within the local authority area.

- Two case study sites no longer process residual waste, influenced by the introduction of source segregated biowaste collections and, in one instance, due to EfW being a cheaper option. A third site will be significantly impacted by a change in legislation that will significantly impact the mode of operation, potentially threatening the future of the facility.
- Only one case study facility was required to biostabilise waste to a contractual limit, with the intention for it to be subsequently landfilled, and that limit was not achieved in performance testing.

The extent of biostabilisation achieved at the case study sites is not known to Ricardo. Because the purpose of five of the facilities is not to biostabilise waste prior to landfill, it is unlikely that the level of biostabilisation being achieved would meet the stringent level required to allow landfill in Scotland after 2025. It would not be possible at the sites that utilise wet AD.

Considering that the case study facilities were selected with no prior knowledge of any issues at the sites, it is notable that issues at several of the case study sites have been experienced.

As described in section 3, MBT facilities are designed to produce a range of outputs and around assumptions on waste composition, and typically for a lifespan of 20 to 25 years.

MBT facilities are typically promoted as having a high level of flexibility with respect to input waste composition. The composition of residual waste can be expected to change as consumer habits change and with changes in policy and legislation. However, at several UK MBT facilities, Ricardo staff have observed how facility design, based around assumptions on physical properties of waste (e.g. density, moisture level, particle size etc.), composition and behaviour of the waste within the process have not allowed sufficient flexibility for the input waste. The case study information reviewed does not provide a thorough insight into specific problems encountered at the sites, but it is evident that a drop in organic content within the waste has led to significant changes at two of the sites, and it is probable that it will be encountered at a third site.

Whilst the drivers and experiences of MBT implementation in France, Germany, Italy and Spain are of interest, and perhaps offer some lessons, the combined conditions in which MBT facilities have been developed are different for each country. Furthermore, conditions in Scotland do not closely align with those countries.

If further consideration is to be given to MBT development in Scotland, Ricardo recommends that an in-depth review is made of the experience of MBT implementation in England. That might include liaison with UK waste management companies and local authorities that have experience of MBT implementation. As described in section 4, MBT implementation in England has been problematic at times, and there will be some valuable ‘lessons learnt’ to be gained from review of English case studies.

# 10 Carbon life cycle assessment

## 10.1 Approach

To assess the carbon implications of biostabilisation prior to landfill as a means of treating residual waste in Scotland, an MS Excel spreadsheet model of the process was developed. The model uses a life cycle analysis (LCA) approach to measuring greenhouse gas impacts in terms of the mass of carbon dioxide equivalent emitted or avoided per tonne of MSW treated (kg $CO_2$ eq/t).

Source data is summarised in Appendix A5 and section 10.3.

The carbon LCA considers carbon emissions and carbon savings (avoided emissions) of fossil origin, and methane of biogenic origin. Biogenic carbon means that the carbon is of recent plant or animal origin, whereas fossil carbon means it is of ancient origin. Biogenic carbon dioxide emissions are not considered, because they are in balance with the carbon dioxide recently removed from the atmosphere by plant growth. Put another way, if you compost plant material, you will release the carbon dioxide back into the atmosphere that the plant only recently removed from the atmosphere as it grew.

Ricardo's remit did not include making comparisons to other treatment methods, i.e. EfW. However, the model draws upon input waste datasets and approaches, such as the allocation of carbon emissions including avoided emissions from recycling and energy generation, utilised by Zero Waste Scotland in a model it developed for EfW. Such consistency will assist interested parties when comparing treatment options.

Anticipated mass and energy balances were provided by two established technology providers, one of which operates in the IVC market and the other in the dry-AD market. The companies were approached as both have multiple reference facilities, across several countries, that treat a variety of waste types and compositions. The information was provided upon review of the waste composition provided by Zero Waste Scotland and is based on the experience of the two companies. The information was not provided following detailed engineering design, but is nonetheless appropriate for the purposes of the carbon LCA modelling.

Ricardo incorporated its own mass balance assumptions, based on its experience, for removal of recyclables and RDF in mechanical pre-treatment. Neither of the two technology providers specialise in that part of the process and their information provided was primarily focussed on the biological process.

Landfill emission assessment involved the use of GasSimlite[58] software. GasSim/GasSimlite software has been in use in the UK, for modelling emissions and risks from landfills, for approaching 20 years and was determined to be the most appropriate way to assess the carbon emissions from the landfill of stabilised waste from an MBT facility.

The model does not follow the input waste carbon assumptions all the way through the model on a material by material basis. The model developed is a hybrid of:

- Input waste composition and carbon content supplied by Zero Waste Scotland.
- The two technology provider's, and Ricardo's, mass balance information.
- GasSimlite software modelling.

The hybrid approach, drawing upon the experience of the two technology providers and the sophistication of the GasSimlite software, was deemed preferable to the academic approach of forming assumptions for the fate of carbon on a material by material basis from arriving at the MBT facility to being landfilled.

The various data sources, described above, are explained in further detail below.

The model is based upon 1,000 tonnes of residual waste sent to MBT, although users can select an alternative value. The choice of input waste tonnage does not alter the end result of the model, as

[58] http://www.gassim.co.uk/

results are provided on a per tonne input waste basis, but does affect interim values in terms of how user friendly they are (too low a value causes interim numbers within the model that are not user friendly, i.e. low values to many decimal places).

## 10.2 System boundary

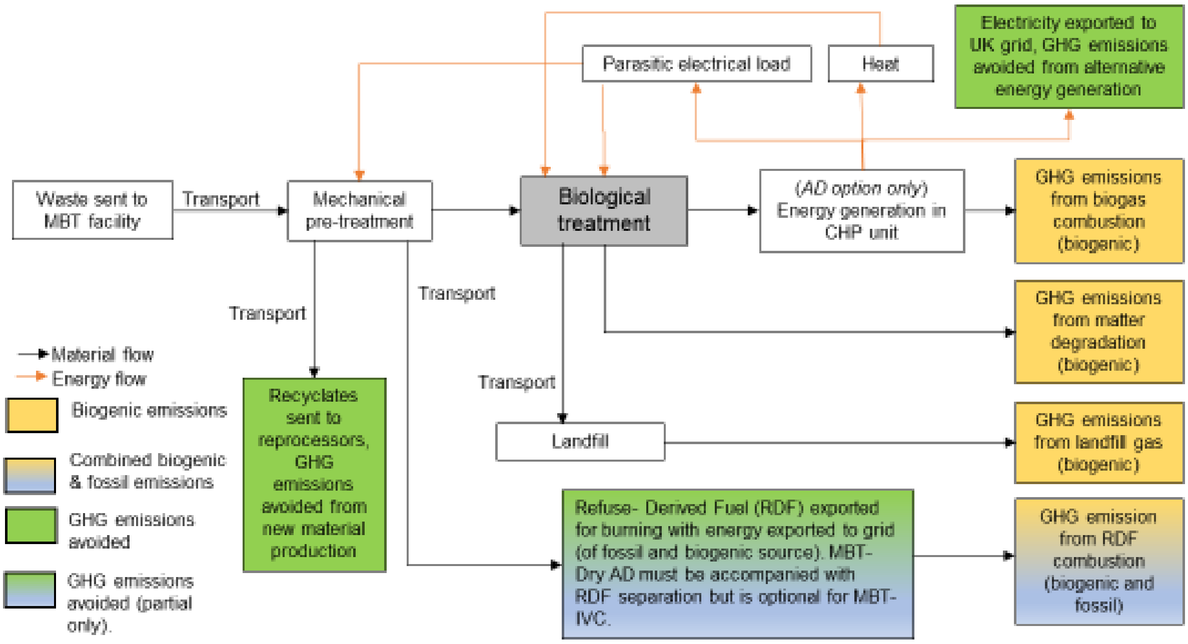
The system boundary for the model starts with residual waste arising at a waste transfer station (WTS). This is driven to the MBT facility, where pre-sorting removes metals, glass and plastics for recycling, as well as RDF in some instances. The model allows users to switch-off RDF removal for MBT-IVC, but RDF removal is a necessary step at MBT-Dry AD facilities. After biological treatment, the remaining biostabilised material is sent to landfill for final disposal.

The model takes account of various activities, for example the recycling of materials, that may potentially be undertaken by third parties (scope 3 activities) to the organisation operating the MBT facility (scope 1 and 2 activities).

The model does not consider the carbon impacts of facility construction, noting that they will exist for any MBT facility construction.

The process is depicted schematically in Figure 2.

Figure 2: Schematic diagram of MBT carbon model




## 10.3 Source data

### 10.3.1 Waste composition and carbon content

Waste composition[59] and carbon content[60] data was provided by Zero Waste Scotland and is shown in Table 9. The model also contains provision for the use of WRATE[61] carbon content data.

[59] For year 2018
[60] The biogenic and fossil content are based on assumptions used in a DEFRA (2014) EfW and landfill comparison study.
[61] The Waste and Resources Assessment Tool for the Environment; see http://www.wrate.co.uk/

Table 9. Default residual waste composition for MBT carbon model

| Waste fraction | Proportion of waste | Carbon content | Proportion of carbon which is biogenic | Proportion of carbon which is fossil |
|---|---|---|---|---|
| Animal and mixed food wastes | 27% | 14% | 100% | 0% |
| Discarded equipment (excluding discarded vehicles, batteries and accumulator wastes) | 2% | 0% | 0% | 0% |
| Glass wastes | 3% | 0% | 0% | 0% |
| Health care and biological wastes | 10% | 19% | 79% | 21% |
| Household and similar wastes (refuse and furniture) | 7% | 45% | 50% | 50% |
| Metallic wastes (mixed ferrous and non-ferrous) | 3% | 0% | 0% | 0% |
| Mineral waste from construction and demolition | 4% | 7% | 50% | 50% |
| Paper and cardboard wastes | 16% | 32% | 100% | 0% |
| Plastic wastes | 15% | 52% | 0% | 100% |
| Rubber wastes | 0% | 0% | 0% | 100% |
| Textile wastes | 6% | 40% | 50% | 50% |
| Vegetal wastes | 6% | 24% | 100% | 0% |
| Wood wastes | 1% | 44% | 100% | 0% |
| **Total** | **100%** | **26.5%** | **15.2%** | **11.2%** |

Waste composition will affect the carbon performance of different waste treatment technologies and it will change over time. This should be kept in mind when reviewing the LCA. However, the LCA was undertaken utilising a single waste composition provided by Zero Waste Scotland.

Net calorific value (net CV – the energy that is in the waste that would be released on combustion) and moisture (the proportion of the waste that comprises water, expressed in % mass terms) data for the input waste components were obtained from WRATE.

### 10.3.2 Carbon emission factors

Carbon emission factors were taken from the BEIS Greenhouse gas reporting: conversion factors[62], although not necessarily from the latest year of reporting, so that the factors were consistent with Zero Waste Scotland's EfW model. The GWP of methane (at 28 kg $CO_2$eq/kg $CH_4$ over a 100-year period) was taken from Assessment Report 5 from the IPCC[63], still used as the basis for UK government reporting. The 100-year period is the most widely used period within LCA reporting and was deemed relevant to the scenarios modelled, especially because landfill emissions will be generated long after an MBT ceases operation.

### 10.3.3 Transport activities

The default modelling assumes the distances and associated emission factors (EF) presented in Table 10, which can be changed by the user. The factors assume only full truck loads will be taken from the MBT to the landfill, but waste from the WTS to the MBT will be in average laden trucks.

[62] See https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021
[63] See https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf

Table 10. Key model parameters for IVC-alone treatment

| Parameter | Value | Unit | Commentary |
|---|---|---|---|
| Distance from WTS to MBT | 15 | km | From Zero Waste Scotland Carbon Metric 2018 |
| Distance from MBT to landfill | 50 | km | From Zero Waste Scotland Carbon Metric 2018 |
| Emission factor for waste to MBT | 0.14054 | $kgCO_2e/t.km$ | BEIS (2018) Conversion factors, Freighting goods tab - HGV (all diesel) - Articulated (>3.5 - 33t) - t.km - Average Laden |
| Emission factor for waste from MBT to landfill | 0.07723 | $kgCO_2e/t.km$ | BEIS (2018) Conversion factors, Freighting goods tab - HGV (all diesel) - Articulated (>3.5 - 33t) - t.km - 100% Laden |
| Emission factor for RDF from MBT to end user | 27.64520 | $kgCO_2e/t$ | From Zero Waste Scotland EfW model (it is the average of EFs for export to Scotland, rest of UK and Europe, in-turn based upon distance and mode of travel from Carbon Metric 2018 and EFs from BEIS (2018)) |

The EF for RDF transport is in different units to that for the transport of other waste fractions. The highest transport emissions come from the transport of RDF, because it is the average of EFs for transport to a range of locations, including shipping by sea to locations beyond the UK. If it was assumed that the end user for RDF was in Scotland, the EF for RDF transport would be 7.72 $kgCO_2e/t$, considerably below the value used. However, the model is not sensitive to such variance in transport assumptions, because transport impacts are small compared to other impacts.

### 10.3.4 Mechanical pre-sort recyclables

The level and sophistication of recyclate pre-sorting technology varies by MBT facility, so the level of material diversion was set to be one of the input parameters for the model that can be adjusted by the user. For the default, the values (for both Dry-AD+IVC and IVC alone) chosen are presented in Table 11.

Table 11: Default diversion rates for recyclates in MBT pre-sort

| | |
|---|---|
| Metal diversion rate | 75% |
| Glass diversion rate | 50% |
| Plastic diversion rate | 30% |

In general, not specific to the waste composition provided Zero Waste Scotland, nor the model's system boundaries, MBT facilities that remove metal only might typically recover around 2 or 3% of the input waste for recycling. At the other extreme, facilities that employ comprehensive methods to extract recyclables, and assuming the materials are within the input waste in enough quantity, might typically recycle around 10%, maybe as high as 15%, of input waste. Such a high level might reflect poor capture rates at the doorstep and therefore high concentration within the residual waste. A reasonable performance to assume would be in the range of 5 to 10%.

The diversion rates in Table 11, coupled with the model's input waste composition, provide a modelled removal of recyclable materials of 7.9% of input waste, which Ricardo considers to be a credible value.

Published Scottish Carbon Metric emission factors (for 2018) for the recycling of materials were obtained from Zero Waste Scotland.

### 10.3.5 RDF Separation

As discussed elsewhere in this report, many MBT facilities are designed to produce RDF, so this option can be enabled in the MBT model for MBT-IVC if desired. A continuous operation MBT-Dry

AD+IVC process would need to first produce RDF for the biological process to function, and so there is no option within the model to not remove RDF.

For simplicity, the diversion of RDF is modelled to occur post recyclate pre-sorting, although RDF and recyclate removal will occur at various stages within the mechanical pre-sort process and is subject to facility design. Based on Ricardo's experience of the performance of certain confidential MBT facilities, the model diverts waste between the RDF and residual fractions according to the splits presented in Table 12.

Table 12: Assumed waste fraction split between RDF and residual waste (after recyclate removal)

| Waste Fraction | RDF | Residual |
|---|---|---|
| Animal and mixed food waste | 5% | 95% |
| Discarded equipment (excluding…) | 10% | 90% |
| Glass wastes | 0% | 100% |
| Health care and biological wastes | 70% | 30% |
| Household and similar wastes | 50% | 50% |
| Metallic wastes, mixed ferrous and non-ferrous | 31% | 69% |
| Mineral waste from construction and demolition | 5% | 95% |
| Paper and cardboard wastes | 95% | 5% |
| Plastic wastes | 65% | 35% |
| Rubber wastes | 65% | 35% |
| Textile wastes | 95% | 5% |
| Vegetal wastes | 35% | 65% |
| Wood wastes | 75% | 25% |

The assumptions in Table 12, when coupled with the modelled input waste composition, provide a modelled RDF diversion of 43% of input waste. Waste composition and facility design varies between MBT facilities, but typically around half of all waste is removed as RDF, and so the modelled assumptions are considered reasonable.

### 10.3.6 Biological treatment process (Option 1: Dry-AD plus IVC)

Key data for the Dry-AD+IVC part of the model is provided in Table 13 and has been derived from information supplied by a dry-AD technology provider.

Table 13: Key model parameters for AD+IVC treatment

| Parameter | Value | Unit | Commentary |
|---|---|---|---|
| Electricity input to pre-sort | 17.66 | kWh/t | Ricardo assumption (not provided by technology provider). This is for the waste mass input at the very front of the MBT facility. |
| Electricity input to balance of facility | 60 | kWh/t | Per tonne of waste treated in AD (which is 50% of waste input to facility) |
| Electricity output from gas engines | 285 | kWh/t | Per tonne of waste treated in AD (which is 50% of waste input to facility) |
| Rate of use of additives | 20.5 | %w/w | Including steam, iron chloride and polymer solution-as a proportion of waste processed in AD (which is 50% of waste input to facility) |
| Rate of production of biogas | 16.8 | %w/w | As a proportion of waste processed in AD (which is 50% of waste input to facility). |
| Rate of production of effluent | 23.6 | %w/w | As a proportion of waste processed in AD (which is 50% of waste input to facility) |
| Rate of material loss | 23.0 | %w/w | As a proportion of waste processed in AD (which is 50% of waste input to facility) |

| Parameter | Value | Unit | Commentary |
|---|---|---|---|
| Rate of production of output (biostabilised waste for landfill) | 57.2 | %w/w | As a proportion of waste processed in AD (which is 50% of waste input to facility) |

### 10.3.7 Biological treatment process (Option 2: IVC alone)

Key data for the 'IVC only' part of the model is provided in Table 14 and was provided by an IVC technology provider.

Table 14: Key model parameters for IVC-alone treatment

| Parameter | Value | Unit | Commentary |
|---|---|---|---|
| Electricity input to facility (high level of recyclables removal and no RDF removal) | 39 | kWh/t | Range of 38-40 provided by technology provider |
| Electricity input to facility (typical level of recyclables removal and no RDF removal) | 36.5 | kWh/t | Range of 35-38 provided by technology provider |
| Electricity input to facility (high level of recyclables removal and with RDF removal) | 44 | kWh/t | Range of 43-45 provided by technology provider |
| Electricity input to facility (typical level of recyclables removal and with RDF removal) | 41 | kWh/t | Range of 40-42 provided by technology provider |
| Rate of recyclable removal | 7.5 | %w/w | Range of 5-10 provided by technology provider. The model only uses this to inform electricity consumption. The modelled value is determined by Ricardo/user assumptions (see section 10.3.4). |
| Rate of process loss (moisture and carbon dioxide) | 22.5 | %w/w | Range of 20-25 provided by technology provider. Ricardo assumed a quarter of this is moisture loss and the remainder is gases (predominantly $CO_2$). |
| Rate of production of biostabilised material (for landfill) | 70 | %w/w | This is the balance following removal of recyclables and process loss. If RDF is removed (see section 10.3.5) then this will impact the process loss and biostabilised material to landfill. |

### 10.3.8 Landfill emissions

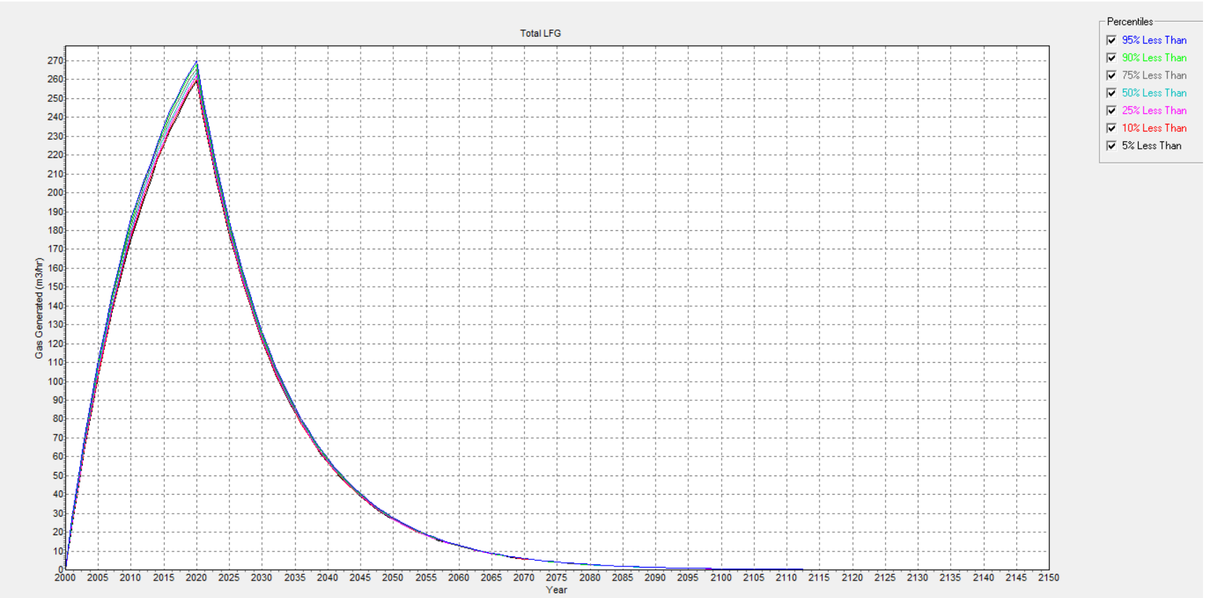
The methane emission from the landfill of biostablised residual waste has been determined using GasSimlite software. The main input assumptions used in the model are provided in Appendix A6, and some of the most pertinent assumptions are listed below:

- 70,000 tonnes per annum of composted organic material are landfilled over a twenty-year period.
- The waste is progressively capped every four years, i.e. on five occasions.
- The landfill gas is flared, noting generation of landfill gas would be so low as to not warrant use of an engine to generate energy (and any co-landfilled waste is assumed to have similarly low biodegradability). The modelled highest rate of gas generation is around 260 or 350 $m^3/h$ (subject to assumptions used), which is only achieved for a brief period.
- The lower rate of landfill gas generation that the flare will operate at is 100 $m^3/h$.

- The flare destruction efficiency for methane is 99%.
- 10% of landfill gas passing through capping soils is biologically oxidised as it passes through the soil.
- The landfill gas is 50% methane and 50% carbon dioxide.
- The period of interest is 100 years (120 years from commencement of landfill operations, or 100 years from ending of landfill operations).

During the operation of a landfill site, the total landfill gas generated will rise as more waste is input each year. On cessation of waste input, the total gas generation will reduce exponentially. The modelled total landfill gas generation chart is shown in Figure 3.

Figure 3. Total landfill gas generated




There is a lower limit of gas production, below which it is not technically and economically feasible to collect landfill gas to flare it or to combust it to produce energy. That limit is more significant when it applies to a large landfill area, because abstracting a small amount of landfill gas from a large landfill is technically challenging.

The gas generation, on a per tonne of input waste basis, is low which is because the waste has been through a composting process prior to landfill. At face value, a peak of 260m$^3$/hr may seem a lot, but that is for the landfill of 1,400,000 tonnes of composted organic material (70,000 tonnes per year over 20 years) and is not a large amount for such a high mass of landfilled material.

The software contains default properties for 'composted organic material' which were utilised (default hemi-cellulose in the range of 7.47% to 9.59% with an assumption that 57% will decompose in the landfill, and the same values again for cellulose), albeit in varied form as described below. The results were then adjusted within the LCA model to account for the other materials, that are non-biodegradable, that would also be present in biostabilised residual waste. Put another way, the biostabilised residual waste is a mix of both 'composted organic material' and all the non-biodegradable waste fractions that have not been removed as recyclable or RDF materials.

Landfills can be designed and operated in many ways and the landfill gas emissions will vary considerably subject to how and when the landfill is capped to allow the landfill gas to be flared or utilised for energy production. If landfill gas is combusted, emissions are primarily characterised by carbon dioxide (GWP of 1) in combustion products and most of the methane (GWP of 28 over 100-year period) generated in the landfill will be converted to carbon dioxide in this manner, rather than being emitted directly to atmosphere from the landfill surface.

Prior to capping, most landfill gas generated will be lost to atmosphere. Temporary capping, sacrificial local gas collection and small portable flares are sometimes utilised prior to final capping, although collection efficiency is lower than from a permanent cap and permanent gas collection system.

However, for waste that is only generating a low level of gas, such measures are of limited practicality and were not considered in the model. On the flip side, the model assumption that permanent capping would be undertaken on a five-cell phased approach is of more significance, because the greatest gas collection efficiency is from permanently capped areas. If it was, for example, assumed that permanent capping only occurred in two phases (e.g. capping in year 10 and year 20) then emissions of methane to atmosphere would be much greater than for the five-phase capping approach modelled.

Ricardo chose a balance of assumptions that was considered reasonable in practice for the type and volume of waste being landfilled.

Four model runs were performed with some changes to assumptions for each model run, as listed below:

- Model 1: Default hemi-cellulose and cellulose content of the composted organic material and a minimum flare capacity, below which gas cannot be flared, of 100 $m^3$/hr.
- Model 2: As model 1, but with a 25% reduction in hemi-cellulose and cellulose content. This assumes that meeting the Scottish ban's biostabilisation criteria will require a high degree of biostabilisation.
- Model 3: As model 1, but with a lower end flare capacity of 50 $m^3$/hr. However, most modern enclosed ground mounted flares, that meet necessary regulatory requirements, have a low-end capacity of 100 $m^3$/hr.
- Model 4: Hemi-cellulose and cellulose content, and flare, modified as described in models 2 and 3.

The GasSimlite model provides the methane and carbon dioxide quantities (mass) emissions (with the latter split by combustion products or direct emission) for each year. The total mass of each gas was derived for the whole period (120 years) and then divided by the total mass of composted organic material landfilled. The results are provided in Table 15. Any non-biodegradable materials in the biostabilised waste from an MBT facility, such as minerals, metals, plastics and so forth, are excluded from the emission calculations as Ricardo's carbon model adjusts for these.

Table 15: Assumed rates of emissions

| Scenario | Methane (t $CH_4$ / t composted organic material) | Total carbon dioxide (t $CO_2$ / t composted organic material) |
|---|---|---|
| Model 1 | 0.006755 | 0.091141 |
| **Model 2** | **0.005650** | **0.066634** |
| Model 3 | 0.004842 | 0.096694 |
| Model 4 | 0.003992 | 0.071576 |

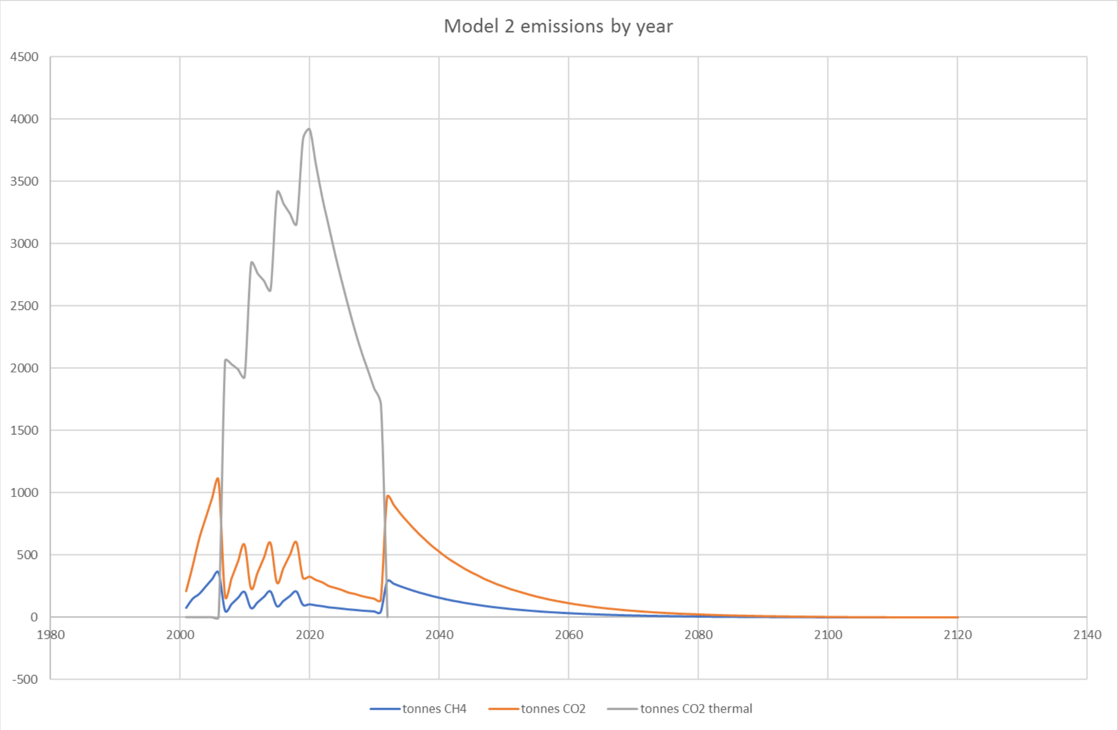
The model 2 results were selected for use in the carbon model.

Figure 4 shows the 'model 2' emissions profile (mass) across the 120 years considered and demonstrates:

- When gas is flared, the greatest mass emission is $CO_2$ within combustion products ('thermal $CO_2$).
- Progressive capping leads to a 'jagged' emissions profile because the percent of waste capped fluctuates as more waste is continually added when capping only occurs on five occasions.
- If no gas was collected, the profile of mass emissions would be similar to the profile of the volume emission of total landfill gas generated (see Figure 3). Figure 4 shows the impact that gas collection has upon gas emitted from the landfill surface, methane (GWP of 28 over 100-year period) emissions are significantly curtailed. This shows the importance of effective capping and gas collection.

- Gas can only be collected and combusted when there is enough gas present. Either side of the period when this is possible, all global warming gases will be emitted directly to atmosphere. This highlights the need to avoid the landfill of organic material, and that if it is to happen there is significant benefit in prior biostabilisation. However well designed, constructed and operated a landfill is, some direct emissions to atmosphere are inevitable, even when gas is being collected for combustion.
- When composted organic material is landfilled (same applies to biostabilised residual waste), emissions in 100 years' time are almost nil.

Figure 4. Model 2 emissions profile




# 10.4 Results

## 10.4.1 Default carbon modelling

As described above, many assumptions had to be made to arrive at a complete model of the fate of residual waste through an MBT process, and its associated carbon impacts.

Using the default inputs within the model, the overall carbon results are as follows:

- **Treatment of residual waste through an MBT facility employing Dry-AD and IVC technologies (which must involve RDF removal prior to biostabilisation), followed by landfill, yields a carbon impact of 66 kg$CO_2$e per tonne.**
- **Treatment of residual waste through an MBT facility employing IVC technology alone (without RDF removal), followed by landfill, yields a carbon impact of 12 kg$CO_2$e per tonne.**

Further detail, showing constituent components of the results, are provided in Table 16 at the end of section 10.4

The following conclusions can be made:

Dry-AD+IVC versus IVC only

- Both Dry-AD+IVC and IVC only create a carbon impact.

- Dry-AD+IVC provides the greatest impact (66kg $CO_2$e/t versus 12kg $CO_2$e/t for IVC only), principally due to the requirement to produce RDF and the net impact of combusting that RDF to generate electricity. From a carbon LCA perspective, IVC performs better than Dry-AD+IVC.
- The carbon saving from extracting materials for recycling is the same for both MBT options, because the removal of recyclable materials in pre-sort is independent to the form of biological processing subsequently employed.
- Transport and materials only contribute to the overall impact at a low level.
- The impact from landfill methane emissions is greater for IVC only than for Dry-AD+IVC (81kg $CO_2$e/t versus 33kg $CO_2$e/t). The difference is because RDF removal reduces the amount of waste landfilled and that RDF is rich in biogenic carbon (modelled biogenic carbon content of RDF is 20.4% versus 13.0% for residual waste after RDF removal).

Dry-AD+IVC (with obligatory RDF production)

- The overall result is predominantly driven by RDF production (impact of 128kg $CO_2$e/t, comprising combustion emissions of 216kg $CO_2$e/t, only partially compensated for by a benefit from electricity generation of 88kg $CO_2$e/t). RDF removal in pre-sort is an unavoidable requirement for continuous operation Dry-AD+IVC processes.
- The second largest contribution to the result is a carbon saving of 84kg $CO_2$e/t resulting from the recycling of materials extracted in pre-sort. The biggest saving is from the recycling of metals.
- Transport and materials make the lowest contributions (impacts of 15kg $CO_2$e/t and 3kg $CO_2$e/t respectively). That is despite the model assuming that the emission factors for RDF transport are the average of transport within Scotland, within the remainder of the UK and overseas transport involving transport by sea.
- The electricity produced by the AD process (burning biogas in a CHP engine) more than offsets the electricity consumed by the facility. The overall carbon saving, after the offset, is 28kg $CO_2$e/t. However, that saving from the AD process can only be achieved by first removing RDF materials from the waste in pre-sort, and the impact of RDF combustion greatly outweighs that saving.
- Methane emissions from landfill provide a modest impact, at 33kg $CO_2$e/t. That impact would be greater if RDF was not removed in pre-sort. RDF comprises 43% of all input waste and has a high biogenic carbon content, with paper and cardboard making the largest single contribution. If that RDF was landfilled the methane emissions from landfill would increase. However, that is not possible because the RDF would not comply with the Scottish ban biostabilisation criteria. Whilst paper and cardboard extracted from residual waste can be recycled in theory, in practice the quality of paper and cardboard removed from residual is poor and so the model assumes that it is not removed for recycling.

IVC only (without RDF production)

- The overall result is predominantly driven by recycling of materials (carbon saving of 84kg $CO_2$e/t) and methane emissions from landfill (carbon impact of 81kg $CO_2$e/t).
- Transport and energy consumption are minor contributors to the overall impact.

In future years, the mix of the supply of electricity to the grid in Britain is expected to decarbonise substantially to meet legally binding targets. A grid mix with lower carbon intensity will entail lower carbon emissions from the production of electricity consumed at MBT facilities, as well as lower carbon benefits associated with electricity generation at Dry AD facilities or generated from the combustion of RDF separated at MBT facilities. Overall, this is likely to make IVC without RDF production even more advantageous, from a carbon performance perspective, compared to Dry-AD with IVC and IVC with RDF production.

### 10.4.2 Diversion of RDF stream in IVC only MBT

The first sensitivity test was to enable diversion and subsequent combustion of RDF for the IVC only option. This would simultaneously provide carbon impacts and savings as follows:

- Impact from the combustion of fossil carbon in the waste to create $CO_2$.
- Saving from the associated generation of electricity from the heat produced by combustion (electricity production assumed to be 24% efficient- based on the average of three Scottish facilities reported in Zero Waste Scotland's EfW model).
- Reduced impact from the lower mass of biostabilised waste landfilled, noting that the RDF has greater biogenic carbon content than the residual waste remaining after its removal.

The results are presented in Table 16 and, when compared to Dry-AD+IVC and IVC only with no RDF production, demonstrates:

- IVC with RDF production has a greater overall carbon impact (115kg $CO_2$e/t) than IVC without RDF production (12kg $CO_2$e/t), which is due to the large impact of combusting RDF that contains fossil carbon that would be 'stored' if deposited in landfill. That impact is the greatest contributor to the overall result for IVC with RDF production.
- IVC with RDF production is the worst of all options, from a carbon LCA perspective, noting that it does not have the positive saving gained from electricity production from biogas generated in the Dry-AD process (the overall impact of the Dry-AD+IVC process is 64kg $CO_2$e/t).
- The landfill methane emissions are broadly similar for IVC with RDF production (45kg $CO_2$e/t) and Dry-AD+IVC (with obligatory RDF production) (33kg $CO_2$e/t). Those emissions are much lower than landfill methane emissions for IVC without RDF production (81kg $CO_2$e/t).

Table 16. Carbon impact assessment results (NB. +ve value is benefit and –ve value is impact)

| | | Dry AD+IVC (kg $CO_2$eq/t MSW) | IVC (no RDF) (kg $CO_2$eq/t MSW) | IVC (RDF) (kg $CO_2$eq/t MSW) |
|---|---|---|---|---|
| **Pre sort** | Glass (50%) | +11 | +11 | +11 |
| | Fe/non-Fe Metal (75%) | +49 | +49 | +49 |
| | Plastic (30%) | +24 | +24 | +24 |
| | **Sub-total** | **+84** | **+84** | **+84** |
| **Transport** | To MBT | -2 | -2 | -2 |
| | From MBT | -1 | -3 | -2 |
| | From MBT (RDF) | -12 | | -12 |
| | **Sub-total** | **-15** | **-5** | **-16** |
| **Materials** | Water supply | 0 | | |
| | Auxiliary materials | -3 | | |
| | Water treatment | 0 | | |
| | **Sub-total** | **-3** | | |
| **RDF** | Electricity generation | +88 | | +88 |
| | RDF combustion | -216 | | -216 |
| | **Sub-total** | **-128** | | **-128** |
| **Energy** | Electricity consumed | -14 | -10 | -12 |
| | Electricity produced | +43 | | |

| | | Dry AD+IVC (kg $CO_2$eq/t MSW) | IVC (no RDF) (kg $CO_2$eq/t MSW) | IVC (RDF) (kg $CO_2$eq/t MSW) |
|---|---|---|---|---|
| | **Sub-total** | **+28** | **-10** | **-12** |
| **Landfill** | Methane emissions | **-33** | **-81** | **-45** |
| | **Grand total** | **-66** | **-12** | **-115** |

### 10.4.3 Wider sensitivity tests

With the above results in mind, the next step was to explore the sensitivities in the results to the numerous assumptions made in the calculations and described above. It was not practicable to explore how the results responded to changes in every input, so it was decided to focus on the following parameters:

- Glass recycling
- Metal recycling
- Plastic recycling
- Landfill gas emissions
- RDF combustion efficiency

For each of the above parameters, the input values were reduced by 20% or increased by 20% from the default value, to see what influence the change would have on the final GHG benefit. The results are presented schematically in Figure 5, where:

- The green circles reveal the, pre-sensitivity analysis, default values for the overall GHG benefit.
- In most cases, increasing the parameter by 20% increases the GHG benefit (so the orange triangle appears above the green circles). However, this is reversed for landfill gas emissions, where higher emissions reduce the GHG benefit.
- The variance between the three MBT types is similar for the same parameters, other than for two exceptions. Where RDF is not produced, in the scenario of IVC only without RDF production (the middle of the three scenarios in Figure 5) the impact upon GHG benefit of adjusting the percentage of plastic recycled is less than for the other two scenarios. The quantity of plastic within RDF will be influenced by the amount of plastic removed for recycling and it has a notable impact upon GHG benefit when it is incinerated. However, if no RDF is produced, any plastic not recycled will be landfilled without creating emissions. The second exception is the influence of landfill gas emissions in the IVC scenario without RDF production. In this case, more material will be landfilled, than in the other two scenarios, and that will include biodegradable materials such as cardboard, which will cause more landfill gas to be generated.
- The parameter of most impact, for the scenarios with RDF, is RDF combustion, while for the IVC without RDF, the landfill gas emissions impact the results the most.

As with any model, Ricardo's model contains many assumptions and changes in some assumptions can be expected to influence the overall model results. However, the sensitivity analysis demonstrates that, whilst some impact is seen for all three scenarios, the overall finding remains unchanged; from a carbon perspective, IVC without RDF production performs best, IVC with RDF production performs worst and dry AD+IVC sits between the two.

Figure 5: Schematic presentation of sensitivity analysis

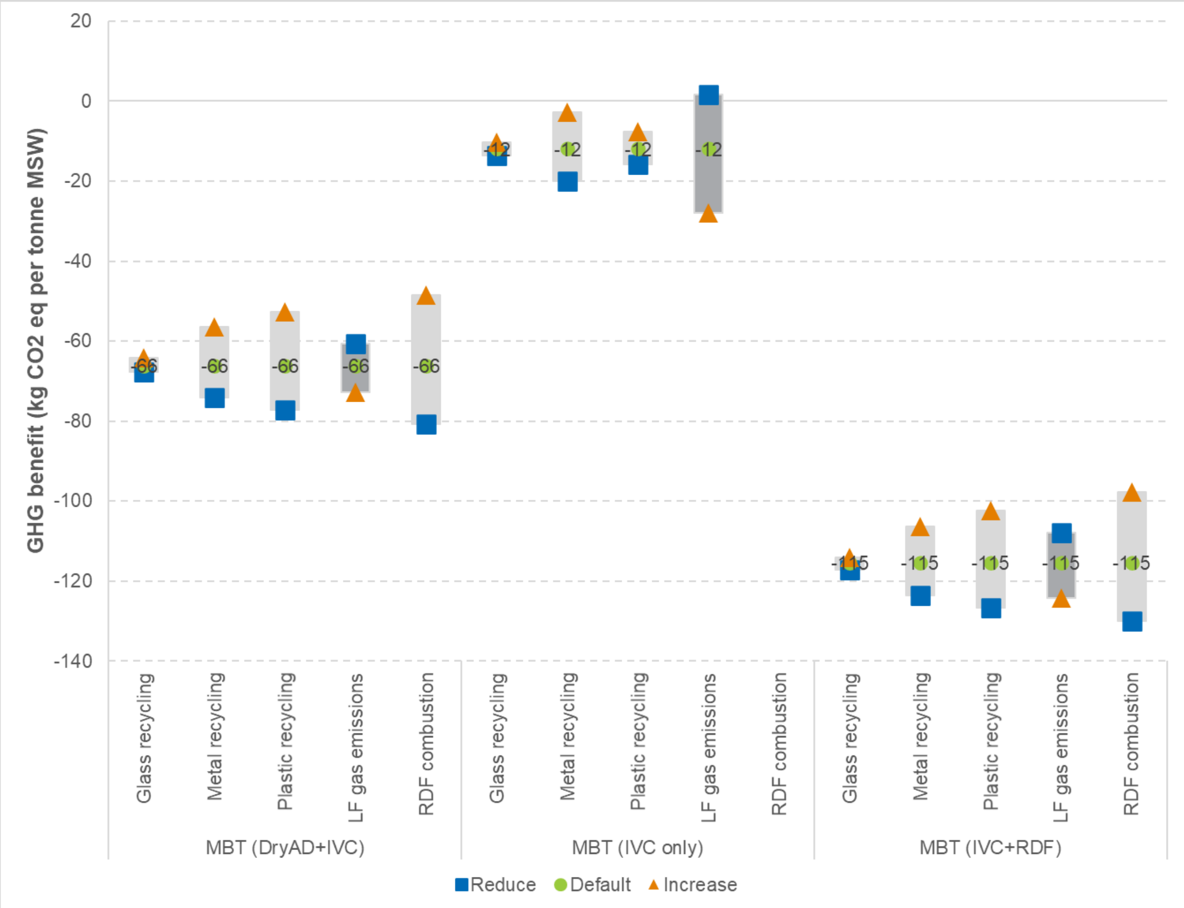



Table 17 presents the sensitivity analysis results in more detail.

Table 17: GHG Benefit (kg $CO_2$eq per tonne MSW) and impact of parameters

| | Dry AD+IVC | % change (from default) | IVC (no RDF) | % change (from default) | IVC (with RDF) | % change (from default) |
|---|---|---|---|---|---|---|
| Overall GHG benefit (default- no sensitivity analysis) | -66 | - | -12 | - | -115 | - |
| Effect of 20% increase in glass recycling | -64 | 3% | -10 | 13% | -114 | 1% |
| Effect of 20% decrease in glass recycling | -68 | -2% | -14 | -15% | -117 | -2% |
| Effect of 20% increase in metal recycling | -56 | 15% | -3 | 77% | -106 | 8% |
| Effect of 20% decrease in metal recycling | -74 | -12% | -20 | -69% | -124 | -7% |
| Effect of 20% increase in plastic recycling | -53 | 20% | -8 | 35% | -102 | 11% |

| | Dry AD+IVC | % change (from default) | IVC (no RDF) | % change (from default) | IVC (with RDF) | % change (from default) |
|---|---|---|---|---|---|---|
| Effect of 20% decrease in plastic recycling | -77 | -17% | -16 | -34% | -127 | -10% |
| Effect of 20% increase in RDF combustion efficiency | -49 | 27% | n/a | n/a | -98 | 15% |
| Effect of 20% decrease in RDF combustion efficiency | -81 | -22% | n/a | n/a | -130 | -13% |
| Effect of 20% increase in landfill gas emissions | -73 | -10% | -28 | -137% | -124 | -8% |
| Effect of 20% decrease in landfill gas emissions | -61 | 8% | 2 | 114% | -108 | 6% |

## 10.5 Biogenic carbon stored in landfill

When waste decomposes in a landfill some biogenic carbon will remain as it is not all degraded. Fossil carbon, e.g. plastic of petroleum origin, will practically remain in entirety as it degrades extremely slowly compared to biogenic carbon, and not to a meaningful level within the 100/120-year timeframe considered in the landfill emission assessment. It is the stored/sequestered fossil carbon that will make the biggest difference when it is landfilled rather than incinerated.

This stored carbon, whether biogenic or fossil, is neither an emission nor a carbon saving and so does not form part of Ricardo's carbon LCA. However, Zero Waste Scotland requested that an assessment be made of the biogenic carbon remaining in the landfill. Zero Waste Scotland was interested because most of that biogenic carbon would be released as carbon dioxide if the waste was incinerated and the information will assist interested parties when making carbon balance comparisons between different methods of treating residual waste.

The approach agreed between Zero Waste Scotland and Ricardo, was to determine the biogenic carbon present in the incoming waste (152.08 tonnes of biogenic carbon for 1,000 tonnes of residual waste input into the MBT facility) (using the Zero Waste Scotland supplied data presented in Table 9) and to deduct all emissions of biogenic carbon throughout the MBT and landfill processes. This required the determination of those biogenic emissions, whether carbon dioxide or methane, and establishing the carbon present within those emissions. The emissions considered are listed below.

For Dry-AD+IVC, the following biogenic emissions were discounted (for 1,000 tonnes of residual waste input into the MBT facility):

- Biogenic carbon removed with the RDF (88.84 tonnes)
- Biogenic carbon in $CO_2$ emitted by the IVC process (4.37 tonnes)
- Biogenic carbon in effluent (3.94 tonnes)
- Biogenic carbon in $CO_2$ entering and exiting the CHP engine at the AD facility, i.e. not a combustion product (16.35 tonnes)
- Biogenic carbon in $CO_2$ generated by the combustion of $CH_4$ in the CHP engine at the AD facility (21.45 tonnes)
- Biogenic carbon in $CH_4$ landfill emissions (0.88 tonnes)
- Biogenic carbon in $CO_2$ landfill emissions (3.79 tonnes)

For IVC without RDF production, the following biogenic emissions were discounted (for 1,000 tonnes of residual waste input into the MBT facility):

- Biogenic carbon in $CO_2$ emitted by the IVC process (46.02 tonnes)
- Biogenic carbon in effluent (there will be effluent produced, but data was not provided by the technology provider- however, this is a minor impact upon the carbon balance)
- Biogenic carbon in $CH_4$ landfill emissions (2.17 tonnes)
- Biogenic carbon in $CO_2$ landfill emissions (9.30 tonnes)

For IVC with RDF production, the following biogenic emissions were discounted (for 1,000 tonnes of residual waste input into the MBT facility):

- Biogenic carbon removed with the RDF (88.84 tonnes)
- Biogenic carbon in $CO_2$ emitted by the IVC process (19.14 tonnes)
- Biogenic carbon in effluent (there will be effluent produced, but data was not provided by the technology provider- however, this is a minor impact upon the carbon balance)
- Biogenic carbon in $CH_4$ landfill emissions (1.2 tonnes)
- Biogenic carbon in $CO_2$ landfill emissions (5.14 tonnes)

The biogenic carbon remaining in the landfill (after 100/120 years) for each of the three scenarios is presented in Table 18.

Table 18. Biogenic carbon remaining in landfill after 100/120 years.

| MBT Scenario | Biogenic carbon stored / 1,000 tonne input to MBT (tonne) | Biogenic carbon stored / 1,000 tonne input to MBT ($kgCO_2e$) | Biogenic carbon stored / 1 tonne input to MBT ($kgCO_2e$) |
|---|---|---|---|
| Dry-AD+IVC (RDF removal obligatory) | 12 | 45,703 | 45.7 |
| IVC without RDF production | 95 | 346,826 | 346.8 |
| IVC with RDF production | 38 | 138,470 | 138.5 |

# 11 Non-carbon environmental impacts

Many of the non-carbon potential environmental risks of MBT are similar in nature to most other forms of residual waste treatment, and measures can be put in place to help mitigate impacts. Risks may include:

- Traffic
- Noise
- Litter
- Dust
- Odour
- Bioaerosols
- Pests (rodents, birds, flies etc.)
- Liquids and effluents (leachate, wastewater and process chemicals)
- Animal by-products

As reported in trade press, several British MBT facilities have been subject to high levels of complaints and regulatory attention in relation to odour and pests, notably flies.

The nature of MBT processes means that waste is typically temporarily stored in several areas of the facility, including incoming waste, separated outputs awaiting collection or waste undergoing biodrying or full IVC processing. Furthermore, mechanical separation processes involve waste being transported on conveyors and being thrown around within equipment.

With the extent of waste storage and mechanical handling that takes place at MBT facilities, the potential for odour issues is often greater than for EfW facilities, where the main source of odour is limited to reception areas for delivered waste.

MBT facilities involving aerobic processes, which is likely to include any facility designed to biostabilise waste destined for landfill in Scotland, draw air through the waste and that air can contain high levels of odour, especially if the waste contains high nitrogen content or there are anaerobic zones within the waste mass. The air removed from composting processes will also contain bioaerosols which can be harmful if inhaled.

Biogas at AD facilities is odorous, but it should not be routinely released to atmosphere. Careful maintenance and process control can mitigate emission of biogas to atmosphere.

Risks from odour and bioaerosols can be mitigated with careful design and careful selection of facility location and activities should take place within buildings maintained under negative pressure with thorough treatment of extracted air prior to emission.

Employees at MBT facilities are also at risk from inhalation of bioaerosols, dust and gases such as ammonia and hydrogen sulphide. The risk can be managed with careful attention to building ventilation, monitoring and gas alarms and personal protective equipment.

# 12 Conclusions

## 12.1 MBT technology and ability to achieve ban criteria

Some MBT technologies can treat BMW to a level of biostabilisation that will meet the Scottish ban criteria, and it performs well from a carbon emissions perspective. However, MBT can take many forms and its implementation can be problematic.

Some forms of MBT, wet-AD and biodrying, will not stabilise BMW enough for it to meet the Scottish ban criteria. Such MBT approaches could, nonetheless, have a role to play in diverting waste from landfill. However, the brief for this study was to consider biostabilisation to allow subsequent landfill of waste, informed by an interest in understanding the carbon balance performance of such a practice.

In all instances, IVC is necessary to achieve the required extent of biostabilisation for subsequent landfill of the waste. Where that is preceded by dry-AD, it will be necessary to first remove materials that are best suited for use as RDF. IVC alone can be undertaken without RDF removal.

The brief for this study had a focus on biostabilisation of waste with a view to it being landfilled. Some MBT facilities do that, but it is not common[64].

Some MBT facilities biostabilise, or biodry, waste followed by refining of the IVC output for use as RDF, and many more remove RDF materials in mechanical pre-treatment irrespective of what happens to the output of the biological process. It is very common for MBT facilities to generate RDF at some point in the process. If that RDF is combusted such that the carbon content of its ash is below the ban criteria, then such practice will help Scotland in complying with the ban. However, RDF combustion has a greater carbon impact than the landfill of that same material if it has first been biostabilised.

## 12.2 Carbon lifecycle assessment

All scenarios modelled in the Carbon LCA showed a calculated carbon impact (not benefit), per tonne of residual waste treated, as shown below.

- IVC only, without RDF production: 12kg $CO_2$eq/t
- Dry-AD+IVC (must involve RDF production): 66kg $CO_2$eq/t
- IVC only, with RDF production: 115kg $CO_2$eq/t

The greatest influences on the carbon balance are whether RDF is produced, and subsequently combusted elsewhere for energy recovery, and whether materials are recycled. The former unfavourably impacts the carbon balance whereas the latter benefits it.

The combustion of RDF has a net impact (not benefit) of high significance to the overall carbon balance, as is evident from the difference between the two IVC only scenarios considered (see above). That is due to the combustion of fossil carbon, which is ‘stored’ if landfilled under an MBT scenario wherein RDF is not generated and the MBT output is landfilled.

Dry-AD+IVC has the benefit that biogas, of biogenic origin, is produced and combusted to generate electricity, but that advantage comes with a need to remove RDF and the impact associated with RDF combustion.

In future years, the mix of the supply of electricity to the grid in Britain is expected to decarbonise substantially to meet legally binding targets. Overall, this is likely to make IVC without RDF production even more advantageous, from a carbon performance perspective, compared to Dry-AD with IVC and IVC with RDF production.

For many years, waste policy and waste legislation within Europe has focussed on reducing reliance upon landfill and on applying the waste hierarchy. The carbon impacts of waste management options have had some bearing on those drivers, e.g. fugitive methane emissions from landfills have

[64] For example, the Waterbeach MBT facility in Cambridgeshire is the only British facility identified as doing that (see section 4.4).

influenced thinking, as has the carbon and resource benefits of recycling of materials. However, the consideration of the holistic net carbon balance of waste management options has not played a central role in informing decision making, although it is likely to become more prominent in future decision making.

Carbon impacts are not the only aspect that needs to be considered. Any solution must be sustainable, in all senses of the word, for the anticipated lifetime of a waste facility. Other aspects that have been considered in this study are discussed below.

## 12.3 Experience of MBT implementation in Britain, France, Germany, Italy and Spain

On paper, MBT looks good and promises a lot. Nonetheless, EfW is more popular, in terms of number of facilities and tonnage treated, than MBT in Britain.

The experience of MBT in Britain and in mainland Europe has been heavily focussed on processes that generate RDF. Some projects have failed, and some have had issues associated with accommodating the waste composition and changes to it.

All but one of Britain's 23 MBT facilities produced RDF in 2019. The operator of the facility that does not produce RDF wishes to construct an energy from waste facility at the site.

Ricardo staff have, collectively and including experiences outside of Ricardo, worked on several British MBT projects in a range of roles and including facilities that have been subject to disputes, insurance claims and some ceasing to operate with MBT processes.

Five of the case study sites featured in this report, all located in France, Germany and Spain produce RDF. It is unclear whether the sixth case study site, located in Spain, produces RDF. The authors of this report are not aware of any Italian MBT facilities that do not produce RDF.

The case studies reviewed in this study number just six, and they were not selected with any prior knowledge of any issues that might have been experienced. However, some of the facilities have encountered issues, sometimes linked to a change in waste composition and sometimes resulting in a need to modify the process or cease input of residual waste. The four countries reviewed differ considerably in waste policy and tax instruments, including policies and approaches that may or may not favour MBT over other residual waste management methods. They do all, however, have high level similarities aimed at diverting waste from landfill, waste reduction and application of the waste hierarchy.

Zero Waste Europe published a report promoting alleged benefits of MBT facilities that have possible high recycling levels, including via extrusion of mixed plastics, and that do not produce RDF. The report stated that such facilities have a high degree of flexibility. These statements do not reflect the experiences of Ricardo staff. The extrusion of mixed plastics separated at MBT facilities is not normal practice, and Ricardo is aware of a waste contractor that investigated its feasibility and did not proceed with implementation.

MBT processes involve separation of different components of residual waste, for recycling or further treatment. Any waste component separated will inevitably, with a practicable degree of processing, be of lower quality than it would be if it arose through source segregation; residual waste is a low-quality waste stream and its reduction must be given high priority.

Source segregated organics are much better quality than organic fines from MSW, i.e. organic material separated in an MBT facility. In most instances, source segregated organics can be treated to reach end of waste status. In France and Spain, compost and digestate of residual BMW origin can gain end of waste status, albeit that is to stop in France from 2027. At present, that is a factor in favour of MBT in France and Spain. In Scotland, it is not possible for organic material from residual waste to gain end of waste status.

MBT processes can be complex and sensitive to changes in waste composition over time, for example introducing source segregated organics collection can have a significant impact. Such impact is likely to be greatest at an AD facility, whose design and anticipated performance involve electricity, heat or biomethane production from the organic fraction of the waste. However, the process loss will be reduced in an IVC facility if the organic content in the input waste reduces. If the aim of the facility is to stabilise waste prior to landfill, the impact may not be too significant for an IVC facility. If the aim is to minimise waste sent to landfill, it may be more significant because low process loss reduces the benefit that the biological process brings in terms of mass reduction.

With consideration to Scotland's BMW, MBT with biostabilisation of waste prior to landfill is bound to result in more waste being landfilled than would result from the landfill of ash and air pollution control residues from EfW processes.

How the contract between a local authority and waste management company is structured, and what performance guarantees and penalties are within that contract, is important to the long-term sustainability of the contract. That applies to any waste management contract, but the complexity of MBT processes and the range of facility outputs can increase the chance of contractual disputes.

The performance of an MBT facility contract will also be greatly influenced by available markets for outputs and the UK experience has shown that securing outlets for CLO is particularly problematic. Furthermore, the quality of recyclable materials separated at MBT facilities can be poor and market prices highly variable. However, if residual waste was subject to removal of recyclable materials, biostabilisation and landfill, without RDF production, there would be no need to find an outlet for CLO.

## 12.4 Recommendations

To employ MBT in Scotland, with landfill of most of the facility outputs, would require a step-change in attitude and approach by many involved, in whatever manner, in waste management. That approach is not currently practiced in Scotland, and only one English facility has been identified that does so.

If employed, the result would be unlikely to cause a decrease in waste landfilled. It would most likely increase, and it would not be in keeping with the waste hierarchy, wherein energy recovery is deemed preferable to landfill.

If further consideration is to be given to MBT development in Scotland, Ricardo's recommendations for future consideration are detailed below:

1. Priority should always be given to minimising waste generation, and to collection of source segregated waste wherever practicable. The carbon LCA undertaken for this study demonstrates the carbon benefits that recycling brings. However, recovering and recycling components of residual waste is more difficult than for source segregated materials. Furthermore, unlike organic fines from MBT of residual waste, source segregated organics can be processed to gain end of waste status in Scotland. If successful source separation of recyclable materials and organic waste in Scotland limits opportunities for MBT in Scotland, then that must be considered a good outcome so long as residual waste generation is minimised as much as possible.
2. Establishing a typical gate fee cost for MBT processes is hindered by the wide variety of processes and outputs that MBT can involve, as well as the cost often being wrapped-up within wider waste management costs under complex PPP/PFI contracts. However, the available evidence indicates that it is not a cheaper option than EfW but instead a similar, or potentially greater, cost. If MBT was to be promoted in Scotland, it is likely that policy or financial instruments would need to be developed to allow it to become the favoured option. If MBT aimed at landfill and not RDF production was to be promoted, then a review could be undertaken into how landfill tax might be applied to support such practice.
3. A review could be made of the waste hierarchy and whether it requires amendment, in a time when the carbon balance of waste management is becoming ever more prominent in decision making. The carbon LCA undertaken in this study demonstrates a marked difference in incinerating RDF versus its landfill, if that material is biostabilised prior to landfill.
4. A review could be made of the experience of MBT implementation in England. That might include liaison with UK waste management companies and local authorities that have experience of MBT implementation. That was not within the remit of this study, which was primarily aimed at understanding practices in continental Europe. However, the regulatory

and market environment in England has more similarity to Scotland, and the technologies employed in different countries are broadly similar. A lot of the technology installed at English MBT facilities is supplied by companies based in continental Europe.

5. A review could be made of the remaining landfill capacity in Scotland and changes in the tonnage and volume inputs to Scottish landfills that might result from the landfilling of biostabilised residual waste in Scotland. That was outside the remit of the current study.
6. A review could be made of the practice of producing mixed polymer pellets from materials separated at MBT facilities. To begin with, that could involve liaison with Zero Waste Europe to understand the evidence base informing its statements.
7. Because most designers and operators of MBT facilities are familiar with RDF production, greater due diligence will be needed if selecting MBT-IVC technologies that do not involve RDF production. With no RDF production, there will be more waste input to biological treatment processes. It is likely that waste will have a different density, particle size profile and potentially materials that may have a negative impact on the ability to turn the waste. The suitability of MBT will have to be assessed on a case by case basis and with consideration to the local authority specific residual waste composition and any forecast future variation.

# Appendices

# A1 Typical mechanical pre-treatment technologies

Wet AD of residual waste requires addition of water and equipment to produce a homogenous organic slurry, along with equipment to remove grit and plastic contaminants. However, for the reasons explained in section 3.1.3 of this report, wet AD is not appropriate to the focus of this report and so this equipment is not considered further here.

Equipment commonly found in the ‘pre-treatment’ (prior to the biological process) part of an MBT process is described in the table below.

| Equipment | Description/purpose |
|---|---|
| Grabs | For inputting waste. These are typically mounted on mobile plant or overhead crane rails. |
| Conveyors | An MBT facility mechanical pre-treatment process will feature conveyors, often belt conveyors, to convey waste through the process and between items of equipment. |
| Bag openers | To open bags to liberate contents, without shredding the waste. |
| Shredders | For size reduction. Sometimes situated near the beginning of the process, but not in all instances, although generally present somewhere within the process flow. Often employed as a final step in an RDF line at MBT facilities. They are often installed with screen baskets beneath the cutting rotors, such that material will only exit once its size is reduced sufficiently to allow its exit. |
| Trommel screens | A trommel screen (often simply called a ‘trommel’) is an inclined cylindrical screen/s that rotates along its axis. Trommel apertures can be round or square and formed of wire mesh, punch-plate holes or thick metal bars. When waste enters, it is churned around such that most waste particles, if small enough, should have an opportunity to pass through the screen. A trommel can have one or more screen sizes installed in series and will also generate an ‘oversize fraction’ formed of material too large to fit through the screen apertures. Trommels are often found near the start of the MBT process and the smallest particle size output fraction is often the fraction that contains the most organic material. Trommel screens are also often employed to remove oversize material in CLO refining. Some oversize material will make it through the screen if it is only oversize in one dimension, such that it can potentially pass through the screen apertures if presented ‘end-on’, as is possible with any screen. Similarly, some fine fraction material will make it into all fraction flows, owing to entrainment within the larger particle size materials. No separation process is perfect. |
| Vibrating screens | These are flat screens and normally have two outputs, being undersize and oversize. Vibrating screen can be a single screen or can be formed of a deck of screens. There are a variety of other screen types, including star screens and finger screens. |
| Ballistic separators | These take advantage of individual waste component shape, to separate flat fractions, e.g. paper and card, from rolling fractions, e.g. bottles and cans. They also act as screens to capture fine material. A series of slightly inclined ‘steps’ rapidly move up and down with a small front and back oscillating movement. The upper plate of the steps has apertures in it, through which fine material can fall through. Rolling fraction materials roll back down the steps, while flat fraction materials are ‘walked’ in the opposite direction. |
| Overband magnets | Used to remove ferrous metals. These electromagnets sit above conveyor belts and have their own short conveyor belt that circulates around the magnet. The magnet attracts the metal object from the conveyor beneath and the integral belt around the magnet then moves |

| Equipment | Description/purpose |
|---|---|
| | the metal object to the side, away from the magnet. Once the metal object has been moved away from the magnet, it drops into a bin or bunker. |
| Eddy current separators | Used to remove non-ferrous metals. The waste enters the unit, often via a vibrating plate to distribute the waste in a thin layer, and travels along a short fast-moving conveyor belt. The waste that is not non-ferrous metal drops from the end of the conveyor via a chute. The chute has a partition ‘splitter wall’ within it. Non-ferrous metals are repelled from the end of the conveyor via fast spinning rotor magnets within the conveyor’s end pulley. The non-ferrous metal items are flung over the splitter wall into the second half of the chute from where they typically drop into a bin or bunker. |
| Optical sorters | Used to remove selected waste by material type, often different types of polymers. As waste passes along a conveyor belt, it passes beneath overhead instrumentation oriented across the width of the conveyor belt. The overhead equipment emits near infrared light and measures the wavelength of returned light reflected from the waste. This allows material identification, and the equipment detects the location of the desired material across the width of the belt. Running across the width of the head end of the conveyor, is a strip of nozzles attached to compressed air. The optical sorting equipment utilises the measured location of the desired material, and the speed of the conveyor belt to discharge a short burst of compressed air from the appropriate nozzle as the desired waste item passes over it. The main waste stream drops through a chute from the end of the belt. However, the discharge of compressed air blasts the desired waste component over a splitter wall in the chute in order to separate it from the main waste flow. |
| Air classification equipment | This can take various forms and relies upon a flow of fast-moving air to strip away light fractions such as plastic film. |
| Baling equipment | Used to produce bales of separated materials, typically with wire or plastic ties. |
| Compacting bins | Used to compact waste into a container for removal from site. Often utilised for RDF. |

# A2 English MBT facilities

| MBT facility/ fate of outputs (2019 waste return) | Type of biological process/ fate of outputs (2019 waste return) |
|---|---|
| North Manchester MBT (Reliance Street) | Wet AD<br><br>The MBT process generates RDF in pre-treatment. Data is available for two environmental permits, which is understood to reflect the handover of operations in mid-2019 from Viridor to Suez. Under one permit ‘incinerator’ accounted for 30% of outputs, whereas for the other it accounted for 70% of outputs. The lower number was associated with a higher ‘transfer’ value, which included a lot of RDF. RDF is a notable output. |
| Total tonnes of solid outputs | 120,513 |
| Incinerator | 39% |
| Landfill | 24% |
| Recovery | 5% |
| Transfer | 30% |
| Treatment | 1% |
| Bredbury Parkway MBT (Manchester) | Wet AD<br><br>The facility includes HWRC, transfer station, IVC and MBT-Wet AD.<br><br>The MBT process generates RDF in pre-treatment. The ‘treatment’ and ‘recovery’ material percentages cited are largely formed of ‘biodegradable kitchen and canteen waste’ and so would not be associated with the MBT facility. The MBT facility is, therefore, likely to have generated >42% RDF in 2019. |
| Total tonnes | 172,670 |
| Incinerator | 42% |
| Landfill | 1% |
| Recovery | 22% |
| Transfer | 3% |
| Treatment | 31% |
| Arkwright Street Resource Recovery Centre (Manchester) | Wet AD<br><br>The site is actually a residual waste MRF (organic fines are sent to Bredbury Parkway wet AD) |
| Total tonnes | 88,935 |
| Incinerator | 20% |
| Landfill | 3% |
| Recovery | 18% |
| Transfer | 60% |
| Treatment | 0% |
| South Manchester Resource Recovery Centre (Longley Lane) | Wet AD |
| Total tonnes | 267,818 |
| Incinerator | 55% |
| Landfill | 5% |

| MBT facility/ fate of outputs (2019 waste return) | Type of biological process/ fate of outputs (2019 waste return) |
|---|---|
| Recovery | 38% |
| Transfer | 2% |
| Treatment | 0% |
| Cobden Street MBT (Manchester) | Wet AD |
| Total tonnes | 97,000 |
| Incinerator | 50% |
| Landfill | 7% |
| Recovery | 7% |
| Transfer | 34% |
| Treatment | 3% |
| Byker Resource Recovery Centre (Newcastle Upon Tyne) | MRF (organic fines are sent to Ellington IVC) |
| Total tonnes | 114,319 |
| Incinerator | 56% |
| Landfill | 14% |
| Recovery | 29% |
| Transfer | 1% |
| Treatment | 0% |
| Brookhurst Wood MBT (Horsham, West Sussex) | Wet AD |
| Total tonnes | 179,948 |
| Incinerator | 41% |
| Landfill | 17% |
| Recovery | 5% |
| Transfer | 24% |
| Treatment | 12% |
| Bursom Waste Treatment Facility (Leicester) | MRF (organic fines are sent to Wanlip wet AD) |
| Total tonnes | 114,246 |
| Incinerator | 36% |
| Landfill | 31% |
| Recovery | 31% |
| Transfer | 1% |
| Treatment | 0% |
| Waterbeach MBT (Cambridgeshire) | IVC<br>The main destination of the output from the IVC process is landfill. However, the operator (Amey) is keen to construct an energy from waste plant to prevent the landfill of the output. A planning appeal was rejected in June 2020. |

| MBT facility/ fate of outputs (2019 waste return) | Type of biological process/ fate of outputs (2019 waste return) |
|---|---|
| Total tonnes | 101,723 |
| Incinerator | 0% |
| Landfill | 90% |
| Recovery | 2% |
| Transfer | 8% |
| Treatment | 0% |
| Southwark IWMF (London) | Biodrying<br>The facility includes a co-mingled MRF, MBT (aimed at RDF production), reuse and recycling centre and transfer station. The high recovery percentage reflects the other activities undertaken separately from the MBT. |
| Total tonnes | 214,486 |
| Incinerator | 14% |
| Landfill | 2% |
| Recovery | 84% |
| Transfer | 0% |
| Treatment | 0% |
| Frog Island (London) | Biodrying |
| Total tonnes | 146,227 |
| Incinerator | 41% |
| Landfill | 1% |
| Recovery | 33% |
| Transfer | 25% |
| Treatment | 0% |
| Jenkins Lane (London) | Biodrying |
| Total tonnes | 148,307 |
| Incinerator | 42% |
| Landfill | 0% |
| Recovery | 20% |
| Transfer | 38% |
| Treatment | 0% |
| Hespin Wood Resource Park (Cumbria) | Biodrying<br>It is unrealistic that 95% of residual waste is recovered (recycled) and more likely that the waste return included RDF under 'recovered' in error. The majority of the 'recovered material' was described as '*other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11*' in the waste return. That description could be used for RDF. Online sources describe this facility as producing RDF. |
| Total tonnes | 44,729 |
| Incinerator | 0% |
| Landfill | 0% |

| MBT facility/ fate of outputs (2019 waste return) | Type of biological process/ fate of outputs (2019 waste return) |
|---|---|
| Recovery | 95% |
| Transfer | 0% |
| Treatment | 4% |
| Sowerby Woods Resource Park (Barrow-in-Furness, Cumbria) | Biodrying<br><br>It is unrealistic that 87% of residual waste is recovered (recycled) and more likely that the waste return included RDF under 'recovered' in error. The majority of the 'recovered material' was described as '*other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11*' in the waste return. That description could be used for RDF. Online sources describe this facility as producing RDF. |
| Total tonnes | 38,228 |
| Incinerator | 0% |
| Landfill | 0% |
| Recovery | 87% |
| Transfer | 0% |
| Treatment | 13% |
| Bolton Road (Rotherham) | Biodrying with SRF production and dry AD followed by IVC for the organic fines (i.e. mainly dry AD/IVC) |
| Total tonnes | 168,856 |
| Incinerator | 82% |
| Landfill | 3% |
| Recovery | 6% |
| Transfer | 1% |
| Treatment | 9% |
| Northacre Resource Recovery Centre (Westbury, Wiltshire) | Biodrying |
| Total tonnes | 49,141 |
| Incinerator | 57% |
| Landfill | 39% |
| Recovery | 0% |
| Transfer | 0% |
| Treatment | 4% |
| Canford MBT (near Poole, Dorset) | IVC |
| Total tonnes | 109,678 |
| Incinerator | 76% |
| Landfill | 6% |
| Recovery | 6% |
| Transfer | 0% |
| Treatment | 12% |

| MBT facility/ fate of outputs (2019 waste return) | Type of biological process/ fate of outputs (2019 waste return) |
|---|---|
| Avonmouth MBT (Bristol) | IVC<br>This facility is for sale and its current operational status is unknown. |
| Total tonnes | 146,869 |
| Incinerator | 72% |
| Landfill | 7% |
| Recovery | 14% |
| Transfer | 1% |
| Treatment | 5% |
| Tovi Eco Park (Essex) | IVC |
| Total tonnes | 192,668 |
| Incinerator | 81% |
| Landfill | 3% |
| Recovery | 14% |
| Transfer | 0% |
| Treatment | 2% |
| Renesciene Northwich | Wet AD<br>This facility is the first of its kind (commercial scale prototype) for the technology employed, which involves addition of enzymes prior to wet AD to help maximise production of an AD substrate where the organic material is made readily available for the microbes in the wet-AD process. |
| Total tonnes | 36,776 |
| Incinerator | 36% |
| Landfill | 0% |
| Recovery | 37% |
| Transfer | 0% |
| Treatment | 27% |

# A3 WRAP gate fee data

At the end of its 2014 Gate Fee Report, WRAP summarises gate fee data for 2012/13 and that includes Defra supplied information on PPP/PFI energy from waste projects that had been procured since 2005 (not all of which had reached contractual close at the time of the report). The information from Defra is provided in the table below.

Defra supplied gate fee information for PPP/PFI energy from waste projects (source: WRAP's 2014 Gate Fee Report)

| Facility size (tonnes per year) | Median gate fee (per tonne) | Gate fee range |
|---|---|---|
| <200kt | £111 | £80 - £135 |
| 200kt to 300kt | £78 | £57 - £105 |
| 350kt to 450kt | £68 | £59 - £80 |

Economies of scale can be expected with waste facilities and that is evidenced by the energy from waste gate fees presented in the table above. However, in recent years, several large EfW facilities have been constructed, and subsequently expanded, in Britain. The throughput at some of those sites considerably exceeds a typical large capacity MBT facility's throughput.

The construction of numerous EfW facilities in Britain in recent years, especially those of very large scale, is likely to have caused energy from waste facilities to offer competitive gate fees.

WRAP's 2011 Gate Fees Report comments upon the difficulties in researching and reporting MBT gate fees:

- *'The wide range of facility types and the variety of treatment processes to which the label of MBT is attached makes it difficult to provide an analysis of gate fees.*
- *The quality of the MBT output has a significant impact on the gate fee, as low quality process residues may attract a higher rate of landfill tax. Other major influencing factors on MBT gate fees are the SRF market, recovered materials prices, the feed in tariff and the allocation of contractual risk.*
- *Factors expected to influence the market for MBT in future were increases in the landfill tax and developments in market prices for MBT outputs (metals, plastics, SRF). Feedback from WMCs* [waste management companies] *indicated that the latter may lead to lower gate fees or an increase in the use of reward share mechanisms in future contracts'.*

The 2015 WRAP Gate Fee Report notes that it was not always possible to determine MBT gate fees from data submitted by local authorities, as the cost was included within a broader PPP or PFI contract. The data presented is reliant upon those local authorities that supply data and, of those, the authorities that supply data that can allow determination of the MBT gate fee.

The WRAP gate fee reports stopped reporting MBT gate fees altogether from 2018 onwards, and whilst the exact reason is not provided in the reports, the report authors state it was removed at the request of WRAP.

The WRAP gate fee report information should be reviewed with consideration to the above points, and wider caveats provided within the reports. A summary of the gate fee information, for WRAP reports published between 2011 and 2020, is provided in the table below. The reports contain data that predominantly applies to the previous year.

Summary of WRAP Gate Fee Report gate fees (local authority reported)

| Report (£/tonne) | MBT | EfW (pre 2000 facilities) | EfW (post 2000 facilities) | EfW (pre and post 2000 combined) |
|---|---|---|---|---|
| 2011 | £84 (median) | £54 (median) | £73 (median) | Not stated |

| Report (£/tonne) | MBT | EfW (pre 2000 facilities) | EfW (post 2000 facilities) | EfW (pre and post 2000 combined) |
|---|---|---|---|---|
| | £57 - £100 (range) | £35 - £79 (range) | £54 - £97 (range) | |
| 2013 | £76 (median)<br>£66 - £82 (range) | £58 (median)<br>£32 - £76 (range) | £90 (median)<br>£62 - £126 (range) | Not stated |
| 2014 | £84 (median)<br>£25 - £104 (range) | £58 (median)<br>£35 - £100 (range) | £94 (median)<br>£62 - £112 (range) | Not stated |
| 2015 | £88 (median)<br>£68 - £107 (range) | £73 (median)<br>£36 - £110 (range) | £65 (median)<br>£65 - £132 (range) | Not stated |
| 2016 | £85 (median)<br>£67 - £111 (range) | £58 (median)<br>£22 - £90 (range) | £95 (median)<br>£65 - £131 (range) | £86 (median)<br>£22 - £131 (range) |
| 2017 | £88 (median)<br>£66 - £170 (range) | £56 (median)<br>£26 - £90 (range) | £91 (median)<br>£50 - £144 (range) | £83 (median)<br>£26 - £144 (range) |
| 2018 | Not included | £57 (median)<br>£44 - £94 (range) | £89 (median)<br>£33 - £117 (range) | £86 (median)<br>£33 - £117 (range) |
| 2019 | Not included | £65 (median)<br>£44 - £89 (range) | £93 (median)<br>£50 - £121 (range) | £89 (median)<br>£44 - £125 (range) |
| 2020 | Not included | £62 (median)<br>£49 - £104 (range) | £95 (median)<br>£48 - £150 (range) | £93 (median)<br>£48 - £150 (range) |
| | | | | |

# A4 Facility case studies

Case study 1: ECOCEA, Chagny, France

Case study 2: Freienhufen, Germany

Case study 3: Lübeck, Germany

Case study 4: Vorketzin, Germany

Case study 5: Barcelona Ecoparc 4, Spain

Case study 6: CTR Vallès Occidental, Vacarisses, Barcelona, Spain

# Case study 1: ECOCEA, Chagny, France

## Parties

The facility was constructed for, and serves, SMET 71 (Syndicat Mixte d'Etude et de Traitement: mixed syndicate of study and treatment), which is the Saône-et-Loire department waste management association. A department in France is equivalent to a Scottish local authority and the Saône-et-Loire department is the 71st department of 96 French metropolitan departments. SMET 71 is responsible for the waste generated by ten-member local authorities (315,000 inhabitants).

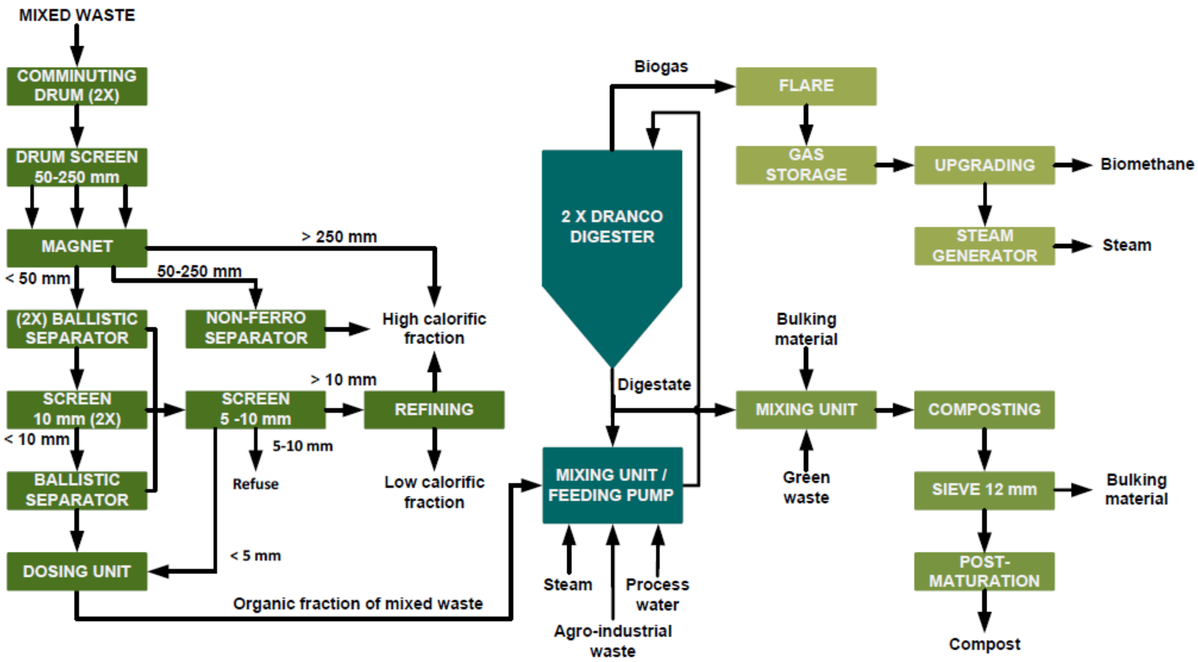
Tiru (Traitement Industriel des Résidus Urbains: Industrial Treatment of Urban Waste) is the designer, builder and operator. Tiru is a subsidiary of Dalkia and the EDF Group and operates 37 waste management facilities (thermal, biological and MRF), mostly in France (27 no.) but also in Britain (3 no.), Canada (5 no.) and the Caribbean (2 no.).

GRT-Gaz (75% owned by Gaz de France-Suez- 'GDF' and 25% by the French government) is the operator of the national high-pressure natural gas network that supplies industry. Biomethane from the facility is input into the network.

## Technology

Commissioned in 2015 and employing around 18 staff, the facility utilises mechanical processing followed by dry AD (supplied by OWS/Dranco) of residual MSW, followed by tunnel composting of the dry AD digestate mixed with green waste. The biogas is upgraded to biomethane. The process flow is provided in the figure below.

Flow diagram of the Chagny facility (source: OWS/Dranco)




The comminuting drums are long-inclined solid cylinders that rotate along their axis, churning the waste inside to open bags and shake and separate individual waste components.

The drum screen is a literal translation from the German and Dutch word 'Trommel'. However, in the UK we use 'trommel' instead of 'drum' to describe the equipment. In this instance, there are two screen sizes, one of 50mm and one of 250mm aperture size, meaning that there are three streams exiting the trommel:

- <50mm fraction (first screen size on the entry of the trommel and first material to exit the trommel), which is where the organic fraction will be concentrated

- 50mm to 250mm fraction (second and final screen size on the latter part of the trommel and second size fraction to exit the trommel)
- >250mm fraction that simply spills from the end of the trommel as it is too large to pass through the screen.

The <50mm fraction from the trommel is further processed through various screening devices to recover combustible material that goes to form low and high calorific RDF and, in so doing, the quality of the material sent to the AD process should be fairly good because it is of <10mm particle size. This is pertinent because the destination of the composted organic output from the facility is application to agricultural land in accordance with French Norme NFU 44-051.

The Dranco AD technology utilises a high dry solids, unmixed, continuous digester that is a cylindrical vertical tank fed by pumping the prepared feedstock, which is first mixed with a small amount of output digestate, to the digester entry point at the top of the tank. The contents of the tank passage through the tank under gravity to exit at the centre point of the base of the digester. There are two digesters with a combined capacity of 35,000 tonnes per annum. The digesters are unmixed and operate at thermophilic temperature (around 55ºC) with a retention time of around 25 days.

Biogas is stored in a ground mounted ‘gas bubble’, which helps to stabilise gas pressure within digesters and pipework, provides a short-term buffer storage for biogas and helps to stabilise gas flows.

The biogas is upgraded to biomethane in an upgrader plant with injection to the national high-pressure natural gas distribution network that supplies industry, with supply to a local tile manufacturer.

The addition of green waste prior to composting will help to provide structure to the waste and helps to produce a compost quality which meets current French compost standards. The green waste is shredded prior to input and tunnel composting, with 14 day residence time, is employed.

## Outputs

The facility was designed to process 73,000 tonnes of residual MSW and 8,000 tonnes of green waste.

The facility produces around 30,000 tonnes per annum of compost per year for application to agricultural land, under French Norme NFU 44-051, and 2,600,000 $m^3$ per year of biomethane. Other outputs comprise:

- High-CV RDF (utilised in cement kilns)
- Low-CV RDF
- Rejects (landfilled)
- Ferrous and non-ferrous metals (sent for recycling)

From 2027, the CLO will no longer be classed as a compost product and this is likely to have notable implications for SMET-71 and the facility. Furthermore, the push in France to introduce source segregation of organics is also likely, if introduced in the area, to have a notable implication on the operation and economics of the facility. It is only very fine fraction (<10mm) that is input into the digester tanks and so it is mixed with green waste prior to IVC to provide structure. However, the forthcoming changes will most likely mean it would be more beneficial to open windrow compost the green waste for it to still be possible to apply it to agricultural land.

## Regional waste collection

Plastic, paper, cardboard, metals and glass are collected at the doorstep and at bring banks. Textiles bring banks are available and home composters are also promoted.

The remaining residual waste typically contains 30 to 40% organic content, as there is no doorstep food waste collection.

The local authorities collect waste and SMET-71 is responsible for its treatment. Some local authorities in France collect segregated organic waste at the doorstep. However, in this authority area it was deemed too expensive, owing to a large geographic area relative to the population within it.

## Influencing policies

Prior to the development of this facility, the residual waste was landfilled. The development of the facility was informed by the waste hierarchy, i.e. a desire to divert waste from landfill and move the management of residual waste up the waste hierarchy.

At the time of facility development, the region's household waste elimination plan did not sanction incineration.

At the time of facility development, France's general tax on polluting activities (TGAP) was increasing for landfill, and it was anticipated that the cost of operating an AD plant would soon be equivalent to that of landfilling the residual waste, i.e. that AD would represent a similar or better financial option.

## Additional information

The capital cost was US$46m and the facility took 21-months to construct and created around 20 to 25 jobs.

# Case study 2: Freienhufen, Germany

## Parties

The facility operator is Abfallentsorgungsverbandes Schwarze Elster (AEV) (Schwarze Elster waste disposal association). AEV is a public waste disposal company formed by the districts of Elbe-Elster and Oberspreewald-Lausitz within the state of Brandenburg.

The technology provider was HAASE Anlagengau AG.

## Technology

In the UK, HAASE technology is present at three of the Manchester MBT facilities (Viridor was the EPC contractor) and in West Sussex (Biffa was the EPC Contractor).

The facility has been modified to treat source segregated biowaste, which is principally kitchen waste and green waste, instead of residual MSW. This was the result of the mandatory introduction of source segregation of biowaste.

The process described below describes the facility prior to the modification.

- Two stage wet AD of residual MSW (household and similar commercial)
    - Pre-sorting using mobile plant on the floor of the waste reception area to remove large items or items unsuitable for processing in the facility.
    - Trommel screening into three size fractions: <56mm, 56-105mm and >105mm.
    - Removal of ferrous metal on each of the above three output lines from the trommel.
    - The >105mm is conveyed to a compactor container.
    - The 56mm and 56-105mm each pass through a non-ferrous metal separator (eddy current separator).
    - The waste is then screened using a 35mm screen.
    - The 35-105mm fraction goes to join the >105mm fraction in the compactor container.
    - The <35mm fraction goes on to wet pre-treatment to prepare it for AD.
    - Wet mechanical pre-treatment of the organic fraction including water addition (recirculated process water) and production of homogenous slurry.
    - 2-stage (hydrolysis and methanation) wet AD with biogas production and CHP electricity generation (heat used on site).
    - On exit from the digesters, the digestate enters a tank where it is aerated to stop the anaerobic process.
    - Digestate is separated (dewatered) and the solid fraction is subject to thermal drying.
    - Treatment of odorous air, removed from process buildings and pre-AD tanks, using regenerative thermal oxidation.
    - Process water treatment using ultrafiltration and 2-stage reverse osmosis.

The facility has a separate line for bulky waste processing, which involves pre-sort by mobile plant, shredding, screening and ferrous and non-ferrous metal recovery. Besides metals, the other outputs from bulky waste processing are wood that is recycled and the remainder is sent for energy from waste.

The total approved plant capacity is 50,000 tpa (includes bulky waste processing).

Facility construction began in 2006 and operation began in 2007. A facility upgrade took place in 2011/12 and further modifications were recently made to allow the facility to operate for the sole processing of source segregated biowaste.

## Outputs

In 2012, when residual waste was still being processed, the facility mass balance was as shown below.

- Input waste: 27,327 tonnes (residual waste only- not including bulky waste which is processed separately at around 7,000 to 8,000 tpa).
- Sent for EfW (non-AD) (56.6% of total input waste):

  - Output from pre-sort sent for use as fuel in EFW facility (different plant to high CV fuel): 2,156 tonnes (7.9%)
  - Sent for use as high-calorific value fuel in EfW facility: 12,673 tonnes (46.4%)
  - Clinical waste for incineration: 641 tonnes (2.3%)
- Sent for recycling (1.3% of total input waste):
  - Ferrous metal: 316 tonnes (1.2%)
  - Non-ferrous metal: 14 tonnes (0.1%)
- Landfilled:
  - Dried digestate: 7,923 tonnes (29.0%)
  - Pre-treatment rejects: 1,221 tonnes (4.5%)
  - Other : 10 tonnes (0.04%)
- Process loss (AD): 2,373 tonnes (8.7%)

AEV class the material sent for use as a fuel in an energy recovery plant as being ‘recycled’.

## Regional waste collection

Biowaste (food and garden waste, paper towels and newspaper), paper and card, metals and plastics (including films) are collected in separate streams and glass is collected in bring banks.

Most waste collection, including residual waste, is undertaken by third parties on behalf of AEV.

Residents pay a basic fee for their waste management service, and then a charge per collection of residual waste that is based on the container volume that is collected. Alternatively, an annual fee can be paid for a specific container volume which is then collected on all collection days. Excess residual waste can be deposited in a separate bag that is first purchased.

## Influencing policies

Landfill diversion was the main driver behind the facility construction.

In 2013, AEV explored the potential of more intensive cooperation with other waste authorities in the region (state of Brandenburg) in the context of residual waste treatment in order to find the most economical overall solutions.

In 2018, the operator considered switching the operation of the facility from residual MSW AD to source segregated organics (i.e. biowaste) AD. That was due to the introduction of source segregated biowaste in the area, resulting from the requirements of the Recycling Management Act (Kreislaufwirtschaftsgesetz- KrWG) and the Brandenburg State Waste Management Plan. This is understood to have now taken place, with some modifications and the addition of tunnel IVC with four-week retention time in order to process 20% kitchen waste with 80% green waste.

AEV place high importance upon the fee model it utilises for residual waste to encourage waste avoidance and to increase recycling[65].

[65] https://www.schwarze-elster.de/wp-content/uploads/2015/02/AWKAEV2014.pdf

# Case study 3: Lübeck, Germany

## Parties

The facility was constructed for Entsorgungsbetriebe Lübeck (EBL- Lübeck Waste Disposal Company) and was developed by Ingenieurbüro für Abfallwirtschaft und Energietechnik GmbH (IBA-Engineering Office for Waste Management and Energy Technology) utilising technology supplied by HAASE Anlagengau AG.

The facility is operated by Stadtreinigung Lübeck GmbH (SRL- City Cleaning Lübeck), which was set-up in 2008 under a PPP model and is formed by EBL and Nehlsen GmbH & Co. The PPP arrangement is for 20 years.

## Technology

As with the Freienhufen facility (case study 2 above), the Lübeck facility processes residual waste utilising the HAASE MBT process, including wet AD.

Construction commenced in 2004 and waste receipt and commissioning took place in 2005/2006.

The residual waste process is described below.

- Pre-shredding of input residual waste.
- Separation of metals, RDF, organic fine fraction and impurities with screens, magnets, optical sorters and air separation, and post-shredding of RDF.
- Wet pre-treatment involving four mixers, where water is added and a homogenous 'soup' is produced, followed by contaminant grit removal.
- Hydrolysis tank (1 x 4,500m$^3$)
- Two digesters (2 x 5,000m$^3$)
- Post digestion aeration tank (1 x 8,000m$^3$)
- Digestate separation (solid/liquid)
- Thermal drying of solid fraction (drum) prior to landfill
- Process water treatment using ultrafiltration and 2-stage reverse osmosis
- Power generation from biogas via CHP (around 15.0 MWh/a including biogas from the biowaste line).

The MBT facility forms part of wider waste treatment infrastructure at the Lübeck Waste Management Centre.

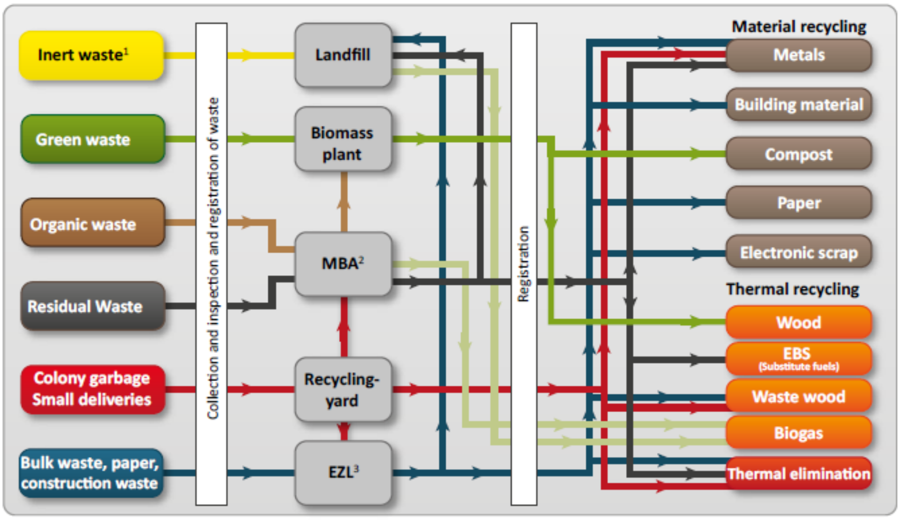
The MBT has three lines, one for biowaste (source segregated organic waste) and sewage sludge, one for doorstep household residual waste and one for bulky waste, and there is some interaction between the residual waste line and the bulky and commercial waste line.

There is also a separate 'biomass facility' which receives green waste as well as woody material and digestate from the source segregated organics line from the MBT facility. The biomass facility utilises tunnel IVC (12 no.) technology followed by open windrow composting.

The whole MBT process was originally designed for around 120,000 tonnes per annum of residual waste and 26,000 tonnes per annum of sewage sludge.

The interaction of the various facilities in Lübeck is shown in the figures below.

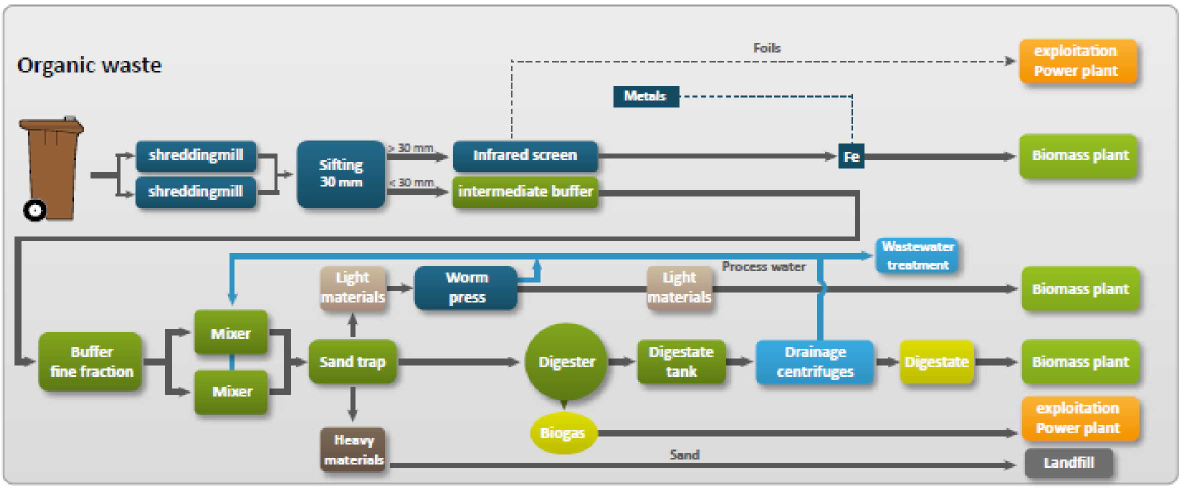
## Integration of waste facilities (source: operator literature[66])



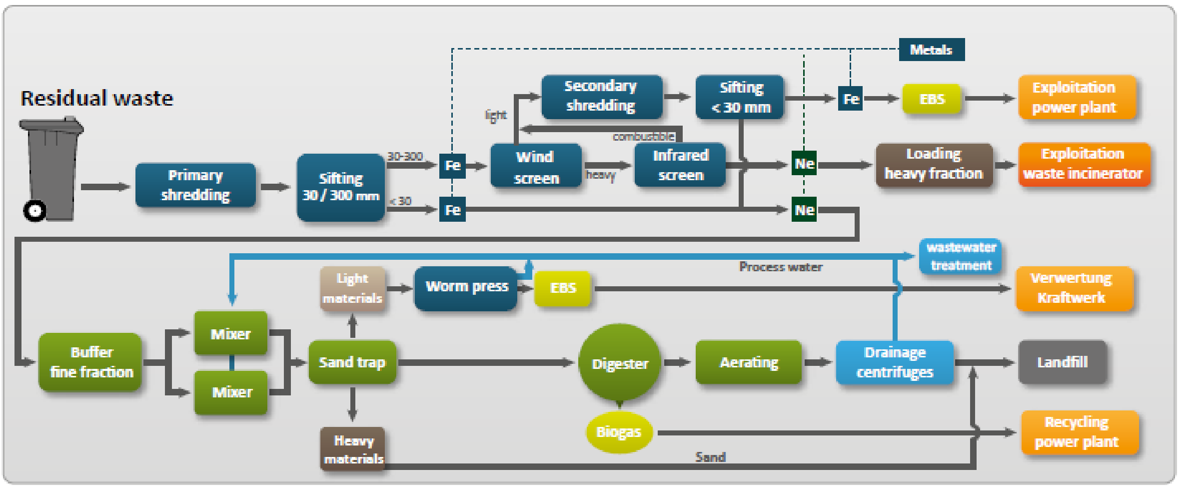

¹ = End-treated waste ² = Mechanical biological waste treatment plant ³ = Entsorgungszentrum Lübeck GmbH

## Flow of waste within the MBT facility (source: operator literature[66])

**The path of organic waste in the MBA (Mechanical Biological Waste Treatment Plant)**




**The path of residual waste in der MBA (Mechanical Biologcal Waste Treatment Plant)**

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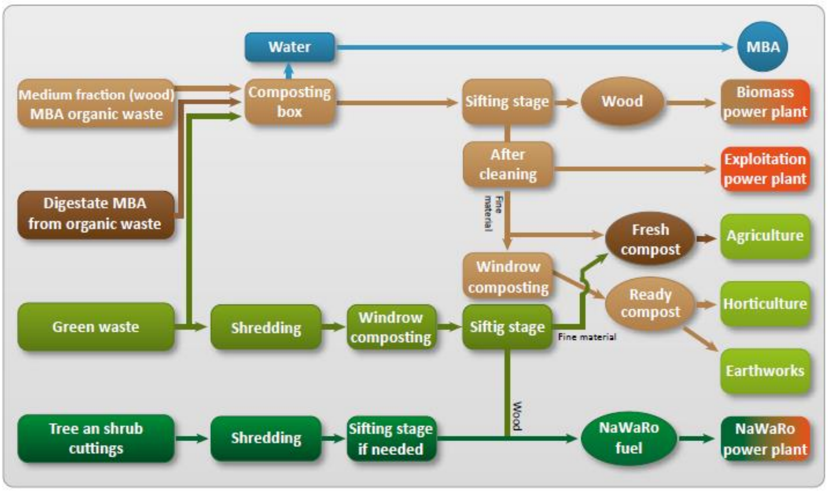
[66] https://www.entsorgung.luebeck.de/files/Flyer/brosch_abfallwirtschaftszentrum_englisch.pdf

### Flow of waste within the biomass facility (source: operator literature[66])




## Outputs

The reported[67] 2017 outputs are detailed below.

- 22,800 tpa RDF produced
- 1,210 tpa metals recovered for recycling
- 25,170 tpa landfilled
- 15,920 tpa of woody material and digestate from the source segregated process line material was sent to the biomass plant.
- 5,000,000 m$^3$ of biogas produced [approximately 5,750 tonnes]. Biogas is combusted in CHP plant (2 no. totalling 1.9 MW capacity) with heat and electricity used on site and electricity exported to the national grid.

## Regional waste collection

Biowaste (food and garden waste, paper towels and newspaper), paper and card, plastics (including polystyrene), metals and glass are collected in separate streams.

## Influencing policies

The facility was developed as a result of a ban on untreated waste being landfilled, which came into force in Germany in 2005.

## Additional information

- €30M capital cost
- Delivery hall area is 3,240 m$^2$.
- Processing hall area is 2,160 m$^2$.
- The area of external roadways and yards is 18,000 m$^2$.
- The following description is taken from operator literature66: With a CO2 credit of more than 200 kg per ton of waste, the MBA of Lübeck is well above the national average of incinerators. In a treated waste of about 100,000 tons per year, this is a major contribution to sustainability and conservation of resources. But not only can the amount of biogas obtained be recycled energetically. Even the alternative fuels produced from residual waste and the coarse material from the treated organic waste (wood) are sent for recovery of energy in various power plants. The digestate produced during biological treatment of organic waste and sorting residues freed and crushed from impurities are further processed in the local biomass plant.

[67] The 2017 MBT facility annual emissions report (Jahresbericht Emissionen 2017 Mechanisch-Biologische Abfallbehandlungsanlage (MBA) Lübeck)

# Case study 4: Vorketzin, Germany

## Parties

The facility was constructed through the collaboration of ARGE MBA Vorketzin, Horstmann GmbH & Co. KG, Fechtelkord&Eggersmann GmbH and Heilit+Wörner Bau GmbH.

Iba & Energietechnik GmbH was the technology provider for the biological treatment equipment and the operator was MEAB (Märkische Entsorgungsanlagen Betriebsgesellschaft) mbH.

## Technology

The facility started operating in 2005 and stopped the biological treatment of waste in 2012[68] and operations ceased altogether on 31/12/2015[69].

The facility had a capacity of 180,000 tonnes/ year and involved:

- Pre-shredding.
- 2-stage screening.
- multi-stage screening.
- Fe-metal separation.
- 2-stage aerobic tunnel and windrow composting.
- Air treatment: biofilter and RTO.

## Outputs

The facility had an annual capacity of 180,000 tonnes, of which 96,000 tonnes were treated biologically and landfilled in 2009. The metals that were recovered within the mechanical pre-treatment were sent for recycling, while the RDF was sent to EfW facilities[70].

## Regional waste collection

The district where the facility was located introduced separate kitchen and garden waste collection systems in 2016[71]. A press release from the district council[72] shows that in 2011 there was separate collection of paper and recyclables, but the archives do not indicate when the collections were introduced.

## Influencing policies

The site was built as a response to the 2005 ban on landfilling untreated waste. However, the biological treatment process was stopped in 2012. It is possible that the plant was affected by the introduction of separate organic waste collections in the catchment. Additionally, other residual waste reduction and diversion policies, such as the separate collection of recyclable streams, resulted in the reduction of the overall residual waste stream.

MEAB decided to stop the operation of the Vorketzin MBT, principally because the districts that provided the facility with residual waste decided to send it to EfW plants because the gate fees were lower[73].

## Additional information

- Site area: 5 ha
- Site area occupied by buildings and infrastructure: 2.3 ha
  - Reception hall: 0.33 ha
  - Process hall: 0.27 ha
  - IVC hall: 0.86 ha

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[68] https://www.meab.de/informationen-der-oeffentlichkeit/
[69] https://www.meab.de/unternehmen/
[70] https://opus4.kobv.de/opus4-slbp/files/10143/Amtsblatt_Ketzin_Nr._04_2010.pdf
[71] https://www.havelland.de/presse/einzelansicht/news/detail/article/landkreis-havelland-fuehrt-die-biotonne-ein/
[72] https://www.havelland.de/presse/einzelansicht/news/detail/article/neuer-abfallkalender-wird-ausgeliefert-aenderungen-bei-entsorgungstouren/
[73] https://www.maz-online.de/Lokales/Havelland/Land-fordert-Abbiegespur-zur-Deponie

    - Maturation: 0.73 ha
    - Roads: 0.12 ha
- 4.7 MW load (electrical connected load)
- 3.5 years development time (13 months in construction)

# Case study 5: Barcelona Ecoparc 4, Spain

## Parties

The facility is located in, and serves 48 municipalities in, the Barcelona metropolitan area and is owned by the ECOP4RC Consortium. The consortium is a public entity, created in 2006, formed by the Agència de Residus de Catalunya (ARC), the Barcelona Metropolitan Area (AMB) and the Hostalets de Pierola City Council.

The management and operation of the Ecoparc 4 facility is carried out on a concession basis by Ecoparc de Can Mata SL, which is 100% owned by the CESPA Gestió de Residus SA. CESPA SA was responsible for facility construction.

The main technology providers are TOMRA (mechanical pre-treatment) and Sorain Cecchini Tecno (SCT) (IVC).

## Technology

Although undertaken within the same buildings, source segregated organic waste (brown bin) and residual MSW (grey bin) are processed separately at the facility. As to be expected, the mechanical treatment of the source separated organic waste is much simpler than the residual waste and the organic waste line has one IVC hall (reactor) compared to two for the residual waste.

The facility was constructed between 2008 and 2010 and full commercial operation began in 2011. It has a treatment capacity of 365,000 tonnes per year (75,000 tonnes source segregated organics and 285,000 tonnes of residual waste).

The residual waste pre-treatment process is extensive and separates the waste into fine organic fraction, RDF, recyclables and material for landfill. The residual waste process is described below.

- Waste unloaded into pits that are emptied by overhead grab.
- 350mm trommel.
- The trommel oversize fraction is hand-sorted to remove paper, cardboard, film and metal for recycling. The remainder of the oversize fraction is landfilled.
- The trommel undersize is hand-sorted to remove contaminants/undesirable materials, including glass which is recycled, metal which is recycled and residues that are landfilled.
- Primary shredder.
- Multi-stage trommel <90mm (organic fraction) and 150x200mm screens (three outputs: small, medium and large).
- Ballistic separator for the medium and large outputs from the multi-stage trommel. This separates medium and large-sized waste that has come out of the multi-stage trommel into three types: flat and light packaging, fine and rolling waste. Flat and light packaging includes, amongst others, folded bags and card. Rolling waste includes cans and plastic jars. Fine waste is mostly organic waste. Flat and rolling wastes continue with the pre-treatment to completely separate them by material. Fine organic waste is put together with the small waste from the multi-stage trommel and is sent for IVC.
- Conveyor head wind-sifter to remove plastic bags and film carried into the rolling fraction of the ballistic separator.
- Over-band magnets to remove ferrous metals (located after multi-stage trommel and ballistic separator).
- Optical sorters on the rolling fraction line from the ballistic separator to remove PET and natural and coloured HDPE for subsequent recycling.
- Eddy current separator to remove non-ferrous metal (predominantly aluminium) from the rolling fraction line from the ballistic separator. The material not removed is destined for landfill.
- Optical sorting on the flat waste line from the ballistic separator to remove paper and cardboard for recycling.
- Conveyor head wind-sifter to remove plastic film from the flat fraction line from the ballistic separator.

- Manual sorting of certain final lines from the automated separation lines. Material is removed for recycling with the remainder destined for RDF.
- Shredder (20 to 30mm) to shred the flat fraction line output once paper and film have been removed (i.e. mostly paper and film not removed).
- High speed trommel: Paper is hurled out through the trommel apertures, while plastic forms a central ball and gets to the end of the cylinder. The dirty, wet, paper joins the conveyor that goes to composting. The remaining shredded plastics are sent for RDF.
- Composting in in-building IVC reactors (2 no.) with recycling of leachate and addition of water and air to both reactors. Residual MSW organics are composted for 42 days. The waste spends 14 days in reactor 1 after which it is processed in a 40mm trommel. The trommel small fraction will be mostly organic whereas the oversize fraction will be mostly small plastic packaging materials that were not removed in the pre-treatment process. The oversize material is landfilled. The undersize material is sent to the reactor 2 where it is matured for 28 days. The output from reactor 2 goes through a 10mm trommel and the oversize fraction (mostly stone and glass) is landfilled. Lastly, the organic material passes through cyclones to remove small fraction dense materials that are also landfilled.

There are ten TOMRA AUTOSORT optical separators, four of which are single-valve separators to recover the paper from the flat fraction, four are double-valve separators placed at the exit of the rolling or heavy fraction, where the first valve separates plastic and the second Tetra-Pak, and lastly two further double-valve optical separators that separate the PET in the first and the HDPE in the second from the plastic fraction of the first optical separators.

The source segregated organics process is simpler than the residual waste process. Owing to the poor structure associated with such waste, shredded green waste (30% w/w) is added prior to IVC. Source segregated organics line are composted for 36 days.

## Outputs

Around 22,225 tonnes per annum of biostabilised compost like output is produced, which is around 8% of the residual waste input.

Ferrous metal, non-ferrous metal, paper, HDPE plastic, PET plastic, brick and plastic film are sent for recycling. Most materials are baled prior to leaving the facility.

Waste that cannot be recycled or used as SRF is baled or compacted and sent to the adjacent Can Mata landfill, reportedly with an organic matter content <15%.

SRF is sent to a waste to energy facility and compost like output can be used for soil restoration, slope filling in civil engineering works, in landfill restoration and in non-food plant production (these applications are mentioned on the AMB website). All material landfilled accounts for around 48%w/w, meaning that around 52% of the waste input (source segregated and residual waste lines) is recovered.

## Regional waste collection

Wastes that are source segregated within the MBT facility catchment are listed below.

- Organics (small garden and food waste) (introduced in 2010)
- Glass (introduced in 1980)
- Paper and card (introduced in 1985)
- Metal packaging and plastics (introduced in 1997)

## Influencing policies

The waste hierarchy and a desire to limit disposal to landfill were two guiding principles that informed the choice of the MBT technology to treat residual waste.

## Additional information

The facility has created 70 direct jobs and 150 indirect jobs.

The facility has a 5ha area, was constructed between 2008 to 2010 and the construction cost was originally forecast to be EUR 55.08 million, although it is reported that the final cost was EUR 65.71 million.

The cost of waste treatment at Ecopark 4 in 2012 was EUR 16 million.

The facility and adjacent landfill have been subject to frequent complaints regarding odour, which it is claimed increased once the MBT facility had been constructed.

# Case study 6: CTR Vallès Occidental, Vacarisses, Barcelona, Spain

## Parties

The facility is operated by Consorci per a la Gestió de Residus del Vallès Occidental (Consortium for waste management of the Valles Occidental). The Valles Occidental is a county in Catalonia, Spain.

The consortium is a public body and was formed in 2001 and now comprises 19 member councils, of a total 23 councils in the region. The consortium's role is varied and includes planning the management of waste, development of waste infrastructure, establishment of separate waste collections, promoting waste awareness and recycling and the undertaking and commissioning of research aimed at developing waste management policies. Some services are developed across the whole consortium, whereas others might only apply to two or three councils.

The consortium manages two facilities: the Vallès Occidental Waste Treatment Center (CTR-Vallès), located in Vacarisses and the facility discussed here, and the Can Barba AD facility in Terrassa. In addition, the Vallès Occidental has an extensive network of municipal landfills managed by the town councils.

The facility was jointly funded by the Agencia de Residus de Catalunya and the consortium and it was constructed by Grupo Hera, FCC and Urbaser. The pre-treatment and refining technology was supplied by Masias (now Bianna Recycling) and the composting process technology was designed and supplied by Taim Weser, both of which are companies of Spanish origin.

## Technology

Commissioned in 2010, the MBT facility has been designed with a 245,000 tonnes per annum capacity to treat residual MSW.

The MBT facility is located upon the Coll Cardús landfill, which was near to closure at facility construction, and utilises 3.5 MW of power from the landfill gas.

The technology employed at the MBT facility comprises:

- Masias pre-treatment technology (three pre-treatment lines of 25 t/h capacity per line), including removal of recyclable material (paper, metals, packaging, etc .)
- Taim Weser in building IVC comprising of two automatic infeed systems, two automatic stack turning machines (overhead gantry mounted Rotopala turning equipment) , a discharge system and an aeration system. The composting halls have a capacity of 154,000 tpa, meaning that they are designed to process 63% of the waste input to the facility.
- Masias post IVC compost refining equipment (one line of 20 t/h capacity).
- Wastewater treatment and reuse.

Taim Weser and Masias have supplied technology to UK MBT facilities, including the Tovi Eco Park facility in Essex (Urbaser is the EPC Contractor) and the Waterbeach facility in Cambridge (Amey-Cespa is the EPC Contractor).

As part of the contract, the construction of a source segregated organics treatment facility was also originally planned, to treat 20,000 tonnes per year, but it was never built.

## Outputs

The facility produces:

- Recyclable materials (paper, metals, packaging, etc.) (recycled)
- Reject materials (landfill)
- CLO, which is reported to meet European Standards and to be suitable for landscaping or gardening. However, some data sources state that it is either used for restoration of quarries and landfills or it is packed in shrink-wrapped bales with a very small percentage of biodegradability, which suggests it is landfilled.

## Regional waste collection

Organic waste, paper and cardboard, glass, plastic, metals, coffee capsules and used oils are collected separately.

## Influencing policies

The idea for the MBT facility, the Can Barba AD facility and the source segregation of various recyclable waste streams came from an independent consultancy study undertaken in the early 2000's[74]. At that time, it was anticipated that the Coll Cardús landfill would be completely filled in 2005 and an alternative to landfill was required.

## Additional information

The area of the facility is 43.9 ha, of which 37.1 ha is developed, and approaching 80 jobs were created at the facility.

The Can Barba AD facility (25,000 tonnes/year) has been in operation since the end of 2006 and utilises Dranco AD technology for processing of kitchen waste, followed by mixing with green waste and tunnel and windrow composting. The facility was constructed at the location of a former composting plant.

In 2017, the audit office of Catalonia published an audit of the El Vallès Occidental County Council for the 2013 financial year. Several matters discussed in the report are listed below.

- The cost of sending waste to the MBT facility was so high that some municipalities, such as Sant Cugat del Vallès, decided not to use the centre and, instead, to take the their waste to ecoparks II and IV, which are other facilities in the Barcelona area.
- The feasibility study for the MBT facility was completed in July 2006 and the contract for the facility was signed in 2008. The contract included a 25,000 tonnes/year source segregated organics treatment plant (tunnel composting), which is separate to the MBT facility and not to be confused with the existing Can Barba AD facility.
- The original contract price was EUR 74.90 million including VAT (EUR 56.96 million for the residual waste MBT facility and EUR 17.94 million for the source segregated organics facility), which increased in 2010 by EUR 15.69 million (20.9%) (EUR 15.31 million for the MBT facility and EUR 0.38 million for the organics facility). The final cost for the MBT facility was higher again, at EUR 76.77 million (which included EUR 1.74 million paid due to the partial resolution of the contract not to construct the source segregated organics facility). Therefore, the final cost of the MBT facility was 31.7% higher than the original contract price.
- In 2010 the construction and commissioning programme slipped for the first time. In 2013 it was determined that the MBT facility was not in a state to pass warranty tests and the contractor was granted a further six months to resolve the situation.
- On 19 June 2013, the contractor requested the partial termination of the contract in order not to remove construction of the source segregated organics facility, although the work had already started, due to the sharp decrease in the collection forecasts for the organic fraction, which made the projected capacities were significantly higher than actual needs. The facility construction ceased, and liquidated damages were paid.
- On 1 April 2014 the MBT facility appears to have been 'definitively received' (i.e. contractual obligations have been accepted as being met), despite not having the necessary environmental licence and not passing the performance tests for the biostabilisation system and the quality of the biostabilised material, nor of the air treatment system performance and emissions. The remedy was an undertaking to take the pertinent measures necessary to comply with the parameters of the failed tests and the deposit of a EUR 2.80 million guarantee. This stage of the contract should originally have occurred on 19 July 2013.
- The capital cost of the facility was paid for by the Government of the Generalitat de Catalunya, whereas at the time the contractor bid for the project the intention was for the initial capital cost to be contractor funded.

[74] http://www.sindicatura.cat/reportssearcher/download/2016_14_es.pdf

- In the 2013 financial year, 142,030 tonnes of residual waste entered the MBT facility at a gate fee to the municipalities of EUR 70.43 / tonne.

In August 2016 it was reported[75] that the receipt of waste from the MBT facility at the Coll Cardús landfill would cease in one years' time when the landfill closes. The report stated that the sending of waste, from the MBT facility, to facilities further afield would increase the MBT gate fee paid by councils by 1.85% per tonne, so they will pay EUR 77.89 / tonne, a price that includes the treatment, deposit and waste tax.

[75] http://www.elpuntavui.cat/territori/article/11-mediambient/992431-coll-cardus-rebra-20-000-m-de-residus-mentre-es-fa-el-pla-de-clausura-en-un-any.html

# A5 Carbon LCA assumptions

<table>
<tr><th>Item</th><th>Assumption</th><th>Function</th><th>Source</th></tr>
<tr><td>Efficiency of RDF combustion</td><td>24%</td><td>Electricity generated from RDF combustion</td><td>Industry knowledge</td></tr>
<tr><td>Target moisture content pre-organic stage</td><td>50%</td><td>Water content target for dry AD</td><td>Technology provider assumption</td></tr>
<tr><td>Distance from waste transfer station to facility</td><td>15km</td><td>Transport emissions</td><td>ZWS EfW Model</td></tr>
<tr><td>Distance from facility to landfill</td><td>50km</td><td>Transport emissions</td><td>ZWS EfW Model</td></tr>
<tr><td>Glass diversion rate</td><td>50%</td><td rowspan="3">Amount of material recovered in mechanical pre-treatment</td><td rowspan="3">Industry knowledge</td></tr>
<tr><td>Metal diversion rate</td><td>75%</td></tr>
<tr><td>Plastic diversion rate</td><td>30%</td></tr>
<tr><td>Waste composition</td><td>
<table>
<tr><th>Material</th><th>%</th></tr>
<tr><td>Animal and mixed food waste</td><td>27%</td></tr>
<tr><td>Discarded equipment (excluding discarded vehicles, batteries and accumulators wastes)</td><td>2%</td></tr>
<tr><td>Glass wastes</td><td>3%</td></tr>
<tr><td>Health care and biological wastes</td><td>10%</td></tr>
<tr><td>Household and similar wastes</td><td>7%</td></tr>
<tr><td>Metallic wastes, mixed ferrous and non-ferrous</td><td>3%</td></tr>
<tr><td>Mineral waste from construction and demolition</td><td>4%</td></tr>
<tr><td>Paper and cardboard wastes</td><td>16%</td></tr>
<tr><td>Plastic wastes</td><td>15%</td></tr>
<tr><td>Rubber wastes</td><td>0%</td></tr>
<tr><td>Textile wastes</td><td>6%</td></tr>
<tr><td>Vegetal wastes</td><td>6%</td></tr>
</table>
</td><td>Input to MBT facility</td><td>SEPA (2019) Waste composition update, reflecting food waste collection impacts</td></tr>
</table>

<table>
<tr><th>Item</th><th>Assumption</th><th>Function</th><th>Source</th></tr>
<tr><td></td><td><table><tr><td>Wood wastes</td><td>1%</td></tr></table></td><td></td><td></td></tr>
<tr><td>Moisture data</td><td>Data available in model (Waste_Props tab)</td><td>Moisture calculation of MBT inputs</td><td>WRATE</td></tr>
<tr><td>Fossil carbon content</td><td>Data available in model (Waste_Props tab)</td><td>Biogenic carbon calculations</td><td>ZWS EfW Model</td></tr>
<tr><td>Carbon emission factors</td><td>Data available in model (Waste_Props tab)</td><td>Calculating carbon emissions</td><td>Chosen for consistency with ZWS EfW model<br>BEIS Greenhouse gas reporting: conversion factors<br>-<br>The global warming potential of methane: Report 5 from the IPCC</td></tr>
<tr><td>RDF Diversion</td><td><table>
<tr><th>Waste Fraction</th><th>RDF</th><th>Residual</th></tr>
<tr><td>Animal and mixed food waste</td><td>5%</td><td>95%</td></tr>
<tr><td>Discarded equipment (excluding discarded vehicles, batteries and accumulators wastes)</td><td>10%</td><td>90%</td></tr>
<tr><td>Glass wastes</td><td>0%</td><td>100%</td></tr>
<tr><td>Health care and biological wastes</td><td>70%</td><td>30%</td></tr>
<tr><td>Household and similar wastes</td><td>50%</td><td>50%</td></tr>
<tr><td>Metallic wastes, mixed ferrous and non-ferrous</td><td>31%</td><td>69%</td></tr>
<tr><td>Mineral waste from construction and demolition</td><td>5%</td><td>95%</td></tr>
<tr><td>Paper and cardboard wastes</td><td>95%</td><td>5%</td></tr>
<tr><td>Plastic wastes</td><td>65%</td><td>35%</td></tr>
<tr><td>Rubber wastes</td><td>65%</td><td>35%</td></tr>
<tr><td>Textile wastes</td><td>95%</td><td>5%</td></tr>
<tr><td>Vegetal wastes</td><td>35%</td><td>65%</td></tr>
<tr><td>Wood wastes</td><td>75%</td><td>25%</td></tr>
</table></td><td>Materials removed during RDF separation stage</td><td>Industry knowledge (based on confidential information held by Ricardo for operational facilities)</td></tr>
</table>

<table>
<tr><th>Item</th><th>Assumption</th><th>Function</th><th>Source</th></tr>
<tr><td colspan="4">Dry AD</td></tr>
<tr><td>Energy data - Input electricity to pre-treatment</td><td>5kg $CO_2e$/ tonne</td><td>Energy consumption calculation</td><td>ZWS EfW Model</td></tr>
<tr><td>Energy data - Input electricity to AD/IVC</td><td>3,000,000 kWh/a</td><td>Energy consumption calculation</td><td>Technology provider</td></tr>
<tr><td>Energy data - Output electricity</td><td>14,250,000 kWh/a</td><td>Energy consumption calculation</td><td>Technology provider</td></tr>
<tr><td>$CH_4$ content of biogas (volume)</td><td>57%</td><td>Biogenic carbon in landfill</td><td>Technology provider</td></tr>
<tr><td>Mass Balance data</td><td><table>
<tr><th>Material</th><th>Mass / tpa</th></tr>
<tr><td>Post-pretreatment MSW</td><td>50,000</td></tr>
<tr><td>Iron Chloride</td><td>500</td></tr>
<tr><td>Liquid recycling</td><td>5,000</td></tr>
<tr><td>Steam</td><td>1,010</td></tr>
<tr><td>Biogas</td><td>8,402</td></tr>
<tr><td>Digestate</td><td>48,108</td></tr>
<tr><td>Polymer solution</td><td>8,754</td></tr>
<tr><td>Effluent</td><td>11,777</td></tr>
<tr><td>Pre-stabilisation</td><td>40,085</td></tr>
<tr><td>Losses</td><td>11,485</td></tr>
<tr><td>Stabilite</td><td>28,600</td></tr>
</table></td><td>Mass balance for AD+IVC (dry AD)</td><td>Technology provider</td></tr>
<tr><td>Biogas volume generated per tonne input to AD</td><td>127 $Nm^3$/tonne</td><td>Biogenic Carbon in landfill</td><td>Technology provider</td></tr>
<tr><td>Destruction efficiency of gas flare or engine</td><td>99%</td><td>Biogenic Carbon in landfill</td><td>GasSim Manual</td></tr>
<tr><td colspan="4">IVC</td></tr>
<tr><td>Process loss</td><td>22.5% (average of 20-25% range)</td><td>Calculation of moisture loss and biostabilised outputs (for landfill)</td><td>Technology provider</td></tr>
<tr><td>Recyclables removed</td><td>7.5% (average of 5-10% range)</td><td>Calculation of biostabilised</td><td>Technology provider</td></tr>
</table>

| Item | Assumption | Function | Source |
|---|---|---|---|
| | | outputs (for landfill) | |
| Energy use (typical recyclables) | 36.5 kWh/t (range quoted 35-38kWh/t) | Electricity produced calculation | Technology provider |
| Energy use (high level of recyclables) | 39 kWh/t (range quoted 38-40kWh/t) | Electricity produced calculation | Technology provider |
| Energy use with RDF(typical recyclables) | 41 kWh/t (range quoted 40-42kWh/t) | Electricity produced calculation | Technology provider |
| Energy use with RDF(high level of recyclables) | 44 kWh/t (range quoted 43-45kWh/t) | Electricity produced calculation | Technology provider |
| Portion of process loss due to moisture | 25% | Calculation of moisture loss | Ricardo's judgement |
| Portion of process loss due to $CO_2$ | 75% | Calculation of moisture loss and carbon dioxide loss | Ricardo's judgement |
| Landfill model | | | |
| Annual tonnage landfilled | 70,000 tonnes | Calculation of emissions from landfill | Selected to be a high number of an order that might be landfilled (but the interest is the per tonne emissions) |
| Operational lifetime | 20 years | Calculation of emissions from landfill | Assumed MBT contract length |
| Other assumptions | GasSim model inputs | Calculation of emissions from landfill | See Appendix A6 |

# A6 GasSimLite assumptions

The GasSimLite (and full GasSim) model is a probabilistic model (uses an iterative Monte Carlo simulation approach) and so assumptions can be input as distributions (SINGLE, UNIFORM, TRIANGULAR etc.).

In many instances, especially as the model is not for a specific existing landfill, the GasSim default assumptions have been used.

<table>
<tr><th colspan="2">Source Module</th></tr>
<tr><td>Proportion to $CO_2$ (%) and $CH_4$ (%)</td><td>SINGLE (50) for both<br><br>[Default used]</td></tr>
<tr><td>100% capped at end of operational period</td><td>Yes<br><br>[There is no reason to assume a delay to capping]</td></tr>
<tr><td>% Waste in place capped</td><td>Assumed capping over 20 years done in 5 phases:<br><br>
<table>
<tr><th>Year</th><th>% waste in place capped</th></tr>
<tr><td>2000</td><td>0.0%</td></tr>
<tr><td>2001</td><td>0.0%</td></tr>
<tr><td>2002</td><td>0.0%</td></tr>
<tr><td>2003</td><td>100.0%</td></tr>
<tr><td>2004</td><td>80.0%</td></tr>
<tr><td>2005</td><td>66.7%</td></tr>
<tr><td>2006</td><td>57.1%</td></tr>
<tr><td>2007</td><td>100.0%</td></tr>
<tr><td>2008</td><td>88.9%</td></tr>
<tr><td>2009</td><td>80.0%</td></tr>
<tr><td>2010</td><td>72.7%</td></tr>
<tr><td>2011</td><td>100.0%</td></tr>
<tr><td>2012</td><td>92.3%</td></tr>
<tr><td>2013</td><td>85.7%</td></tr>
<tr><td>2014</td><td>80.0%</td></tr>
<tr><td>2015</td><td>100.0%</td></tr>
<tr><td>2016</td><td>94.1%</td></tr>
<tr><td>2017</td><td>88.9%</td></tr>
<tr><td>2018</td><td>84.2%</td></tr>
<tr><td>2019</td><td>100.0%</td></tr>
</table>
<br>GasSim assumes gas is only collected for utilisation (combustion) from capped areas and so when waste is capped is an important consideration for the model. However, the design of the landfill and its phasing will vary between landfills and operators. The scenario input is considered realistic.</td></tr>
<tr><td>Waste composition</td><td>Default used for ‘Scotland 2020+ waste streams’</td></tr>
<tr><td>Waste breakdown</td><td>100% composted organic material input for each year at 70ktpa and for a period of 20 years from year 2000 onwards.<br><br>The purpose of the modelling is to derive a per tonne landfilled emission for $CO_2$ and $CH_4$ and so the actual GasSim input tonnage is not too important. 70 ktpa was chosen as it is a large number (provides output easier to work with and allows realistic use of flare or engine- although there is insufficient gas for the latter) that is also broadly reflective of what might be landfilled from an MBT facility of over 100 kpta input capacity.</td></tr>
</table>

| | |
|---|---|
| | The year of input commencing has no bearing on the model output (can be past, present or future). An MBT facility might typically operate (have a long-term contract for local authority waste) for 20 to 25 years and so it was assumed that waste would be landfilled over 20 years.<br><br>NB: Ricardo's carbon LCA model adjusts the emissions derived from GasSim to accommodate the presence of non-biodegradable materials that will be landfilled inter-mixed with the composted organic material. |
| Cellulose decay rates | Moderate<br><br>[Default used. Default values are within GasSim for slow, moderate and fast cellulose decay rates and moderate was selected. The cellulose decay rate is the half-life values for the degradation of carbon and thus generation of landfill gas. Table 6.1 of the GasSim manual confirms that composted organic material has a moderate decay rate]. |
| Waste Moisture content | Moisture content = Average<br><br>[Defaults exist for 'Dry' (<30% moisture), 'Average' (30 to 60% moisture) and 'Wet' moisture content (>60% moisture).<br><br>This is an important parameter that affects waste degradation and gas production. The emphasis of the MBT-IVC process is waste degradation and not drying and hence 'Average' was selected- it is anticipated that the material to be landfilled will have around 35% to 45% moisture. Arguably, 'Dry' could have been selected. However, over the course of 100 years, this is likely to affect when gas is generated but it can be assumed that towards the end of the period gas production would be minimal whether 'Dry' or 'Average' is used].<br><br>Waste density (t/m3) = UNIFORM (0.8,1.2)<br><br>[This is the GasSim default, irrespective of waste composition. Uncompacted compost density ranges from around 0.3 to 0.7, but the material landfilled will be compacted and will be alongside other non-biodegradable fractions of MSW. For reference, a value of 0.9 is commonly used for unprocessed MSW when landfill modelling, and around 1.7 for inert materials (soils/rubble etc) the default UNIFORM range selected is considered appropriate for the waste being modelled].<br><br>Leachate head (m) = SINGLE (1)<br><br>[Default and it is the value that regulators in Scotland wish to see not exceeded at a landfill]<br><br>Hydraulic conductivity (m/s) = LOGUNIFORM (1.00e-09, 1.00e-05)<br><br>[Default used]. |
| **Landfill Characteristics** | |

| | |
|---|---|
| Landfill geometry | Input as 374m x 374m = 139,876 $m^2$<br><br>[Landfill geometry will vary considerably from one landfill to another. With an assumed waste depth of 10m and 1,400,000 tonnes of waste deposited (70ktpa for 20 years) at assumed density of 1t/m3, the landfill area will be 140,000 $m^2$ (14 hectares)]. |
| Biological methane oxidation in the cap (%) | SINGLE(10)<br><br>[Default used] |
| Cap and liner | Single clay cap of 1m thickness input.<br><br>Single clay liner of 5m thickness input.<br><br>Hydraulic conductivity of $1x10^{-9}$ m/s input for cap and liner.<br><br>[The above inputs satisfy modern landfill engineering requirements and are typical]. |
| **Infiltration (mm/year)** | SINGLE(50)<br><br>Typical value used. This is the volume of water per unit area which passes into the waste mass. |
| **Gas Plant** | It was assumed that a flare with capability to flare down to 100Nm/hr of landfill gas would be available throughout the landfill life. There was insufficient gas produced to allow realistic use of an engine to allow electricity production.<br><br>Assumptions were input for air/fuel ratio (7), stack height (10m), orifice diameter (1m), temperature (1,000$^{o}$C), methane and hydrogen destruction efficiency (each 99%) and gas collection system efficiency (%) of UNIFORM(85,95). |

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