
Ricardo Energy & Environment

# Waste Treatment Technology Foresighting

## Recycling and Recovery Technology Solutions

Report for Birmingham City Council

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# 1 Introduction

Birmingham is one of the largest local authorities in Europe, with a population of just over 1 million, which is expected for grow by 150,000 by 2031. The City Council has responsibility for removing waste from almost 420,000 households across the city. This amounts to just under 250,000 tonnes of domestic waste per year. With commercial waste included, the total municipal arisings in 2013/14 were approaching 494,000 tonnes. Birmingham City Council will be re-commissioning a new waste contract to begin in 2019. Birmingham is a city with considerable ambitions for sustainability and the future approach to how waste is managed in the city will play a key role in achieving this goal.

Effective waste management represents an 'opportunity' for a city and is a fundamental element that underpins its economic growth. Successful cities will need to transition to a circular economy model, one where technical and biological materials form part of a complex cycle, rather than a linear *produce-consume-dispose* chain.

A modern city's waste management system should aim to:

- Protect health and the local environment
- Reduce emissions from waste and mitigate GHG emissions from other sectors
- Generate jobs
- Help meet a city's resource demands and conserves critical materials
- Produce energy and fuel for power generation, transport, heating and cooling
- Ensure nutrient recovery for agricultural supply chains

This is recognised in the vision of the Birmingham Green Commission. Launched in 2013, the vision is aimed at delivering a comprehensive programme of work to make Birmingham a leading green city. In the Birmingham Green Commission plans, waste and resources management is just one component of targets in climate change adaptation, carbon reduction, green jobs growth and innovation.

The ambition for the new waste contract takes into account maximising resources, minimising waste and putting people at the heart of change and is working to ensure:

- Birmingham will have a sustainable, localised and integrated city waste solution managing its own energy and resources.
- Birmingham is an aspirational city that avoids the creation of waste and maximizes its utilisation.
- All stakeholders and citizens are involved in maximising shared social, environmental and economic value and minimising waste.

In order to ensure that the most effective and sustainable solution(s) are adopted, the City Council appointed Ricardo Energy & Environment to undertake a technology foresighting exercise to explore existing and emerging technologies that are available for sustainable waste treatment and that could move Birmingham towards becoming a 'zero waste city'.

Technologies identified have been assessed against a set of criteria, based on cost, risks and benefits, potential community impact (both positive and negative), carbon reduction potential and the implications for waste collection/ feedstock.

This document considers both established and emerging recycling and recovery technologies in the following categories:

- Recycling technologies and systems;
- Thermal treatment of waste, including advanced thermal treatment (ATT); and
- Biological treatment, including mechanical biological treatment (MBT)

***The overall aim of this document is to enable Birmingham City Council to be an informed customer in the future procurement of a waste management contract/s, and to provide the council with the technical information and necessary evidence base to aid future decision making.***

# 2 Approach and Technology Readiness Level

Technologies and systems reviewed are either described in terms of their context, objectives and outcomes, or, where more detailed technical data are available, information is included on typical application and feedstock, feedstock characteristics, technology scale and capacity, process outputs and advantages and limitations. Examples include both overarching technologies and specific examples of systems and plants. Where possible, each technology and system has been assigned a Technology Readiness Level (TRL), in accordance with Table 1.

**Table 1: Technology Readiness Level**

| Technology Readiness Level | Description |
|---|---|
| 1 | Basic principles observed and reported |
| 2 | Technology concept and/or application formulated |
| 3 | Analytical and experimental critical function and/or proof of concept |
| 4 | Technology basic validation in laboratory environment |
| 5 | Technology basic validation in a laboratory environment, where basic technological components are integrated together with realistic supporting elements |
| 6 | Technology model or prototype demonstration verified in a relevant environment |
| 7 | Technology prototype demonstrated in an operational environment |
| 8 | Actual technology completed and qualified through testing and demonstration |
| 9 | Actual technology qualified through successful operation |

# 3 Dashboard

This document is not intended to be read as a report from cover to cover (although it can be), but to present examples of existing and emerging technologies for recycling and thermal energy recovery and biological energy recovery.

Each of these sections has a dashboard from where the reader choose which examples to read, depending on their own interests in particular technologies or waste types.

Each example contains a link back to the section dashboard from where another example can be selected and navigated to. Finally, each section dashboard contains a link back to this page so that the reader can then move on to a different type of technology.

| | |
|---|---|
|  | Recycling |
|  | Thermal Recovery |
|  | Biological Recovery |

# 4 Recycling Dashboard

This section considers technologies for the collection and processing of recyclable materials. New and innovative collection techniques are examined, for example pneumatic and/or underground recycling systems, as well as existing and emerging recycling technologies for specific materials, for example used cooking oil. This section also examines existing and emerging technologies for the recycling of a range of waste streams, which may be source separated or commingled.

| | Measure/Material | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Sorting technology** | **Collection systems** | **Plastics** | **Tyres** | **Glass** | **Street Sweepings** | **Used Cooking Oil** | **Absorbent hygiene products (AHPs)** | **Carpet** | **Mattresses** | **Chewing gum and cigarette butts** | **Pet waste** | **Cartons** |
| **Examples** | *Multi-material MRF, California* | *Underground waste collection systems, Songdo, Korea* | *Veolia Magpie plastics sorting technique* | *Tyre recycling processes* | *Advanced glass recycling, Lanarkshire* | *Screening and washing of street sweepings, Warwickshire* | *Biodiesel from used cooking oil* | *Recovery of cellulose and polymers from AHP's, Wales* | *Cryogenic carpet recycling, Wirral* | *Mattress recycling, Denbighshire* | *Chewing gum recycling, UK* | *Dog waste digester, Arizona* | *Carton recycling, UK* |
| | *Advanced Mixed Materials Resource Facility, Alabama* | *Envac pneumatic waste collection systems, Worldwide* | *Veolia Plastics sorting facility, Rainham UK* | | *Cathode Ray Tube Recycling, Kent* | *Recovery of aggregate and compost from street sweepings, Dorset* | | *Plastics recovery and composting of AHP's* | | *Mattress and bed recycling, Lancashire and East Midlands* | *Cigarette Waste Recycling, US* | *Dog waste wormeries, UK* | |
| | *Optical sorting of bagged waste, Scandinavia* | *Waste collection app, USA* | *Waterless plastics recycling, Mexico* | | | *Street sweepings recycling, Wolverhampton* | | *Knowaste nappy recycling facilities, UK* | | | | | |
| | | | *Enzymatic depolymerisation of plastics, France* | | | | | | | | | | |

## 4.1 Recycling collection and sorting technologies

| Multi-material MRF, California | |
|---|---|
| Type of technology | Material sorting |
| Technology name | Multi-material MRF |
| Technical description | A Materials Recycling Facility that has been designed to process different waste streams on the same processing line.<br>The MRF first sorts materials according to size and density in to the following waste streams:<br>• Large items such as wood, metals, cardboard and film (these are then subsequently manually sorted)<br>• High density materials such as glass, metals, WEEE, large organics, wood, and other inerts<br>• Medium density products such as plastic packaging magazines, small pieces of wood and textiles<br>• Low density products such as paper and films<br>Each waste stream is then further refined using TITECH sensor based sorting technology. The MRF uses a combination of technologies including air separation equipment from Bollegraaf and Walair, and sensor based sorting technology from TITECH.<br>The flexibility of the individual technologies allows the MRD to be immediately adjusted and reset according to the waste streams being processed. |
| Typical application and feedstock | The technology can process both single stream and commingled recyclables and residual waste from businesses and households. |
| Technology scale and capacity | 600–700 tons per day of any type of incoming material all on the same processing line. |
| Process outputs | Sorted recyclables |
| Advantages | The technology is scalable, and therefore suitable for applications where there are financial or space constraint or when volumes to be processed are lower. The same line can be used to process different waste streams. |
| Limitations | Smaller capacity than a MRF which has multiple processing lines. |
| Reference plants | Grand Central Recycling, California |
| TRL | 9 |
| Further information | http://vdrs.com/news-media/innovative-multi-material-mrf-opened-at-grand-central-recycling-and-transfer/ |

| Advanced Mixed Materials Resource Facility, Alabama | |
|---|---|
| Type of technology | Materials Sorting |
| Technology name | Advanced Mixed Materials Resource Facility |
| Technical description | The system uses screens, a designed, manufactured and installed by Bulk Handling Systems (BHS), features BHS screen, Nihot air separation and NRT optical sorting technology that will separate out up to 95 percent of available recyclables from the mixed waste stream at a rate of 30 tons per hour. The system will also recover organic waste for composting. |
| Typical application and feedstock | Mixed municipal wastes |
| Technology scale and capacity | The facility processes ~30 tonnes per hour |
| Process outputs | High quality, clean recyclables – plastics, mixed paper, cardboard, and metals.<br>Overall recovery rate is reported to be >60% |
| Advantages | In this particular case, the existing recycling program delivered in Montgomery, Alabama was failing due to lack of participation. Following the opening of the MRF, recycling has increased as all waste is processed here. |
| Limitations | Viability is dependent on material prices. The IREP facility was reported to have temporarily closed in October 2015 due to volatility in recyclate markets - |
| TRL | 9 |
| Further information | http://www.bulkhandlingsystems.com/montgomery-celebrates-opening-of-innovative-materials-recovery-facility/ Accessed 20 December 2015<br>https://nerc.org/documents/conferences/Spring%202015%20Conference/Kyle%20Mowitz_Redefining%20Waste.pdf Accessed 20 December 2015 |

| Optical sorting of bagged waste, Scandinavia | |
|---|---|
| Type of technology | Recycling |
| Technology name | Optibag |
| Technical description | Optibag is a fully automated optical sorting system for municipal waste. Users of the system are provided with different coloured waste bags corresponding to the different waste streams that are collected. For example, green bags could be used for food waste, red for paper and yellow for cardboard packaging. The waste is segregated and put into the bags where it is produced, for example at home.<br><br>The waste bags are placed in the designated chute, bin or container and then collected with a conventional waste vehicle and transported to the Optibag plant. Upon arrival, the waste bags are tipped into a reception pit and transferred to a conveyor belt.<br><br><br><br>Camera technology is used to sort the bags by colour. When the target bag is detected a signal is sent from the camera and the bag is pushed off the main conveyor belt, on to a second belt and directed to the appropriate container. The segregated materials are then either recycled or directed to the appropriate recovery facility. |
| Typical application and feedstock | The customers are municipalities, cities, local authorities as well as private contractors within the waste management sector. Users range from households to commercial developments including restaurants and shops. Feedstock is waste that has been sorted in to one or more different coloured bags. |
| Technology scale and capacity | An Optibag plant consists of 1-4 sorting lines. Each individual sorting line has a sorting capacity of 7-9 tonnes per hour. This means that a plant with three sorting lines which are used in one shift have a theoretical annual capacity of 50,000 tonnes per annum. |
| Process outputs | • Residual waste |

| | |
|---|---|
| | • Separated streams of recyclables |
| Advantages | Using different colour bags means that householders can still use one bin, saving space. Less space is required for waste storage and waste logistics are improved. Transport is reduced as several waste streams are collected in the same vehicle. Waste segregation is carried out at source by the business or householder, improving quality of recyclables. |
| Limitations | Impacts on current collection systems. Separated materials still need to be transported to end destinations.<br>Ongoing requirement to supply bags and is dependent on users participation and correct segregation |
| Reference plants | Numerous facilities in Norway, Sweden and Finland. |
| TRL | 9 |
| Further information | http://www.optibag.com/ |

| Underground waste collection systems, Songdo, Korea | |
|---|---|
| Type of technology | Underground waste collection systems and sorting |
| Technical description | Songdo is dubbed as 'The World's Smartest City'. A newly built city on the site of a former landfill, the city is being developed as a sustainable city that demonstrates Korea's technological progress. The city is expected to be complete by 2018. The city is connected by an underground system of pipes, in to which rubbish is sucked directly from premises and routed to an automated waste collection plant for processing.<br><br>The 'Third Zone Automated Waste Collection Plant' automatically sorts the waste into fractions for recycling, landfill of energy recovery. The system covers all apartment buildings and businesses which means there are no bins or refuse collection vehicles on the streets. The system is considered to be the first of its kind in the world and currently requires just seven employees for the entire city. city |
| Typical application and feedstock | Typical applications are apartment blocks, new housing developments, and public sector buildings. |
| Technology scale and capacity | The capacity of the system is bespoke to each building and site. |
| Process outputs | Bulked residual waste and recyclables for onward transport and processing |
| Advantages | Provide collection of household waste whilst minimising vehicle movements. The system is not yet fully operational. |
| Limitations | Easier to install in new developments although can be retrofitted to existing buildings. Makes less waste visible which may mean people are less aware of importance of waste prevention |
| Further information | http://www.theatlantic.com/international/archive/2014/09/songdo-south-korea-the-city-of-the-future/380849/<br><br>http://www.bbc.co.uk/news/technology-23757738 |

| Envac pneumatic waste collection systems, Worldwide | |
|---|---|
| Type of technology | Underground waste collection systems |
| Technical description | Waste is disposed of into ordinary, readily accessible inlets, which can either be indoors or outside. Bags are stored temporarily above a closed storage valve.<br><br>When the control system senses that it is time to empty the inlets, Envac's fan system is initiated and a vacuum is created in the pipe network. A supply air valve is opened in order to allow air into the pipe system to transport waste from the inlets to the waste collection station. The storage valves beneath the inlets are then opened one by one. The waste bags fall down into the underground network and are sucked away to the waste collection station at speeds of up to 70kph and over distances as long as 2km from the waste inlets.<br><br>Waste at the collection station is sucked through a cyclone, where it is separated from the transport air. It then falls down into a compressor where it is compressed and fed into a sealed container. The transport air is released via a flue after having passed through a series of cleaning filters and silencers. |
| Typical application and feedstock | Householders, new housing developments, flats, hotels, businesses<br><br>MSW and C&I waste and recycling |
| Technology scale and capacity | Technology available at adaptable scale and capacity. An example is a facility in Wembley which comprises 4,200 flats, shops and hotel, leisure and entertainment venues. A city centre system in Stockholm processes 11 tonnes of waste per day from 20,000 residents. |
| Process outputs | • Bulked residual waste and recyclables for onward transport and processing |
| Advantages | • Can be adapted to suit each individual project depending on the development's design and requirements.<br>• System can be extended to adjacent areas as new pipework can be added on to the existing underground infrastructure.<br>• Suitable for large-scale new commercial and residential developments as well as being retrofitted into existing buildings and developments. It can also be integrated into individual properties and rows of terraces.<br>• Eliminates kerbside collection and manual emptying of bins |
| Limitations | Impacts on current collection systems. Separated materials still need to be transported to end destinations. Will need to be considered early on in the planning of new developments. |
| Reference plants | Worldwide facilities, including in the UK |
| TRL | 9 |
| Further information | http://www.envacgroup.com/products-and-services/our_products/envac-stationary-vacuum-system |

| Waste collection app, USA | |
|---|---|
| Location | USA |
| Type of measure | An App for waste collection which is similar to Uber, the app for ordering taxis on demand via smartphone. |
| Target audience | Households |
| Type of waste | Household waste |
| Context | Rubicon is aiming to develop an app to allow on-demand collections of waste. Rubicon has appointed Uber's original chief technological officer to assist in the launch of the waste app.<br>It is envisaged that initially, collections will take place within 24 hours of a request via the app; however, Rubicon aims to reduce this time to 30 minutes. |
| Objectives | Minimise waste to landfill by making it simpler to organise waste collections.<br>Offer prompt collections of waste. |
| Outcomes | Not yet operational |
| Further information | http://rubiconglobal.com/news/coming-soon-an-uber-for-trash/<br>http://www.edie.net/news/5/Uber-like-app-for-garbage-aims-to-boost-recycling-rates/ |

## 4.2 Plastics

| Veolia Magpie plastics sorting technique | |
|---|---|
| Type of technology | Innovative Materials Recycling Facility sorting technique |
| Technical description | An approach developed by Veolia is set to use technology in a way that will enable local authorities to collect a wider range of plastics from households without the need for additional containers to be provided. The technology – known as the Magpie – uses infra-red technology to determine the molecular structure of materials. Different types of plastic reflect different amounts of light. The infra-red sensor identifies the most valuable materials first, which are removed from the rest of the materials using an air separator. The waste stream is then sent back through the same machine repeatedly, and a different type of plastic is identified and separated. The technology uses both TiTech and Pellenc optical sorting technology. |
| Typical application and feedstock | The technology is used on commingled recyclables. |
| Technology scale and capacity | 30,000 tonnes per annum |
| Process outputs | Sorted plastics in to individual types |
| Advantages | Increases type of plastics collected and recovered for recycling.<br>The waste moves through the technology repeatedly which avoids having to purchase multiple items of equipment. Veolia claim the technology replaces up to 4 or 5 different machines.<br>The technology can also be upgraded as and when new types of plastic are collected for recycling. |
| Reference plants | There were 2 pilot facilities in France before the technology was used in the Veolia MRF and Padworth in West Berkshire. |
| TRL | 9 |
| Further information | http://www.letsrecycle.com/news/latest-news/veolia-unveils-innovative-mrf-sorting-technique/ Accessed 14 January 2016 |

| Veolia Plastics sorting facility, Rainham UK | |
|---|---|
| Type of technology | Plastics sorting facility |
| Technical description | Veolia has made a £6.5 million investment in the development of a plastics sorting facility which uses the latest optical sorting technology to separate plastics in to 9 different types. |
| Typical application and feedstock | Mixed plastics |
| Technology scale and capacity | 50,000 tonnes per annum of plastics are sorted at the Rainham facility |
| Process outputs | Sorting plastics into 9 different grades of polymer |
| Advantages | The sorting technology results in 9 different types of polymer, therefore increasing their value when compared to mixed plastics.<br><br>Can offer a solution to local authorities who would like to implement a mixed plastic collection service. |
| Limitations | Will require a mixed plastic feedstock, as opposed to a mixed recycling feedstock |
| TRL | 9 |
| Further information | http://www.veolia.co.uk/sites/g/files/dvc636/f/assets/documents/2014/10/PRF_factsheet.pdf Accessed 14 December 2015<br><br>http://www.veolia.co.uk/media/media/case-studies/pioneering-plastics-recovery Accessed 14 December 2015 |

| Waterless plastics recycling, Mexico | |
|---|---|
| Type of technology | Plastics recycling |
| Technical description | Traditional plastics recycling processes use large quantities of water. Mexican company AK Inovex has developed a process which does not use water, and they claim is can produce pellets and half the cost of conventional processes. |
| Typical application and feedstock | Mixed plastics, styrofoam, polystyrene and Acrylonitrile Butadiene Styrene (ABS) |
| Technology scale and capacity | Inovex currently have a small scale prototype facility<br>The current prototype facility is small scale, processing around two tonnes per day; however, the company is working to increase this capacity to 10 tonnes per day |
| Process outputs | Plastic pellets which can then be recycled in to new plastic products. |
| Advantages | If successful, will provide a water-free process for recycling plastics. |
| Limitations | Technology as yet unproven for scale-up |
| Reference plants | The technology is still at the prototype stage. |
| TRL | 4 |
| Further information | http://phys.org/news/2015-01-technology-recycle-plastics.html Accessed 14 December 2015 |

| Enzymatic depolymerisation of plastics, France | |
|---|---|
| Type of technology | Plastics recycling |
| Technical description | A French company – Carbios – are currently developing a technology which utilises enzymatic depolymerisation to break down Polyethylene terephthalate (PET) into its original monomers - TPA (terephthalic acid) and EG (ethylene glycol). The process is aimed at producing monomers of the offer the same quality as virgin monomers produced from petroleum. The separated monomers, once cleaned, could then be used to replace virgin materials in the production of new PET products. |
| Typical application and feedstock | Polyethylene terephthalate (PET) |
| Technology scale and capacity | Facility in the development phase |
| Process outputs | Monomers for reprocessing |
| Advantages | A process which will enable the infinite To develop a process which allows PET to be endlessly recycled.<br>Avoidance of manufacture of new PET from petroleum. |
| TRL | 4 |
| Further information | http://www.carbios.fr/en/press-releases/show/75 Accessed 14 December 2015 |

## 4.3 Tyres

| Tyre recycling processes | |
|---|---|
| Type of technology | Numerous technologies for recycling tyres |
| Technical description | There are several processes which can be used for recycling tyres in to other products. These include ambient or cryogenic processing, or the simple shredding and granulated. In the ambient process, tyres are fed in to a granulator or mill at room temperature. This process can be applied to any size of particle, including whole tyres. Magnets will be used to remove wire and other metal contaminants. Cryogenic processing refers to the use of liquid nitrogen freeze shredded tyres prior to further size reduction. As the tyres become brittle at temperatures below -80°C, the material can then broken up in to a fine crumb-like material. |
| Typical application and feedstock | Used tyres |
| Process outputs | Tyre shred and crumb can also be used under the Quality Protocol for Tyre-derived rubber materials, which sets out end of waste criteria for their production and use. Under this protocol, shredded tyres can be used as aggregate, bound rubber surfacing, artificial playing surfaces, landfill drainage layer, new tyres, and rubber products such as wellington boots. This quality protocol has been approved in a British Standards Institution Publically Available Standard for tyre derived materials (PAS 107).<br>Metals recovered from the tyres will be recycled |
| Advantages | Moves tyres up waste hierarchy, as they are also used in energy recovery. |
| Limitations | Process is dependent on sufficient market for end products. |
| Reference plants | Tyre Renewals, Somerset |
| TRL | 9 |
| Further information | http://www.wrap.org.uk/sites/files/wrap/8%20-%20UK%20Waste%20Tyre%20Management%20-%20May%202006.pdf Accessed 14 December 2015<br>http://www.murfittsindustries.com/the-plant/ Accessed 14 December 2015<br>http://www.tyre-renewals.co.uk Accessed 14 December 2015<br>http://www.tyrerecovery.org.uk/ Accessed 14 December 2015 |

## 4.4 Glass

| Advanced glass recycling, Lanarkshire | |
|---|---|
| Type of technology | Glass reprocessing |
| Technical description | In September 2015, Viridor opened a £25 million advanced glass recycling facility in Newhouse, North Lanarkshire. The plant is now the UK's most advanced glass recycling facility, and one of only three such facilities globally using advanced recycling technology from across the world, including 'scientific eye' optical sorters and x-ray sorters.<br><br>Glass is fed into the main feed hopper and then pre-sorted into two size fractions (>50mm and <50mm). The larger fraction is fed through a picking station where large contaminants are removed by hand. The glass fractions are then passed under a magnet and eddy current separator and a suction hood is used to recover lightweight contaminants such as labels and plastic. Once contaminants have been removed, the material is subjected to further sorting by particle size and ceramics, stones and porcelain removed using optical sorting technology. Finally, the material is sorted into individual colour streams. |
| Typical application and feedstock | The facility recycles mixed glass from 17 local authorities. |
| Technology scale and capacity | The Newhouse facility processes 200,000 tonnes per annum |
| Process outputs | 97% recovery rate and 99% product purity, with materials supplying the container (bottles and jars), aggregate and fibreglass markets. |
| Advantages | The processed glass is expected to exceed the quality requirements for product packaging.<br><br>Does not require the glass to be pre-sorted in to different types. |
| TRL | 0 |
| Further information | https://www.viridor.co.uk/assets/REDESIGN/ABOUT-US/PUBLICATION-PDFS/VIRIDOR-GLASS.pdf Accessed 14 December 2015<br><br>https://blog.viridor.co.uk/2015/11/09/awards-success-for-25m-lanarkshire-glass-plant/ Accessed 14 December 2015 |

| Cathode Ray Tube Recycling, Kent | |
|---|---|
| Type of technology | CRT Glass recycling |
| Technical description | The lead content in the glass of a CRT can be as high as 20%, which is the equivalent of 1kg of lead in a 34" television.<br><br>SWEEEP Kuusakoski has developed a technology which extracts the lead from the funnel glass. The process claims to have no emissions, creates no waste and avoids export of hazardous material from the UK. The process is undertaken in a furnace which enables the removal of the lead fraction, and also creates added value products from the remaining molten glass. |
| Typical application and feedstock | CRT glass |
| Technology scale and capacity | The Kent facility extracts lead from 10 tonnes of funnel glass per day. |
| Process outputs | De-leaded glass - can be used as an aggregate replacement in construction products such as floor screeds and worktops and to produce glass tiles. Other potential applications include road surfacing, grit blasting and production of higher value decorative glass products.<br><br>Lead – can be recycled in to new lead products. |
| Advantages | Cathode Ray Tubes from televisions contain leaded glass which means that this is a hazardous waste, therefore this process provides an alternative to disposal in a hazardous waste landfill. |
| TRL | 9 |
| Further information | http://www.sweeepkuusakoski.co.uk/glassrecycling/ Accessed 14 December 2015 |

## 4.5 Street Sweepings

| Screening and washing of street sweepings, Warwickshire | |
|---|---|
| Type of technology | Recycling of street sweepings |
| Technical description | The plant uses a two-step treatment process; the first stage uses screens and magnetic separators to remove large items such as twigs and stones and ferrous metals, the second stage uses a washing process to sort the material into sands, silts and aggregates. |
| Typical application and feedstock | To process street sweepings and gully material collected by local authorities. |
| Technology scale and capacity | 50,000 tonnes per annum plant which treats 50 tonnes of waste per hour. |
| Process outputs | 85 – 90% diversion from landfill. 10% of the material is organic and is composted; 20% consists of aggregates; 60% consists of material suitable for landfill restoration; 5% leachate, 5% mixed residue and precious metals extracted from the dust including platinum, palladium and rhodium. |
| Advantages | Diverts material from landfill, recovery of precious metals |
| TRL | 9 |
| Further information | http://www.veolia.co.uk/sites/g/files/dvc636/f/assets/documents/2014/10/ST_factsheet.pdf Accessed 14 December 2015 |

| Recovery of aggregate and compost from street sweepings, Dorset | |
|---|---|
| Type of technology | Recycling of street sweepings |
| Technical description | 30,000 tonne per annum capacity soil washing plant. The plant uses a two-step treatment process; the first stage uses screens and magnetic separators to remove large items such as twigs and stones and ferrous metals, the second stage uses a washing process to sort the material into sands, silts and aggregates. |
| Typical application and feedstock | To process street sweepings and gully material collected by local authorities. |
| Technology scale and capacity | 30,000 tonnes per annum |
| Process outputs | 75% of the material is recycled as aggregate.<br>There is also organic and light weight material which is dewatered and then composted. This material can only be classed as a CLO (compost like output) so is presently only suitable on restoration projects. Organic content normally accounts for 20% of the material.<br>The remaining 5% of material is a flocculated sludge which is dewatered. The water is recovered and reused and the remaining sludge has to go to landfill |
| Advantages | Recovery of aggregates and compost |
| TRL | 9 |
| Further information | http://www.thisiseco.co.uk/Street_Sweeping.html Accessed 14 December 2015 |

| Street sweepings recycling, Wolverhampton | |
|---|---|
| Type of technology | Recycling of street sweepings |
| Technical description | Soil washing plant which includes a full water treatment system, bespoke material feed hopper, and RotoMax 60R high attrition system. |
| Typical application and feedstock | To process street sweepings and gully material collected by local authorities. |
| Technology scale and capacity | 40,000 tonnes per annum |
| Process outputs | An estimated 98% of the road sweepings treated by the plant will be recycled for use in products including sand, washed aggregate and compostable material. |
| Advantages | Recovery of aggregates and compost |
| TRL | 9 |
| Further information | http://www.cdenviro.com/case-studies/32/sita-uk-reduce-waste-to-landfill-with-road-sweepings-and-gully-arisings-plan Accessed 14 December 2015 |

## 4.6 Used Cooking Oil

| Biodiesel from used cooking oil | |
|---|---|
| Type of technology | Used Cooking Oil (UCO) recycling |
| Technical description | Olleco has three oil processing sites and the UK's largest biodiesel manufacturing plant. The company collects used cooking oil from businesses which is then processed into biodiesel. The biodiesel plant in Liverpool is powered by outputs from its anaerobic digestion facility which treats manufacturing food waste |
| Typical application and feedstock | Used cooking oil from catering and food manufacturing sectors |
| Technology scale and capacity | Olleco's Liverpool facility processes 16 million litres of biodiesel per year |
| Process outputs | Biodiesel. |
| Advantages | Production of biodiesel that meets the EU standard for specification for diesel engine fuels (EN14214 EU) and is International Sustainability and Carbon ISCC certified.<br>Achieve a 90% carbon saving compared to standard fossil diesel. |
| Reference plants | Southampton, Wales and Liverpool, UK |
| TRL | 0 |
| Further information | http://www.olleco.co.uk/ Accessed 14 December 2015<br>http://www.ewaba.eu/about-us/ Accessed 14 December 2015 |

## 4.7 Absorbent Hygiene Products

| **Recovery of cellulose and polymers from AHP's, Wales** | |
|---|---|
| Type of technology | Recycling of Absorbent Hygiene Products (AHP's) |
| Technical description | Natural UK has developed a 'Hydro-recovery' technology to recycle nappies and other sanitary products. The process recovers plastics and cellulose materials that would have previously been sent to landfill.<br>Through the hydro-recovery process, cellulose and plastic materials are recovered for future use. At its site in Carmarthenshire, Natural UK treats and processes the nappies and absorbent hygiene products, the cellulose fibre is separated and used to produce fibre boards and acoustic panelling. Plastics, including latex, nitrile, vinyl etc. are sent to secondary re-processors for recycling. Natural UK is also experimenting with the manufacture of various types of display panelling, shelving and other uses for this bonded material, including both work tops and even table tops, and continue to look for new and innovative new uses for these recovered materials. |
| Typical application and feedstock | Absorbent Hygiene Products collected from businesses, NHS Trusts and local authorities throughout South and West Wales. |
| Technology scale and capacity | The site processes the equivalent of 300,000 nappies each week |
| Process outputs | Recovered polymers and fibres |
| Advantages | Provides an alternative to landfill, for example, over 1 million disposable nappies have been diverted from landfill for Rhondda Cynon Taf council through the implementation of its NappiCycle scheme |
| TRL | 8 |
| Further information | http://www.naturaluk.co.uk/uploads/media/brochure/NaturalUK%20NappiCycle%20Brochure.pdf Accessed 14 December 2015 |

| Plastics recovery and composting of AHP's | |
|---|---|
| Type of technology | Recycling of Absorbent Hygiene Products (AHP's) |
| Technical description | Envirocomp's facility shreds the AHP waste with green waste and then plastics are removed, leaving compostable material. Compost produced by the process is used for land restoration and the plastics are presently incinerated.<br><br>The AHP waste is supplied by Cannon Hygiene, Envirocomp's sister company in the UK and in New Zealand, material from domestic properties is also part of the service.<br><br>Nappies and other AHP waste are processed with green waste through a HotRot composting unit.<br><br>Once shredded, the AHP and green waste mix is fed into the plant and treated through an in-vessel composting process. The material is treated for a duration and at a temperature sufficient to kill pathogens and the final product can be used for non-food agriculture, leisure areas and other general compost uses. |
| Typical application and feedstock | Absorbent Hygiene Products |
| Technology scale and capacity | The Canterbury plant processes 15,000 nappies per day |
| Process outputs | Recovered polymers , compost |
| Advantages | AHP is estimated to account for 2 – 4% of landfill volumes and the plant has been designed to reduce waste to landfill.<br><br>24% of New Zealanders now have access to a chargeable AHP recycling service. Envirocomp utilises a network of drop-off points in supermarket car parks where service users can deposit their pre-paid bags. In addition, a collection service is provided to commercial customers |
| Reference Facilities | Canterbury, New Zealand and Rochester, UK |
| TRL | 8 |
| Further information | http://envirocomp.uk.com/ Accessed 14 December 2015 |

| Knowaste nappy recycling facilities, UK | |
|---|---|
| Type of technology | Absorbent Hygiene Products recycling |
| Technical description | Knowaste has submitted plans to develop a new AHP recycling plant in West London to recycle 36,000 tonnes of waste per year. The site is planned for opening in 2017.<br><br>AHP waste is shredded and then passed through a sterilisation process, fibres are extracted and the remaining plastics continue to a granulation and washing process. Once washed, the plastics are pelletised for use in the manufacture of new plastic products. |
| Typical application and feedstock | Absorbent Hygiene Products collected by local authorities |
| Technology scale and capacity | 36,000 tonnes of AHP waste per annum |
| Process outputs | Polymers for reprocessing |
| Advantages | The Knowaste process can recycle 97% of the incoming AHP waste. |
| Reference plants | In 2011, Knowaste became the UK's first company to recycle AHPs when a facility was opened in West Bromwich. This facility closed in 2013. The company claimed that they had 'outgrown' the existing facility and that whilst they had proven the concept the current site did not meet the future requirements of the business. |
| TRL | 7 |
| Further information | http://hayes180.knowaste.com/ Accessed 14 December 2015 |

## 4.8 Carpet

| Cryogenic carpet recycling, Wirral | |
|---|---|
| Type of technology | Carpet recycling |
| Technical description | StopWaste Ltd has developed a patented technology which uses cryogenics to freeze the carpet waste to recover all of the fibre along with ultrasonic technology to clean dirty fibres. The process uses sorting, size reduction and fibre pile splitting technologies. 70% of the used carpet material is shredded and used to supply equestrian market as a surface covering. Approximately 10% of the polypropylene from used carpets is supplied to the plastic recycling sector. Approximately 10% of inputs cannot be recycled and are sent to energy from waste facilities. The majority of the remaining material is used to supply the filler/nylon markets. |
| Typical application and feedstock | Waste carpet |
| Technology scale and capacity | 20,000 tonnes of carpet per annum |
| Process outputs | • Carpet tiles – nylon recovery or reuse<br>• Synthetic carpet – polypropylene (PP) recovery or used in equestrian surfaces<br>• Wool rich carpets – land restoration, development for use as a fertiliser, use in underlay |
| Advantages | Diverts waste carpet from landfill or EfW, recovers materials for recycling |
| TRL | 9 |
| Further information | http://www.wirralrecycling.co.uk/our-group/stopwaste.html Accessed 14 December 2015<br>http://www.carpetrecyclinguk.com/downloads/NWnetwork_event_23_11_10_Carpet_Recycling_Technology_Jonathan_Quinn_Stopwaste.pdf Accessed 14 December 2015 |

## 4.9 Mattresses

| Mattress recycling, Denbighshire | |
|---|---|
| Type of technology | Mattress recycling |
| Technical description | Bulky waste collections are undertaken by Denbighshire County Council and mattresses (and carpets) are brought by residents into Denbighshire's three HWRCs run by CAD Recycling.<br>The arrangement between the contractor, CAD Recycling and Denbighshire Council is designed to incentivise innovative approaches to increasing recycling rates, and bonus payments are provided for additional material diverted from landfill. CAD Recycling, in conjunction with recycling firm EOL Recycling, created a dedicated facility for mattress recycling at its site in Denbigh which opened in December 2012. This site now processes all the mattresses brought in to Rhyl Recycling Park, Ruthin Recycling Park and Denbigh Civic Amenity Site, as well as some from neighbouring Colwyn Bay.<br>Mattresses are deconstructed, with the tick (cover) being removed first, then the flock or padding. Materials are sorted and baled. The springs are inspected and sent for re-use (where suitable) or recycled.<br>These materials are then used in the production of low cost refurbished and recycled mattresses and other uses, including:<br>• textiles components are reprocessed into a variety of products including geotextiles,<br>• automotive insulation and new mattress textiles<br>EOL's new facility in Nottingham also recycles soft furnishings, cushions, duvets and pillows as well as mattresses. |
| Typical application and feedstock | Mattresses disposed of at Household Waste Recycling Centres |
| Technology scale and capacity | Around 1,350 mattress collections from HWRCs by CAD Recycling each year and around 100 mattress deliveries by Crest Co-operative each year. |
| Process outputs | Textiles, metals |
| Advantages | With outlets for over 40 different types of materials, EOL Recycling achieves a recycling rate of 96-98% for each mattress. |
| TRL | 9 |
| Further information | http://www.wrap.org.uk/sites/files/wrap/Collection%20of%20mattresses%20for%20component%20re-use%20and%20recycling.pdf Accessed 14 December 2015 |

| Mattress and bed recycling, Lancashire and East Midlands | |
|---|---|
| Type of technology | Mattress and bed recycling |
| Technical description | The Furniture Recycling Group offers a range of furniture recycling solutions, including household mattresses, hotel mattresses, beds and soft furnishings. Items are deconstructed manually using specialist cutting tools which allow the materials to be segregated accurately for onward processing.<br><br>Textiles are segregated and sanitised. Textile products are fed into the UK manufacturing industry, with no products claimed to be exported. Foam is also sanitised and granulated for use in padding and underlay products.<br><br>Steel is sent to steel mills for re-processing.<br><br>Clean wood is sent to be re-processed for chipboard and contaminated wood and contaminated textiles are used for energy from waste. |
| Typical application and feedstock | Mattresses and beds collected by local authorities |
| Technology scale and capacity | Capacity unknown |
| Process outputs | Textiles, steel and wood. |
| Advantages | Recovery of materials for recycling and reuse<br><br>Generation of sustainable employment for a variety of skilled and non-skilled people |
| TRL | 9 |
| Further information | http://www.tfrgroup.co.uk/recycling-process Accessed 14 December 2015 |

## 4.10 Chewing gum and cigarette butts

| **Chewing gum recycling, UK** | |
|---|---|
| Type of measure | Recycling of chewing gum |
| Type of waste | Chewing gum |
| Context | Gum-tec® has developed a system to collect used chewing gum and to recycle it back in to the receptacles it is collected in. The receptacles are designed specifically for the disposal of waste chewing gum. Gumdrop containers are located in city centres and outside busy venues for people to dispose of their chewing gum in. Once the Gumdrop is full, the whole Gumdrop along with its contents of waste gum is recycled and processed to manufacture new Gumdrops, the cycle then starts again. Gumdrop Ltd also collaborates with manufacturers and companies globally to make products from recycled and processed chewing gum. With Gumdrop's help, recycled and processed chewing gum can become a vast number of things from wellington boots, to mobile phone covers, stationary, and packaging.   *http://gumdropltd.com* |
| Objectives | Reduce littering of chewing gum |
| Outcomes | Gumdrop has proved to reduce chewing gum litter by up to 46% in the first 12 weeks of use, and can save as much as £3000 per annum on cleaning bills. |
| Further information | http://gumdropltd.com/about/ Accessed 14 December 2015<br>Case studies - http://gumdropltd.com/bin-launch-case-studies/ Accessed 14 December 2015 |
| TRL | 9 |

| Cigarette Waste Recycling, US | |
|---|---|
| Location | US |
| Type of measure | Recycling |
| Target audience | Employers, local authorities and public sector organisations. |
| Type of waste | Cigarette butts |
| Context | Cigarette waste collected through the Cigarette Waste Brigade is recycled into a variety of industrial products, such as plastic pallets, and any remaining tobacco is recycled as compost.<br>Collections are offered to individual smokers using free postage labels, or receptacles designed to be used in work or public places.<br><br><br>*http://www.terracycle.com/en-US/brigades/cigarette-waste-brigade.html* |
| Objectives | Litter prevention, recycling |
| Outcomes | • Cigarette waste diverted from landfill.<br>• Avoidance of litter<br>• Materials recovered for use in new products<br>• Every pound of cigarette waste collected, Santa Fe Natural Tobacco Company donates $1.00 towards the Keep America Beautiful Cigarette Litter Prevention Program. |
| Further information | http://www.terracycle.com/en-US/brigades/cigarette-waste-brigade.html<br>Accessed 14 December 2015 |
| TRL | 8 |

## 4.11 Pet waste

| Dog waste digester, Arizona | |
|---|---|
| Location | Arizona, US |
| Type of measure | Variety of methods for dealing with dog waste |
| Target audience | Dog owners |
| Type of waste | Dog waste |
| Context | Various measures are being developed to deal with the estimated 10.6 million tonnes of dog waste produced in the US every year. One of these is the E-TURD project, designed by Arizona State University students, and which uses aerobic bacterial digestion to breakdown the waste to a gas. The digested is sited at a dog park, where dog walkers can deposit dog waste in to the e-TURD unit and a lamp post will be lit with a flame from the gas produced.<br>Other dog waste programmes in the US and Canada include:<br>• Toronto's program for composting pet waste<br>• Envirowagg – a project which composts 3 tonnes of dog waste per year in Colorado<br>• GreenPet Composting, Washington |
| Objectives | The e-TURD project aims to:<br>• help residents to clean up dog waste<br>• reduce the amount of waste to landfill<br>• teach students about science. |
| Outcomes | Diversion of dog waste from landfill, reduction of fouling of public spaces |
| Further information | http://news.nationalgeographic.com/news/2006/03/0321_060321_dog_power_2.html Accessed 14 December 2015<br>http://www.livescience.com/44732-eliminating-pet-poop-pollution.html<br>http://envirowagg.com/ Accessed 14 December 2015<br>http://www.greenpetcompostcompany.com/Default.aspx Accessed 14 December 2015 |
| TRL | 7 |

| Dog waste wormeries, UK | |
|---|---|
| Location | UK |
| Type of measure | Recycling equipment |
| Target audience | Dog owners |
| Type of waste | Dog waste |
| Context | Earth Essentials has developed a wormery specifically for treating dog waste. Dog waste is collected in compostable bags, and placed in the wormery where worms will digest the waste. The resulting worm casts can be safely used in the garden.<br><br><br>*http://www.earth-essentials.co.uk/prod_details_dogwormeryNEWEE.htm* |
| Objectives | Alternative solution for dog waste |
| Outcomes | Replaces the poly bag pick-up method which ends up in landfill. Dog waste wormeries have been used at:<br>• The Olympic Village sites<br>• Excel Centre<br>• Brands Hatch<br>• Earls Court<br>• Hampton Court<br>• Hyde Park<br>• Wembley Arena<br>• Lords<br>• Wimbledon |
| Further information | http://www.earth-essentials.co.uk/prod_details_dogwormeryNEWEE.htm |
| TRL | 7 |

## 4.12 Cartons

| Carton recycling, UK | |
|---|---|
| Type of technology | Carton recycling |
| Technical description | In September 2013, ACE UK officially opened the UK's only beverage carton recycling facility in Stainland, near Halifax, West Yorkshire.<br>The plant is a result of an innovative partnership with paper and packaging producer, Sonoco Alcore who will utilise the virgin wood fibres recovered from the cartons to use in its paper mill at the same site. This is then made into cardboard tubes and cores, which are used to wrap paper, man-made fibre yarns, and metal and plastic film around for industrial applications. |
| Typical application and feedstock | Cartons collected by local authorities |
| Technology scale and capacity | 25,000 tonnes of cartons per annum |
| Process outputs | Paper and cardboard fibres, metals and plastic film for reprocessing, |
| Advantages | A UK solution for recycling of beverage cartons.<br>ACE UK is encouraging all organisations that run kerbside collections to utilise this UK facility, as it has various financial and environmental benefits. Previously cartons collected through ACE UK bring banks were recycled at mills in Sweden.<br>Recycling cartons at the new UK facility instead will lead to an estimated annual reduction of 122 tonnes of transport-related $CO_2$. |
| TRL | 9 |
| Further information | http://www.ace-uk.co.uk/recycling/how-are-beverage-cartons-recycled/uk-reprocessing-plant |

# 5 Thermal treatment of waste dashboard

| | Measure/Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | **General information** | **Combustion** | **Advanced Thermal Treatment** | **Alternative thermal treatment** | **Product conversion** | **Energy recovery and boilers** | **Technologies for distribution of heat and power** |
| **Examples** | *Introduction* | *Moving grate* | *Pyrolysis* | *Conversion of waste plastics to diesel, Avonmouth, UK* | *Product conversion – overview of technologies* | *Energy recovery in boilers* | *Private wire networks* |
| | *Principles of thermal treatment* | *Fluidised bed* | *Rodecs (Chinook) Active Pyrolysis® process* | *Rubber/Tyres to fuel, Ireland* | *Thermo-Catalytic Reforming Technology (TCR©),* | *Energy recovery in Turbine and generator set* | *District heating network* |
| | | *Rotary kiln* | *Flash pyrolysis* | *Antaco Hydrothermal Carbonisation* | *Waste to biofuels, Enerkem* | *Energy recovery using heat pumps* | *EON Handelo CHP Plant, Norrköping* |
| | | | *Gasification* | | | *Flue gas condensation* | *High grade heat* |
| | | | *Plasma gasification* | | | *Energy recovery by cooling* | *District cooling network* |

## 5.1 Introduction

This section examines the main types of thermal treatment technologies that are currently available or are emerging. Thermal treatment technologies can generally be split into the following two categories – combustion (often referred to as incineration) and advanced thermal treatment, which includes pyrolysis and gasification. In addition, gasification sometimes consists of a two-stage combustion process, which can be categorised as a gasification process within the Renewables Obligation Certificate scheme.

In this section we examine both conventional combustion technologies and advanced thermal treatment, and we also examine emerging alternative thermal treatments, i.e. the conversion of plastics to diesel, waste to biofuels and commodity chemicals etc.

Also included in this section are technologies used specifically in the recovery of energy, and in the distribution of heat and power. Figure 1 summarises the different type of thermal treatments covered in the examples.

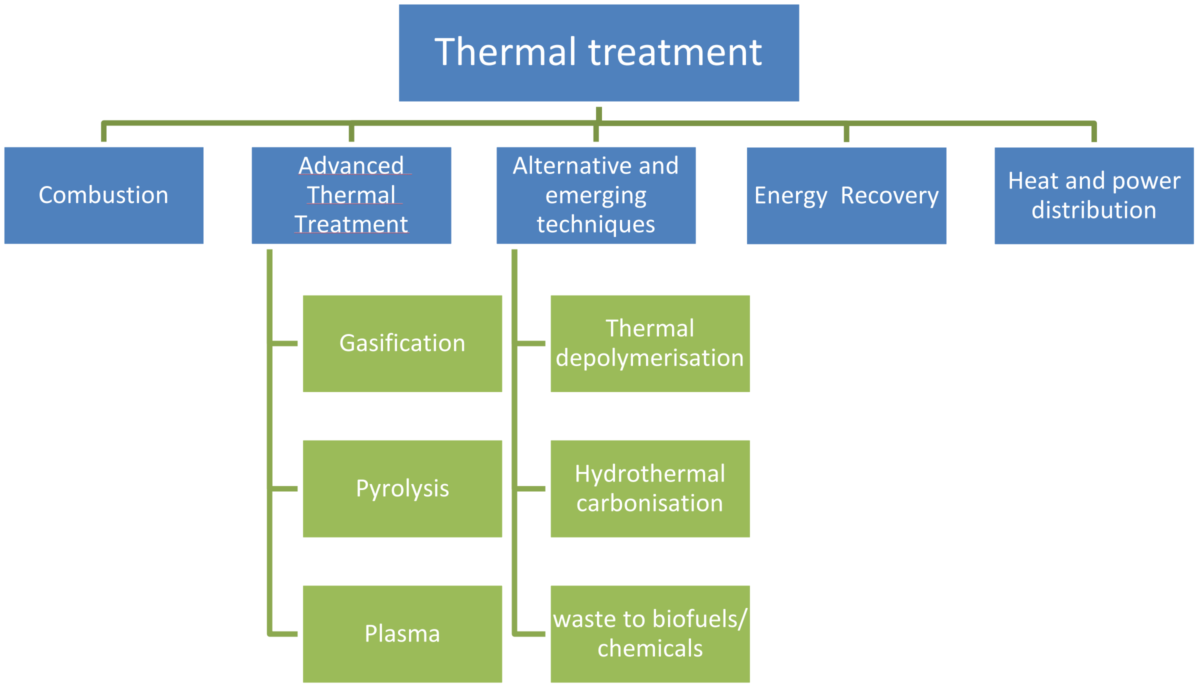



**Figure 1 – Thermal treatment types**

'Advanced' Thermal Treatment (ATT) technologies are so called as thermal gasification and pyrolysis processes produce a synthesis gas 'syngas' which can potentially be used to produce electricity at a higher efficiency than direct combustion, or to manufacture liquid fuels or chemicals. For comparison, combustion processes instantly convert the energy in waste feedstock to heat for power production. Therefore, the main question is whether the additional technical complexity and increased energy consumption of the gasification processes can be justified by the potential increase in efficiency and/or attractive products when compared to conventional combustion.

Thermal gasification and pyrolysis of municipal solid waste (MSW) has a development history of around 25 challenging years in the UK and Europe. However, it is a different story in Japan where they have successfully operated gasification plants for several decades. Whilst proven on biomass and single-stream waste types, ATT technologies generally require MSW and variable waste streams to undergo extensive pre-processing. In addition, longer term operational experience is sparse and availability has been shown to be significantly lower than for that of modern incineration plants, with higher operational costs.

For comparison, incineration is a proven technology with 125 years of operational experience and a long list of reference plants in the UK and Europe. It is mature technology, but it still being continually improved with regard to energy efficiency, minimisation of corrosion, lower emissions and better control systems.

The two stage combustion technology developed by companies including Energos has a number a reference plants, primarily in Scandinavia. Some of the facilities have been in operation for 10 years, but it is notable that most of the facilities are designed with relatively low steam parameters with no power output (only heat export), require waste pre-treatment, and experience lower availability compared to moving grate fired plant.

Whilst a number of alternative technologies are being actively promoted by development companies there is only low level evidence to suggest they have achieved the track record and performance levels required to treat high volumes of residual MSW. The commercial and stakeholder relationship consequences of service failure at a municipal scale are significant for any waste disposal authority.

Over the last decades there have been drivers towards development of ATT technologies as an alternative to moving grate based incineration. These technical and financial drivers are as follows:

1. Potential to apply for government financial incentives including double ROCs (Renewables Obligation Certificate) or CfDs (Contracts for Difference) in the UK.
2. Syngas can potentially be used for the production of high-value energy carriers or materials. The syngas can be used as feedstock for gas engines, which have a high energy efficiency, or the syngas (as hydrogen) can be used for liquid fuel in the transport sector, or converted to ethanol or methanol which can be used in the chemical industry;
3. Reduced production of pollutants including $NO_x$, HCl and $SO_2$ due to the ability to more closely control the waste combustion conditions;
4. Some gasification technologies melt ash residues to form a vitrified bottom ash, which effectively immobilizes heavy metals.

With regard to achieved results to date from these drivers, the following conclusions can be made:

1. Ability to apply for government financial incentives: This has been perhaps the key driver in promoting ATT in the UK, but now appears to be falling away. The ROCs scheme is now closed to new EfW plants and the political landscape in the UK has changed, where government support for renewable energy subsidies appears to be declining in favour of other low carbon energy. The first planned round of CfD awards was completed in 2015, but at the time of writing there is no confirmation that future rounds of CfD awards will occur for waste projects in 2016 and beyond.
2. The use of syngas as a fuel or product: The use of syngas as a fuel or product is a developing technology which has had to overcome many challenges, including being sufficiently free from contaminants to be suitable for its intended use. As a gas engine fuel, the presence of tars is a key issue. For the production of chemicals, the presence of contaminants can damage downstream catalysts used in the chemical production process. The removal of contaminants to the required level may now be technically possible, but the costs can become prohibitive making the commercial case difficult.
3. Reduced production of pollutants: The cleaned emissions from conventional combustion facilities are likely to be similar to ATT plants due to the strict emission requirements in the Industrial Emission Directive, IED. To achieve this same result, conventional combustion facilities will require somewhat more extensive flue gas clean-up plant, which will have slightly higher Capex and as reagent use such as lime is slightly greater, Opex will be somewhat higher also.
4. Production of a vitrified ash: Outside of Japan, there is far less requirement for a vitrified ash. Although the quantities of incinerator bottom ash (IBA) produced by conventional combustion are generally higher, the recycling of IBA as an aggregate is now commonplace in the UK and Europe.

## 5.2 Principles of thermal treatment

Complete combustion of waste in an EfW facility consists of a sequence of pyrolysis, gasification and combustion steps. With a conventional EfW combustion system, these three steps are simultaneous and integrated, whereas in alternative conversion systems, an intermediate product is generated and the combustion process is carried out later. Figure 2 presents a general overview. If limited heat and air is added then gasification occurs. If excess air is supplied then complete combustion takes place.

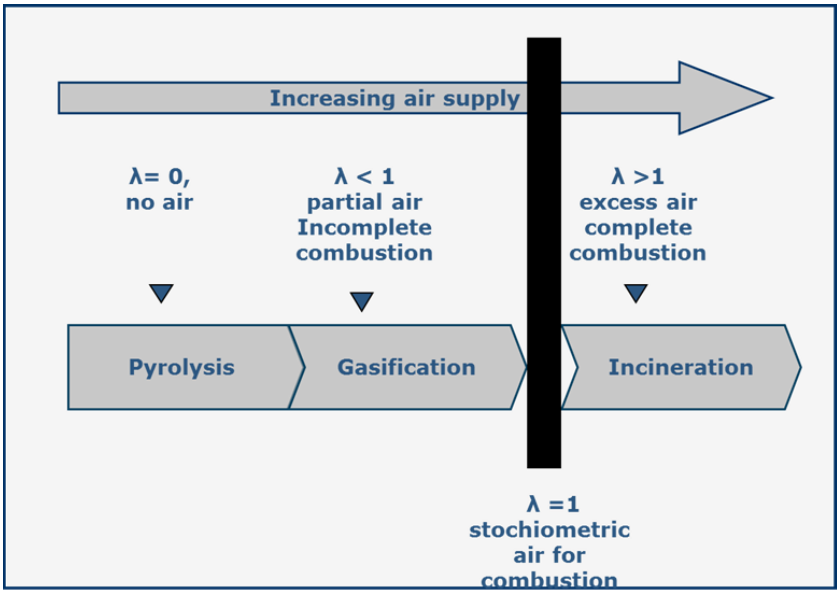



**Figure 2: Principal of thermal treatment with air supply**

## 5.3 Combustion

The combustion technology group encompasses those processes where the waste feedstock undergoes complete oxidation in a furnace, releasing heat into the gaseous and solid combustion products. Energy recovery is achieved by using the hot combustion gases to heat water to produce steam, which is then expanded through a steam turbine to generate electricity.

This technology type is well established, with a large number of technology providers offering a wide variety of different furnace configurations.

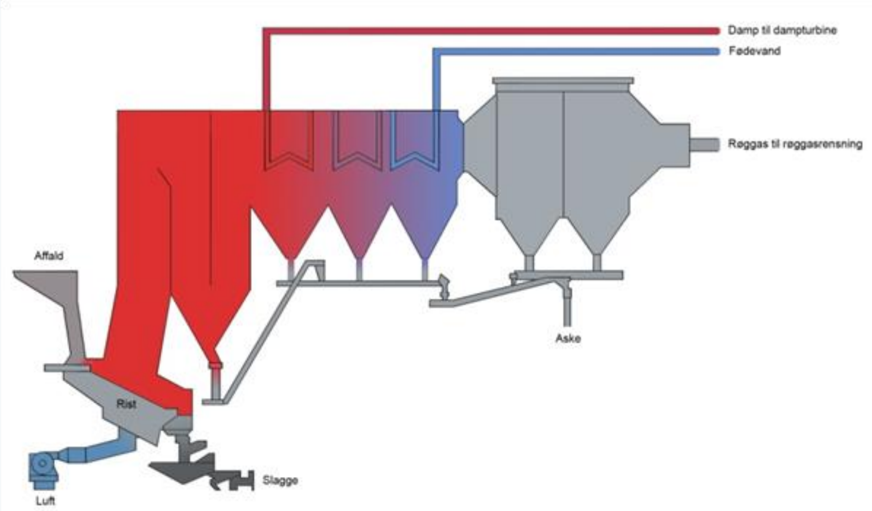
Principle furnace types include:

- Moving grate;
- Fluidised bed; and
- Rotary kiln.

- ***Cory Riverside Resource Recovery Facility, London***

### 5.3.1 Moving grate

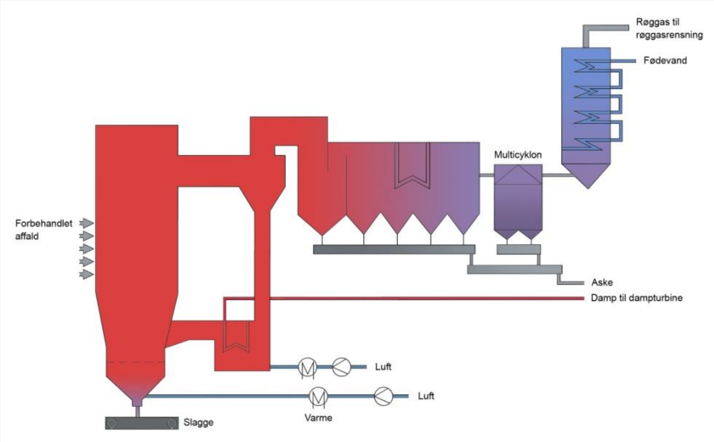
| **Moving grate combustion** | |
|---|---|
| Type of technology | Combustion |
| Technology name | Moving grate |

| **Moving grate combustion** | |
|---|---|
| Technical description | Residual waste is taken from a storage bunker by a crane and dropped into a chute. Waste at the bottom of the chute is mechanically pushed onto the combustion grate. The waste on the grate is combusted at a temperature of 850°C or more, with combustion air injected from below the grate. The waste is moved forward on the grate and the resultant bottom ash drops into a water bath at the end of the grate. Complete gas phase combustion is reached by injection of secondary air above the grate. The system ensures that a temperature of at least 850 °C for a minimum of 2 seconds is reached (IED requirement) in the secondary combustion zone. Auxiliary fuel is only used for start-up and shutdown to achieve temperature conditions for waste feed.<br><br><br>The roller grate is a variation on the walking grate. Instead of indexing the waste forward, the roller grate passes waste over a series of inclined rotating rollers. This form of combustion grate is much less common than the walking grate. |
| Type of energy conversion or recycling technology | Waste is fully oxidised in the presence of excess oxygen to recover the energy content of the waste fuel. The hot flue gases have little or no chemical energy content following full combustion. Energy conversion of the hot flue gases into electrical power or heat is achieved through a steam boiler. |
| Typical application and feedstock | MSW and can also process refuse derived fuels and solid recovered fuels.<br>Flexibility to handle changes to input with regard to heating value, ash content and moisture. |
| Feedstock characteristics | Conventional combustion will operate on waste over a CV range of 6 to 15MJ/kg. Moisture content can be up to 30% and very little pre-processing of the waste required, with objects of up to a length of 1m able to be processed. Larger objects can be shredded or broken up prior to being fed into the waste chute. |
| Technology scale and capacity | Suited to a wide variety of scales starting at 50,000 tpa up to 320,000 tonnes for each process line.<br>Multi line plants up to 1M tpa plus. |
| Process outputs | Hot flue gases from the combustion zone pass into a steam boiler for energy recovery.<br>Electricity for own use and grid supply<br>Heat for district heating and/or industrial process use |

| Moving grate combustion | |
|---|---|
| Advantages | Is well proven and is flexible in dealing with a highly variable feedstock such as waste. |
| Limitations | Is not eligible for incentives in the UK (unless heat enabled through a CHP scheme) and the overall electrical efficiency through a steam cycle is lower than for a reciprocating gas engine. |
| Reference plants | There are hundreds of examples of moving grate incinerators across the globe. In the UK, some recently opened examples include Ardley, Oxfordshire and Cardiff, (walking grate). Edmonton in North London has a roller grate. |
| TRL | 9 (Commercially proven) |

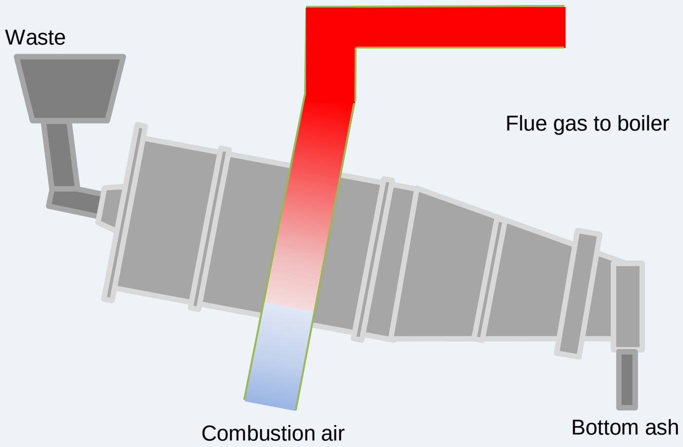
***Spittelau EfW facility, Vienna, Austria***

### 5.3.2 Fluidised bed

| Fluidised bed combustion | |
|---|---|
| Type of technology | Combustion |
| Technology name | Fluidised bed |
| Technical description | Residual waste resulting from a process of metal removal and shredding for size reduction is transferred to the reactor chamber. The reactor chamber contains very hot sand, which is fluidised by an air stream from the windbox below. The IED requirement of minimum 2 seconds at 850 °C is achieved in the secondary combustion zone. Energy is transferred to a boiler system similar to a grate fired facility.   |
| Type of energy conversion or recycling technology | Waste is fully oxidised in the presence of excess oxygen to recovery the energy content of the waste fuel. The hot flue gases have little or no chemical energy content following full combustion. Energy conversion of the hot flue gases into electrical power or heat is achieved through a steam boiler. |
| Typical application and feedstock | Fluidised bed combustion is best suited to a homogeneous feedstock such as biomass but has been tried with limited success using MSW. |
| Feedstock characteristics | Fluidised bed lines are mostly fed by RDF (refuse derived fuel, which is produced from municipal waste after sorting of metals and organic matter) and wood waste. The technology performs best with a relatively uniform feedstock thus very few facilities treat a feedstock mainly consisting of residual waste, which is highly variable.<br>Residual waste – Shredding required, typically to a particle size of 5 - 15 cm (and removal of metals)<br>Restrictions on input changes e.g. heating value, ash content and moisture as the fast combustion process is more sensitive to sudden changes of the waste composition. |
| Technology scale and capacity | The Allington plant in Kent is a large scale plant at circa 500,000 tpa but the scale up to this size has been problematic in terms of both availability and emissions. |
| Process outputs | Flue gases from the combustion zone pass into a boiler for energy recovery.<br>Electricity for own use and grid supply<br>Heat for district heating and/or industrial process use |

| Fluidised bed combustion | |
|---|---|
| | Some of the sand from the fluidised bed is carried over into the fly ash component resulting in a relatively high fraction of fly ash compared to IBA. |
| Advantages | Can burn high moisture content wastes efficiently |
| Limitations | Large quantities of fly ash<br>Extensive pre-treatment of waste<br>Availability and emissions compliance below the standard of a conventional combustion plant. |
| Reference plants | FCC Allington, Kent, UK. |
| TRL | 9 (Commercially proven) |

### 5.3.3 Rotary kiln

| **Rotary kiln combustion** | |
|---|---|
| Type of technology | Combustion - Waste is fully oxidised in the presence of excess oxygen to recovery the energy content of the waste fuel. The hot flue gases have little or no chemical energy content following full combustion. |
| Technology name | Rotary kiln |
| Technical description | Waste is loaded into a hopper and mechanically pushed into the top of a tapering cylinder or kiln. In order to pass the waste through the kiln and control the rate of combustion, the kiln oscillates from side to side, passing the waste between paddles set into the internal walls of the kiln.   |
| Typical application and feedstock | The oscillating kiln is able to treat MSW or hazardous waste. With few internal moving parts, higher combustion temperatures can be achieved in the kiln making it suitable for hazardous waste treatment at temperatures in excess of 1100°C. |
| Feedstock characteristics | Conventional combustion will operate on waste over a CV range of 6 to 15MJ/kg. Moisture content can be up to 30% and very little pre-processing of the waste required, with objects of up to a length of 1m able to be processed. Larger objects can be shredded or broken up prior to being fed into the waste chute. |
| Technology scale and capacity | Best suited to small scale applications with a single line of around 60,000 tpa. A multiline plant is possible, but this would not be economically advantageous compared to a moving grate. |
| Process outputs | Flue gases from the combustion zone pass into a boiler for energy recovery. |
| Advantages | A good alternative in the niche small scale market, can be smaller footprint than moving grate. |
| Limitations | High cost in comparison to alternatives at capacities above 60,000 tpa |
| Reference plants | Exeter, UK |
| TRL | 9 (Commercially proven) |

# 5.4 Advanced Thermal Treatment

## 5.4.1 Pyrolysis (general)

| Pyrolysis | |
|---|---|
| Type of technology | Advanced Thermal Treatment |
| Technology name | Pyrolysis |
| Technical description | Pyrolysis is similar to gasification except that the feedstock is thermally degraded in the complete absence of oxygen. Conventional pyrolysis takes place in temperatures ranging between 400-900°C. Slow pyrolysis is characterised by low heating rates and long residence times, whereas fast or flash pyrolysis is characterised by very high heating rates and short residence times. There are different configurations of pyrolysis equipment, including fluidised bed, moving bed and rotating cone. The design of the pyrolysis process will impact on the characteristics of the process outputs. For example, slow pyrolysis will produce charcoal, oil and gas, whereas fast pyrolysis is designed to maximise the production of pyrolysis oils. |
| Type of energy conversion or recycling technology | Pyrolysis is the thermal degradation or decomposition (thermolysis) of organic materials by heat, without combustion, in either the complete absence of oxygen or where it is so limited that gasification does not occur to any appreciable extent. Conventional pyrolysis takes place at temperatures between 400-900°C and products include syngas, liquid and solid char. Liquid product is also known as pyrolysis oil, olefin, or bio-oil when processing biomass. Utilising pyrolysis for waste treatment is currently less well developed than gasification although there are some examples of these systems being installed. |
| Typical application and feedstock | Pyrolysis is a mature technology in terms of its application to coal, peat and liquid fossil fuels, however there is limited examples in its application to waste derived fuels. There is some experience of slow pyrolysis of MSW, but these still tend to be in development stages, and there are several examples of project failures (for example, the MSW and clinical waste-based pyrolysis process operated by Compact Power in the UK is no longer operational). Successful examples of pyrolysis tend to be those plants using homogenous waste streams such as tyres and wood chip. |
| Feedstock characteristics | Pyrolysis systems may require extensive pre-treatment of the waste stream, depending on the feedstock type and system design. This may involve removing non-combustible materials, shredding or grinding, and drying. Pyrolysis systems are also more widely used on homogenous feedstocks as opposed to mixed wastes. |
| Technology scale and capacity | 0.2 – 30 tonnes per hour |
| Process outputs | Products of pyrolysis of waste are:<br>• gases, predominantly primarily carbon monoxide, hydrogen, methane, $CO_2$ and short chain hydrocarbons;<br>• pyrolysis oil comprising low volatile hydrocarbons up to tars; and<br>• solid residues, which are a mixture of coke and inert ashes. |
| Advantages | The process has low dioxin, furan & VOC emissions as reactions occurring in an oxygen-free environment at high temperature |

| | |
|---|---|
| | Low NOx & SOx emissions due to process occurring in an oxygen-free environment. Syngas and pyrolysis oils produced have the potential to be used as versatile fuels.<br>Potential to recover the material value of the organic fraction, i.e. as methanol<br>Process can be designed to produce a range of outputs for different applications |
| Limitations | Process carries safety risks that may be new to the waste management industry.<br>Still at R&D stages, very limited commercial operating experience demonstrated using MSW and other mixed waste streams<br>Limited experience in operating gasifiers with MSW feedstock.<br>Process requires the input of energy to sustain pyrolysis process (equivalent to 20-25% of input energy). Whilst gasification systems can be designed to release some of the energy in the feedstock to sustain the gasification process, Pyrolysis generally needs energy from an external source to sustain the process.<br>Pyrolysis processes have historically used other feedstocks and have tended to be located on industrial sites where impacts can be managed.<br>Community resistance to pyrolysis due to the perception that it is another form of incineration.<br>Experience of waste pyrolysis remains limited at this time. Bulk of research knowledge to date has been regarding the pyrolysis of fuels such as coal. |
| Reference plants | Pacific Pyrolysis, Somersby, Sydney - http://pacificpyrolysis.com/technology.html Accessed 10 December 2015<br> |
| TRL | 7 |

| **Rodecs (Chinook) Active Pyrolysis® process** | |
|---|---|
| Type of technology | Advanced Thermal Treatment |
| Technology name | Rodecs (Chinook) Active Pyrolysis® process |
| Technical description | The Rodecs system uses a multi-patented Active Pyrolysis® process to reclaim valuables and transform discarded waste materials into usable energy. The process combines both pyrolysis and gasification and is suitable for any form of organic waste from which a syngas is produced from waste that does not require pre-sorting or pre-processing. Waste is processed in a processing chamber under optimised conditions of oxygen, steam and temperature to achieve compete volatilisation of all organic compounds (using the patented Active Pyrolysis process). Syngas recovered from the processing chamber is conditioned in a high-temperature reactor to achieve full conversion of the tars and hydrocarbon molecules. |
| Type of energy conversion or recycling technology | Pyrolysis of waste to generate heat and power, recovery of metals for recycling. |
| Typical application and feedstock | The system is designed to accept a wide range of wastes from various processes, including MSW, industrial waste, medical waste, electronic waste, oil and sewage sludge. |
| Feedstock characteristics | • Can process low CV wastes<br>• Little or no pre-processing required. |
| Technology scale and capacity | The RODECS® is a modular and scalable system (through multiple RODECS lines per plant) so it can be designed to fit various project sizes. Scale ranges from small community scale size, <30,000 tpa to a larger scale in multiples of 90,000 tpa of MSW. |
| Process outputs | • Heat and power<br>• Clean metals<br>• Liquid fuels (an option where fuel commands higher incentives than<br>• Renewable power). |
| Advantages | • No pre-treatment of waste required<br>• High thermal conversion efficiency |
| Limitations | • Currently less proven with MSW |
| Reference plants | The RODECS® system is currently being used in nine countries on four continents, including its most recent reference plant in Oldbury, Birmingham which treats Automotive Shredder Residues. |
| TRL | 8 |
| Further information | http://www.chinooksciences.com/the-rodecs-system/ Accessed 10 December 2015 |

### 5.4.2 Flash pyrolysis

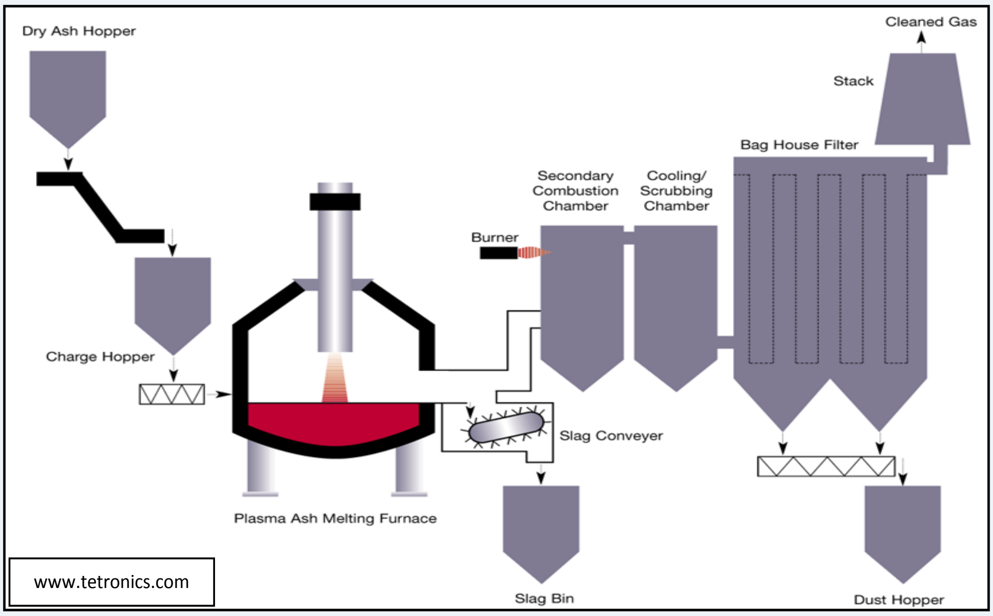
| **Flash pyrolysis** | |
|---|---|
| Type of technology | Advanced Thermal Treatment |
| Technology name | Flash pyrolysis |
| Technical description | With fast or flash pyrolysis, typically finely divided biomass waste is injected into a fluidised bed of inert material operating at 500°C. The size of the fuel and the excellent heat transfer characteristics of the fluid bed ensure a very fast heating rate which maximises the production of vapour. The vapour is subsequently condensed as a liquid that contains approximately 70% of the energy value of the waste feedstock. The by-product char and gas is used in part to provide heat to drive the process. The liquid fuel has been successfully used to fire boilers and kilns. Trials have been undertaken in reciprocating engines and gas turbines. Excess char can be sold as a product for activated carbon manufacture or reducing agent in metal production. The char can also be used as fuel either on its own or as a slurry with the pyrolysis liquids. |
| Type of energy conversion or recycling technology | Pyrolysis of waste to recover energy, heat and chars and syngas. |
| Typical application and feedstock | The main use for fast pyrolysis processes at present is the manufacture of speciality chemicals and food additives although this is expected to change to energy use when the current demonstration plants in Canada come fully on stream. Other fuels include whole tree chips from short rotation coppice, wood waste, and agricultural residues such as straw. |
| Feedstock characteristics | Particle size <3mm |
| Technology scale and capacity | 3 tonnes per hour |
| Process outputs | Bio-oil, char, liquid fuels. |
| Advantages | Currently fast pyrolysis processes are being designed for both clean wood and wood extracted from the waste stream. Operates at atmospheric pressure and lower temperatures (450 C). High bio-oil yields. |
| Limitations | Limited experience at scale. Particles have to be very small to fulfil the requirements of rapid heating. This is costly and reactors which can use larger particles, such as ablative pyrolysers have an advantage. Drying is usually essential unless a naturally dry material such as straw is used. |
| Reference plants | Limited reference facilities using MSW, some examples of flash pyrolysis of waste wood. |
| TRL | 5 for mixed waste, 7 for wood |

### 5.4.3 Gasification

| **Gasification** | |
|---|---|
| Type of technology | Advanced Thermal Treatment |
| Technology name | Gasification |
| Technical description | Gasification is the thermal breakdown/partial oxidation of waste under a controlled oxygen atmosphere (the oxygen content is lower than necessary for combustion). The waste reacts chemically with steam or air at a high temperature (>750 °C). The process is sustained by the heat generated by the partial combustion of the feedstock. The syngas (primarily consisting of CO and H2) produced by gasification has a lower calorific value than pyrolysis gas and is dependent upon the gasification process. The tar levels in the syngas are lower than for pyrolysis gas but depend on the actual gasification technology. Potential syngas uses are the same as for pyrolysis. |
| Type of energy conversion or recycling technology | Gasification of waste to produce a syngas. |
| Typical application and feedstock | Gasification has historically been used for the processing of oil, coke and petroleum products but in more recent times attempts have been made to apply the technology to MSW and other waste derived fuels.<br><br>The market for gasification processes is embryonic within the UK. However, there is significant experience with gasification in other parts of Europe and Japan. In several European countries, the process is used to provide syngas as a chemical intermediate or to generate power. In Japan, several thermo-chemical processes using MSW have been operational for several years. Companies such as Europlasma, Plasco Energy Group, Energos and Advanced Plasma Power are all involved in the development and operation of gasification technologies. |
| Feedstock characteristics | The range of feedstock properties is much narrower than for conventional combustion due to the chemistry and thermo-dynamics of gasification being more sensitive to variations in composition, ash content, moisture content, particle size and density. |
| Technology scale and capacity | <10,000 – 250,000 tonnes per annum<br><br>Fluidised bed gasifiers are typically used at a larger scale and can accommodate wider variation in fuel quality, making them suitable for processing waste and biomass. |
| Process outputs | Syngas can be utilised to generate electricity via boilers, gas turbines or engines.<br><br>In gasification, inorganic materials are converted to either bottom ash (low temperature gasification) or a vitreous slag (high temperature gasification). |
| Advantages | Gasification allows efficient power generating technologies (i.e. reciprocating engines and gas turbines) to be used.<br><br>The process has low dioxin, furan & VOC emissions as reactions occur under a homogenous low oxygen atmosphere at high temperature.<br><br>Low NOx & SOx emissions due to process occurring in a low oxygen environment. |

| | |
|---|---|
| | Process has better volume reduction performance than combustion or pyrolysis due to the higher operating temperatures and the longer residence times.<br>Hazardous heavy metals vitrified in leach resistance slag.<br>The technology is available in a semi-modular format. |
| Limitations | Significant technical residual risk in gas cleaning for power production.<br>Some limitations on the type and mix of input feedstock to ensure the syngas has a high calorific value of syngas and that flue gas emissions limits are not exceeded. This limits feedstock flexibility and availability.<br>Limited experience in operating gasifiers with MSW feedstock.<br>Conversion process requires the input of energy (equivalent to 20-25% input energy) to sustain gasification process. |
| Reference plants | Energos – Norway, Isle of Wight, Germany - http://www.energ-group.com/energy-from-waste/our-plants/ Accessed 10 December 2015 |
| TRL | 8 |

## 5.5 Plasma gasification

| Plasma gasification | |
|---|---|
| Type of technology | Advanced Thermal Treatment |
| Technology name | Plasma gasification |
| Technical description | Plasma gasification is the term that applies to a range of technologies that involve the use of a plasma torch or arc. Plasma is an electrically conductive gas, such as nitrogen or argon, which is heated by an electrical current to very high temperatures. The reaction takes place within a chamber connected to a plasma torch, which is refractory lined to withstand the high temperatures produced by the plasma torch.<br><br>The plasma torch can be applied directly to the feedstock, or to the syngas produced by a proceeding gasification process. Plasma gasification operates at temperatures as high as 7,000°C, resulting in rapid chemical reactions to break down the feedstock into gases. Inorganic materials are melted into a liquid slag, which is cooled into a solid.<br><br>The higher temperatures ensure that the syngas produced by a plasma process is cleaner than conventional combustion, as the higher temperatures allow for the breakdown of tars. Whilst the syngas can be used for energy utilisation, the plasma process itself has a high electric consumption.<br><br> |
| Type of energy conversion or recycling technology | Production of syngas |
| Typical application and feedstock | MSW, C&I, hazardous wastes, ashes |
| Feedstock characteristics | Less sensitive to particle size than gasification |

| | |
|---|---|
| Technology scale and capacity | 0.5-100 tonnes per hour |
| Process outputs | Syngas can be utilised to generate electricity via boilers, gas turbines or engines.<br>Aggregate product or slag |
| Advantages | Proven process for treating hazardous waste |
| Limitations | Complex and expensive process. The technology is not considered proven yet. Significant energy input is required. Syngas cleaning is complex. Quality of syngas not fully demonstrated in a commercial plant. |
| Reference plants | Plasco Energy Group Inc.; Advanced Plasma Power; Alter NRG Corp. (incorporating Westinghouse Plasma); Europlasma; |
| TRL | 7/8 |

## 5.6 Other alternative thermal treatment technologies

In addition to gasification and pyrolysis, there are further technologies which can be classed as ATT technologies. These include processes such as thermal depolymerisation, (the reduction of complex organic materials (usually waste products of various sorts, often biomass and plastic) into oil), and hydrothermal carbonisation (a thermo-chemical process for the conversion of solid biomass or waste matter at elevated temperature and pressure in the presence of water). There is also an increasing focus on the production of second generation biofuels. Second generation biofuels, also known as advanced biofuels, are fuels that can be manufactured from various types of biomass, including waste. This section contains some specific examples of these technologies.

### 5.6.1 Thermal depolymerisation

Thermal depolymerisation (TDP) is a depolymerisation process using hydrous pyrolysis for the reduction of complex organic materials (usually waste products of various sorts, often biomass and plastic) into light crude oil. Materials are subjected to high temperatures and pressure in the presence of water, resulting in a hydrous pyrolysis process. The high pressure and heat work to produce crude hydrocarbons and solid minerals which are then separated by distillation and oil refining techniques.

| **Conversion of waste plastics to diesel, Avonmouth, UK** | |
|---|---|
| Location | Avonmouth, UK |
| Type of Facility | Waste plastics to fuel facility |
| Type of waste | Mixed plastic pots, tubs and trays |
| Context | Contract between SITA and Cynar to construct the plant, with a capital investment of circa £7.5 million.<br>Will convert 6,000 tonnes of plastics per annum into 4.2 million litres of diesel each year.<br>For every tonne of plastic input, the facility will produce:<br>• 700 litres of EN590 diesel<br>• 200 litres of light oil<br>• 100 litres of kerosene<br>• Residual char (5%)<br>Plastic is supplied to the plant as 15mm flake and fed onto a hot melt before entering the furnace. Nitrogen gas is introduced to allow a pyrolysis process to take place by purging oxygen from the process, at this stage circa 5% of the input is lost as char. Resulting vapour is piped into a contractor where molecular bond chains are broken down to create high energy fuel gas. The vapour is fed into a distillation tower where high fractions of gas are fed into a fuel line and low fractions returned to the furnace and used as an additional heat source. Gases of specific weights are cooled and sent to the quality assurance tank before entering a hydrocyclone which removes any impurities. |
| Objectives | To generate fuel from low grade container plastics |
| Outcomes | • Diversion of waste plastics from landfill while producing a fuel with the performance and quality of conventional diesel, but with a lower carbon footprint<br>• The fuel produced can be used directly as vehicle fuel without the need for further processing or adaptations to the engine<br>• Suez (formerly SITA) will benefit from lower internal transport costs to fuel their waste collection fleet |
| Further information | http://www.sita.co.uk/downloads/ELPtoFuelProcess-1205-web.pdf Accessed 10 December 2015 |

| | |
|---|---|
| | See also: http://swindon-business.net/index.php/2014/10/03/funding-for-innovative-swindon-firm-that-is-pioneering-waste-plastic-to-oil-technology/ Accessed 10 December 2015 |
| TRL | 6 |

| Rubber/Tyres to fuel, Ireland | |
|---|---|
| Location | Longford, Ireland |
| Type of Facility | Waste rubber to fuel facility |
| Type of waste | Waste rubber including tyres |
| Context | The facility uses heat to break down the waste rubber into gas, oil, carbon char and other chemicals.<br>The technology is currently in the development phase but uses a continuous process to break down the rubber into its component parts.<br>The company took part in Enterprise Ireland's New Frontiers Programme in 2014 and secured approval for a capital grant from Longford Local Enterprise Office and is currently working on the sixth version of the technology. |
| Objectives | To provide a sustainable solution to the disposal of used tyres and other rubber products. |
| Outcomes | In 2015 the company won regional Best Start up business award in Ireland's Best Young Entrepreneur competition and collected €20,000 in prize money.<br>The technology is still in the development phase. |
| Further information | http://www.mimergy.com/ Accessed 10 December 2015<br>http://www.enviro-solutions.com/dailynews2/171115-mimergy.htm Accessed 10 December 2015 |
| TRL | 5 |

### 5.6.2 Hydrothermal Carbonisation

The hydrothermal carbonisation process uses a combination of heat and pressure to chemically convert biowaste in to a carbon dense material which typically has a high energy value, which in effect replicates the natural process of coal generation. The process is suitable for both wet and dry biomass waste, including agricultural biowaste, municipal biowastes, waste wood, and sewage sludge.

| **Antaco Hydrothermal Carbonisation** | |
|---|---|
| Type of technology | Hydrothermal Carbonisation |
| Technical description | In the Antaco pilot process, Biowastes are either used as single waste streams, or mixed together. The feedstock is fed in to a tube reactor with decreasing water content, heated to 200°C deg under 10-20 bar of pressure. After ten hours, a resulting black sludge is pressed and dried and formed in to pellets, which can be burned as a biocoal. |
| Typical application and feedstock | Mainly proven on biomass and sewage sludge, but is also applied to biowastes such municipal biowaste, agricultural waste, abattoir waste, food processing waste. |
| Technology scale and capacity | Unknown |
| Process outputs | Bio coal |
| Advantages | Produces a biocoal with a heating value of 23 MJ/kg (similar to fossil coal)<br>Process claims to have high feedstock flexibility: all wet and dry feedstocks |
| Limitations | Mainly limited to demonstration plants for mixed biowastes in UK. |
| Reference plants | Muttenz, Switzerland, Kaiserlautern, Switzerland |
| TRL | 9 on biomass, 7 on other biowastes |
| Further information | See video @ http://www.antaco.co.uk/technology/our-process Accessed 11 January 2016<br>www.ava-co2.com Accessed 11 January 2016<br>http://terranova-energy.com/en/ Accessed 11 January 2016 |

## 5.7 Product conversion - Waste to biofuels/commodity chemicals

Following production of a syngas by a gasification or pyrolysis process, there are a number of existing and emerging methods in which syngas and other products can be converted to biofuels or commodity chemicals, as opposed to being used directly for energy production. These applications are summarised in Figure 3.

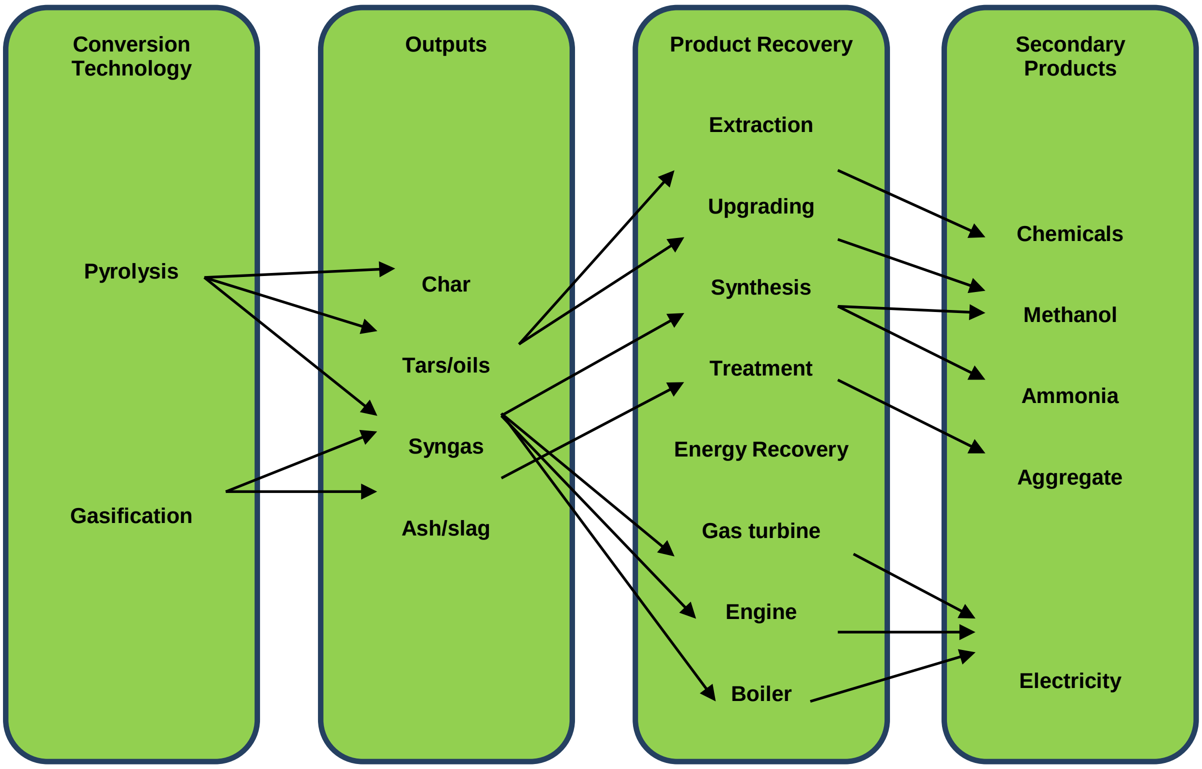



**Figure 3: Summary of Advanced Thermal Treatment outputs and applications**

The table below details some of the overarching technology types and the subsequent tables detail some specific examples and plants where syngas's are being converted in to products.

| Product conversion – overview of technologies | |
|---|---|
| Liquid Product Conversion to Fuels - Catalytic | Bio-oil can be highly oxygenated (e.g. fast pyrolysis oil 40-50% oxygen by weight on wet basis) with a high moisture content derived from moisture in waste and the pyrolysis reaction itself. CV is around 15-20MJ/kg (wet basis).<br><br>Most facilities use direct coupled energy recovery to generate electricity rather than value-added products. To derive products hydrogenation (hydrotreating or hydroconversion) can be used to remove about 90% of contaminants (e.g. nitrogen, sulphur and oxygen) to prevent damage to refinery equipment and catalysts prior to catalytic cracking and protect the quality of final product. Produces paraffinic hydrocarbons or heavy distillates, also known as alkanes (e.g. liquid paraffin and mineral oils).<br><br>Products are more stable and safe for storage and transfer after removing highly reactive components. Catalytic cracking involves breaking up the large, complex hydrocarbon molecules in the presence of a catalyst to increase the quality and quantity of lighter, more desirable middle distillate products and decrease residuals. Zeolite (complex aluminosilicates) is a common catalyst. Lighter fractions include kerosene, gasoline, liquefied petroleum gas (LPG), heating oil and aromatics (e.g. benzene and toluene) and olefins (e.g. ethylene and propylene) for chemical manufacturing. |

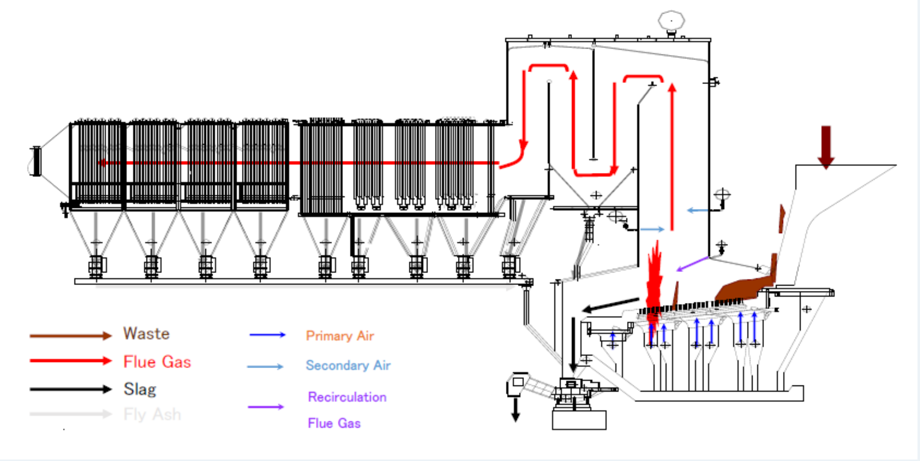
| | |
|---|---|
| Synthesis of Chemicals (Alko Nobel) | Syngas can be used to synthesise a range of liquid hydrocarbons including distillate fuels (including diesel fuel and kerosene), alcohols (methanol and ethanol) and fertilisers (ammonia). The Fishcer-Tropsch process is a combination of chemical reactions which is used to convert syngas into liquids hydrocarbons. |
| Char Product Conversion | Gasification of biomass produces a biochar as a by-product. Biochar is fixed carbon, in the form of highly porous charcoal. Char products from the pyrolysis reactor can also be further processed into useful products or energy. |
| Bio-oil Conversion to Chemical Products | Bio-oil and bio-oil fractions from pyrolysis processes can be used to derive chemicals, replacing petrochemicals of fossil fuel origin. The chemical composition of bio-oil is influenced by feedstock properties and operating conditions therefore process design and feedstock control are essential. |
| Waste conversion to jet fuel using Fischer Tropsch (FT) process | Residual waste (RDF) into high value jet and diesel fuels. Feedstocks are first converted to syngas (via gasification process) and then the with a process called gasification, and then the Fischer Tropsch process reacts these gases with carbon monoxide, hydrogen, and a catalyst to make long hydrocarbon chains. These chains are then “cracked” and separated into finished liquid jet fuels. |

| Thermo-Catalytic Reforming Technology (TCR©), | |
|---|---|
| Type of technology | Thermo-Catalytic Reforming |
| Technology name | Thermo-Catalytic Reforming Technology (TCR©) |
| Technical description | Fraunhofer UMSICT has developed a novel Thermo-Catalytic reforming (TCR©) technology which produces renewable liquid fuels from waste.<br>The process converts organic residue into quality syngas, oil and char through a staged thermal process:<br>1. Thermal Drying: Wet biomass is dried to between 10-30% moisture content through a combination of standard mechanical and thermal drying technology.<br>2. Thermal Decomposition: In a first TCR® reactor stage biomass is carbonized to biochar at intermediate temperatures (400-500°C) and volatile organic compounds are extracted.<br>3. Catalytic Reforming: In the second TCR® reactor stage the biochar is heated up to 500-700 °C and brought in contact with the volatile compounds again. Through catalytic functions the organic compounds are cracked to quality fuel gases and oils. The steam reforming of water steam and carbon increases the yields of a hydrogen rich syngas.<br>4. Product Treatment: Liquid compounds are condensed and separated into oil and water fractions. The permanent syngas is cleaned for particles and aerosols in a simple product treatment stage. This technology essentially converts all types of biomass residues under thermal and catalytic conditions into three main products, 1) H2 rich syngas, 2) stable biochar and 3) primary liquid bio-oil. |
| Type of energy conversion or recycling technology | TCR® converts organic residue into quality syngas, oil and char through a staged thermal process. |
| Typical application and feedstock | • Municipal wastes including sewage sludge, food waste, organic household waste, composting residue and fractions of municipal solid waste such as mixed plastics fractions<br>• Agricultural and forestry wastes including animal manure, harvesting residue, landscaping material and waste wood<br>• Industrial organic wastes including food and animal processing by-products, paper industry wastes and production residues containing polymers |
| Feedstock characteristics | TCR® technologies are claimed to be suitable for almost any biomass and organic residue and many types of polymer residue, and even mixed feedstock with water content up to 30% is not deemed to be an issue. |
| Technology scale and capacity | The technology is currently being operated at a pilot facility with a capacity of 750kg/day. Fraunhofer is collaborating closely with the University of Birmingham to develop the TCR technology further to accelerate renewable energy technologies within the West Midlands area. As part of this programme Fraunhofer will deliver a TCR UK demonstrator to showcase the technology for UK markets.<br>Full operating capacity is not known, however the development strategy is for a network of smaller de-centralised facilities. |

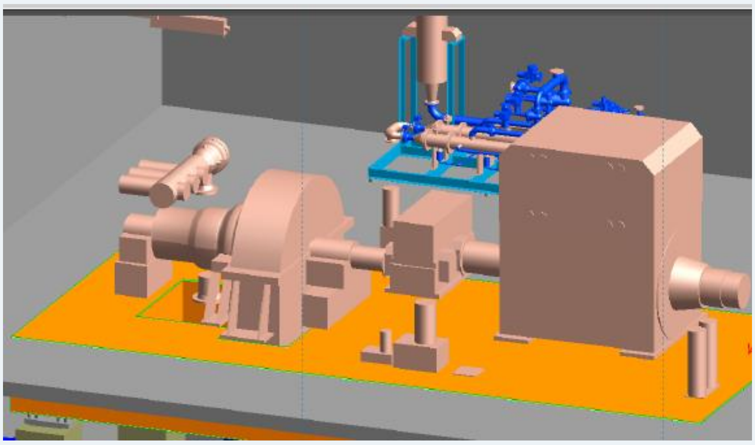
| | |
|---|---|
| Process outputs | • Clean synthesis gas with significant heating value suitable for internal combustion engines<br>• Quality oil with high heating value and low corrosivity suitable for stationary internal combustion engines.<br>• Stable char<br>The fuels produced meet the European standards for gasoline (EN228) and diesel (EN590). |
| Advantages | • High flexibility, modular technology<br>• Combined heat & power generation on-site from all products<br>• High quality diesel, gasoline and aviation fuels<br>• Decentral hydrogen production from syngas for instance for industrial applications<br>• Production of chemical precursors from oil and syngas<br>• Specialized applications for biochar for instance in agriculture |
| Limitations | Currently at pilot scale, unproven at larger scale. |
| Reference plants | The TCR research is currently at TRL-5 with an operational 30 kg/h pilot plant at the Fraunhofer site in Sulzbach Rosenberg Germany. The fuels have already been tested in a 20 KW stationary CHP engine on-site over several hundred hours with stable engine performance achieved. |
| TRL | 5 |

| Waste to biofuels, Enerkem | |
|---|---|
| Type of technology | Advanced Conversion Technology |
| Technology name | MSW to bio-fuels and chemicals |
| Technical description | Enerkem's patented technology chemically recycles the carbon molecules contained in non-recyclable waste by converting these first in to a syngas, which is then converted into biofuels and commodity chemicals, using commercially available catalysts.<br>The thermochemical process consists of 4 steps:<br>• feedstock preparation<br>• gasification<br>• cleaning and conditioning of syngas<br>• catalytic synthesis<br>In Enerkem's system, these feedstocks are converted into methanol, ethanol or other renewable chemicals. |
| Type of energy conversion or recycling technology | Thermochemical process |
| Typical application and feedstock | Since 2000, Enerkem has tested and validated a number of different feedstocks – from solid waste coming from several municipalities to dozens of other types of residues. |
| Feedstock characteristics | Enerkem has tested more than 25 feedstocks in the process, including MSW and plastics. |
| Technology scale and capacity | Following the development of a pilot plant and demonstration plant, Enerkem opened a commercially operating plant in Edmonton, Canada in 2014. The plant processes post-sorted municipal solid waste (after recycling and composting) to produce biomethanol. Full production of biofuels at the plant is expected in late 2015.<br>Products:<br>Capacity: 38 million litres / 10 million gallons per year - See more at: http://enerkem.com/facilities/enerkem-alberta-biofuels/#sthash.Y8fKQHz5.dpuf Accessed 11 January 2016 |
| Process outputs | Methanol, ethanol, renewable chemicals, power generation. |
| Advantages | Feedstock flexibility, output flexibility, significant markets for outputs |
| Limitations | Requires significant feedstock preparation – sorting, shredding and drying |
| Reference plants | Edmonton, Canada - http://enerkem.com/facilities/enerkem-alberta-biofuels/ Accessed 11 January 2016 |
| TRL | 7/8 |

## 5.8 Energy recovery and boilers

| Energy recovery in boilers | |
|---|---|
| Type of technology | Energy recovery |
| Technology name | Boilers |
| Technical description | Typically hot gases from the combustion chambers pass to boilers, which convert the energy from gases into superheated steam which powers steam turbine generators that make electrical energy. Such a process generates heat as a by-product which can also be recovered in a combined heat and power system. The most efficient designs incorporate an integral furnace-boiler, rather than the transport of hot gases in ducting to a separate boiler. Boiler feed water should be preheated in an economiser, which recovers the maximum heat from the flue gases leaving the boiler. There is then a multi-field section of the main boiler, followed by the final super-heater stage, whose tubes will sit in the first pass in the top of the furnace shaft. This superheated steam is passed to the steam turbine generator for electricity generation. The boiler system typically has as an energy efficiency of around 85% for steam production.   |
| Type of energy conversion or recycling technology | The heat energy in the flue gases raises steam at high pressure and temperature. |
| Typical application and feedstock | Combustion energy is almost always recovered via a steam boiler. |
| Feedstock characteristics | Steam boilers are sensitive to flue gases from waste streams with excess chlorine content. |
| Technology scale and capacity | Suited to a wide variety of scales starting at 50,000 tpa up to 320,000 tpa for each process line. |
| Process outputs | High pressure steam exits the boiler and passes to the steam turbine. Flue gases exit to the clean-up plant at approximately 200°C. Boiler feed-water is heated in the economiser boiler section to 120°C ready for steam production. |
| Advantages | Simple, proven technology |

| Energy recovery in boilers | |
|---|---|
| Limitations | Flue gases from waste such as plastics can be acidic and highly corrosive leading to early component failure. Contamination can also cause fouling of the boiler leading to lower heat transfer.<br>Pressure and temperature characteristics of the steam are also limited to prevent undue corrosion occurring.<br>The steam cycle is steadily becoming more efficient but the cost of extra increments in energy efficiency becomes very high. |
| Reference plants | >20 plants in UK, including Tyseley, Chineham, Southampton (Veolia), Ardley, Cardiff, (Viridor), Isle of Man (Sita) |
| TRL | 9 (Commercially proven) |

| Energy recovery in Turbine and generator set | |
|---|---|
| Type of technology | Energy recovery |
| Technology name | Turbine and generator set |
| Technical description | High pressure steam generated by the boiler is fed to the steam turbine. Steam enters the turbine and expands through the turbine blade system, converting energy (Enthalpy) in the steam to mechanical motion. This is known in thermodynamics as the Rankine Cycle.<br>To maximise the energy recovered for electrical energy production, a condensing turbine is specified, where the expansion of the steam across the turbine is maximised and at the exhaust of the turbine, steam will generally be below atmospheric pressure.<br>Where significant district heating is required, a back pressure turbine can be specified where the pressure drop will be less, thus retaining more energy in the condensed steam for heating purposes. CHP enabled condensing turbines have a bleed point to extract steam mid-way along the turbine casing at a pressure of around 5bar to provide high grade heat for district heating / cooling purposes.<br>The turbine is mechanically linked to a generator through a gearbox. The generator rotation is synchronised to the grid at 50hz, with electrical output stepped up to a voltage of 11KV through a transformer.<br>Typically air-cooled condensers are installed onsite to condense the exhaust from the steam turbine.<br> |
| Type of energy conversion or recycling technology | The energy in the steam is converted to kinetic energy as it expands through the turbine, which is converted to electrical energy in the generator set. Heat can be recovered at different points depending on requirements. |
| Typical application and feedstock | Combustion energy is almost always recovered via a steam turbine. |
| Feedstock characteristics | The steam must be free of moisture and particles to avoid erosion to the turbine. This is achieved through effective design of the steam system. |
| Technology scale and capacity | Steam turbines are available from around 1MW up to utility scale plant generating several GW. |
| Process outputs | Turbine bleeds provide high grade heat as steam for other parts of the EfW process and to energise CHP applications. The generator set provides electrical |

| Energy recovery in Turbine and generator set | |
|---|---|
| | power usually at 11kV (but can be higher at 33kV for higher power outputs). Steam from the turbine exhaust is fed to the plant cooling system, usually an air cooled condenser or less commonly a water cooled system. |
| Advantages | Simple, proven technology. |
| Limitations | The conservative design of steam parameters are typically 40bar and 400°C for electricity production. Many new advanced combustion facilities use higher steam parameters (i.e. 60bar and 425°C). The selection of steam parameters is a trade-off between efficiency of the turbine and acceptable boiler corrosion rates that impact availability and maintenance costs. |
| Reference plants | Any conventional combustion plant. |
| TRL | 9 (Commercially proven) |

| Energy recovery using heat pumps | |
|---|---|
| Type of technology | Energy recovery |
| Technology name | Heat pumps |
| Technical description | Heat pumps can be used in a number of ways to optimise energy recovery and to decouple heat and power production in a CHP application. Heat pumps will draw an electrical load which must be small in comparison to the energy efficiency gain to be viable.<br>Heat pumps can remove further heat from flue gases by transferring remaining heat to supplement the energy supply to a CHP system.<br>Heat pumps can also transform electrical energy to heat for use in a district heating system. This electrical energy can be drawn from the grid when there is an excess of electrical energy available (e.g. peaks from wind power) and transformed to heat energy within the district heating system. In this way heat and power can be produced independently according to demand and is a way of storing grid excess generating capacity. |
| Type of energy conversion or recycling technology | Heat pumps perform work to extract heat from a cool area to a relatively warmer area. |
| Typical application and feedstock | Heat pumps can be used where an EfW plant is connected to a heat network or to supplement boiler feed-water pre-heating. |
| Feedstock characteristics | Heat pumps can extract energy from low grade heat sources that might otherwise go to waste. |
| Technology scale and capacity | Heat pumps vary in size from a domestic applications to units of around 80MW. |
| Process outputs | Low grade heat |
| Advantages | Can recover heat that is otherwise wasted. |
| Limitations | They consume energy to transfer heat and add to capital cost - economic viability can be hard to achieve. |
| Reference plants | Amager Bakke, Copenhagen and Drammen, Norway. |
| TRL | 9 (Commercially proven) at small scale<br>8 (Operational demonstration) at very large scale |
| Further information | http://www.star-ref.co.uk/star/images/stories/pdf/Case%20Study%20No%2064%20-%20Neatpump.pdf |

| Flue gas condensation | |
|---|---|
| Type of technology | Energy recovery |
| Technology name | Flue gas condensation |
| Technical description | Flue gas condensation is a technique to recover further energy from the flue gases. The flue gases still contain water vapour following clean up and this vapour can be condensed to a liquid form to enable further low grade heat to be recovered. |
| Type of energy conversion or recycling technology | Low grade heat in the flue gases which is not recovered in the boiler is utilised. |
| Typical application and feedstock | Low grade heat from flue gas condensation recovery can be used in the EfW process for boiler feed water pre-heating or to supplement heat supply to a CHP scheme. |
| Feedstock characteristics | The flue gases enter the flue gas condensation plant at around 130°C and exit at around 50°C. |
| Technology scale and capacity | Can be used in any scale of combustion plant. |
| Process outputs | Low grade heat |
| Advantages | Extra plant efficiency |
| Limitations | Under some conditions (cold weather), the plume from the stack will become more visible due to the lower flue gas temperature. |
| Reference plants | Trident Park, Cardiff |
| TRL | 9 (Commercially proven) |

| Energy recovery by cooling | |
|---|---|
| Type of technology | Energy recovery |
| Technology name | Component cooling |
| Technical description | Heat can be recovered from plant components which generate large amounts of heat such as transformers. |
| Type of energy conversion or recycling technology | Low grade heat from component cooling can be used in the EfW process for boiler feed water pre-heating or to supplement heat supply to a CHP scheme. |
| Typical application and feedstock | Component cooling can be used where an EfW plant is connected to a heat network or to supplement boiler feed-water pre-heating. |
| Feedstock characteristics | Heat recovered from equipment such as transformers and large motors. |
| Technology scale and capacity | Can be used in any scale of combustion plant. |
| Process outputs | Low grade heat |
| Advantages | Extra plant efficiency |
| Limitations | Adds to capital cost for marginal gains - economic viability can be hard to achieve. |
| Reference plants | Amager Bakke, Copenhagen |
| TRL | 9 (Commercially proven) |

## 5.9 Technologies for the distribution of heat and power from thermal treatment

| **Private wire networks** | |
|---|---|
| Type of technology | Electrical power supply |
| Technology name | Private wire networks (PWN) |
| Technical description | A private wire network is a high voltage power supply that is not part of the National Grid (but is usually connected at an interface point).<br>The power is generated at a waste to energy plant (EfW or AD or other) and is distributed to power users via cables, normally buried in trenches and ducts in the road. In the event of power failure, back up from gas fired CHP units and / or the National Grid would normally be provided. |
| Type of energy conversion or recycling technology | Electrical energy is distributed from the EfW plant to a consumer. |
| Typical application and feedstock | Any form of waste to energy plant can have a PWN. |
| Feedstock characteristics | *n/a* |
| Technology scale and capacity | Can be used in any scale of combustion plant, but the high costs of installation favour a large scale scheme. |
| Process outputs | 11kV power supply to commercial power users |
| Advantages | Security of supply, avoidance of network operator costs |
| Limitations | The capital costs and disruption of installing a PWN can be prohibitive in comparison to a simple grid connection by the local Distribution Network Operator (DNO). Planning consent will also be needed which again the DNO does not require. |
| Reference plants | Leeds RERC and Leeds General Infirmary / University of Leeds (proposed) |
| TRL | 9 (Commercially proven) |

| District heating network | |
|---|---|
| Type of technology | Low temperature hot water (LTHW) supply. Heat from combustion is provided to commercial and domestic consumers. It is possible for the overall plant efficiency to approach 100% with a DHN installation. |
| Technology name | District heating network (DHN) |
| Technical description | A district heating network will supply low temperature hot water (LTHW) to consumers through a pipeline loop. Steam from an EfW plant is bled from the turbine system at around 5 bar (refer turbine description) and supplies heat energy to the district heating system through a heat exchanger (or Energy Centre) located close to the EfW plant. For maximum system efficiency, LTHW is supplied at around 120°C and returns to the plant at 90°C. The pipeline is lagged to limit heat loss and in urban areas, is generally laid in trenches in the road network.<br><br>Within the Energy Centre, a backup system (normally natural gas fired) is needed in the event that the EfW plant heat generator is shutdown, this can be mitigated if there are several EfW plants supplying into the network. Back up stations may also operate as peak load stations in the event that heat demand outstrips supply.<br><br>Where there is insufficient heat storage capacity in the heat network itself, a heat accumulator (a large hot water storage tank) is provided to store excess heat produced in periods of low demand to be released at peak periods. |
| Typical application and feedstock | Any form of waste to energy plant which produces excess heat can have a DHN. |
| Technology scale and capacity | Even a small EfW plant generates large amounts of usable heat compared to the electrical energy produced so small or large scale DHN installations are viable over longer periods. |
| Process outputs | LTHW flow and return |
| Advantages | Uses heat that would otherwise be emitted to the atmosphere through the plant cooling system.<br><br>Recent government policy has favoured heat network development. |
| Limitations | High capital costs mean long payback periods (15 to 20 years) that many customers are not prepared to sign up for. Political intervention is normally needed to overcome this obstacle.<br><br>Needs a large anchor site as a baseload consumer such as a hospital. Once this is established other users may be connected more easily.<br><br>In summer, the heat may be dumped as no demand exists.<br><br>Some electrical power is sacrificed to produce power and it can be difficult to meet changing heat and power demands where the production of the two energy forms is intertwined. |
| Reference plants | Eastcroft EfW, Nottingham |
| TRL | 9 (Commercially proven) |

| EON Handelo CHP Plant, Norrköping, Sweden | |
|---|---|
| Type of technology | Energy from waste with district heating |
| Technical description | The EON Handelo plant at Norrköping, Sweden is one of the largest waste and biomass to energy plants in Sweden. The facility can process 1 million tonnes of waste year |
| Typical application and feedstock | There are 5 separate lines at the Handelo plant, one is a vibrating grate, one is a moving grate and there are three circulating fluidised bed lines.<br>• 1, vibrating grate, 90MW – recycled wood chip<br>• 2 – moving grate, 125MW, coal, tyres<br>• 3 – CFB, 130MW, forest fuels, wood chip, tyres<br>• 4 – CFB, 75MW, prepared fuel from MSW and C&I<br>• 5 – CFB, 85MW, prepared fuel from MSW and C&I<br> |
| Technology scale and capacity | 1 million tonnes of MSW, C&I waste, wood chip, coal, tyres and forestry waste. |
| Process outputs | 5TWh/y heat; 0.5TWH/y steam; 0.03 TWH/y district cooling; 0.6TWh/y electricity.<br><br>Almost all of the steam produced is used in an agroethanol plant next door to the facility.<br><br>Heat is supplied via a District Heating Network in Norrköping which features<br>• 2x400km grids<br>• volume of approx. 23 300 m3<br>• almost 100 % availability<br>• 4600 private customers<br>• 650 company customers<br>• Total approx. 6 000 connections |

| High grade heat | |
|---|---|
| Type of technology | Supply of steam to commercial users. Steam generated from combustion is provided to commercial consumers. It is possible for the overall plant efficiency to approach 100% with a steam supply installation. |
| Technology name | High grade heat |
| Technical description | Some EfW plants are located in close proximity to commercial steam users, providing an opportunity to supply steam which can be used in industrial processes. Normally the consumer would need to be under 1km from the EfW plant for the pipeline to be commercially viable. Steam is normally bled from the turbine at higher pressures (around 12 bar) than for a DHN, but is dependent on the requirements of the consumer. Steam pipelines are higher maintenance than LTHW pipelines, so some supply systems are being de-steamed in favour of LTHW.<br>Backup facilities are normally required at the works site to provide for EfW supply outages. |
| Typical application and feedstock | Steam can be provided to generate heat for large scale industrial processes or to drive process equipment. |
| Feedstock characteristics | *n/a* |
| Technology scale and capacity | Even a small EfW plant generates large amounts of usable heat compared to the electrical energy produced so small or large scale steam supply installations are viable. |
| Process outputs | Steam at high temperature and pressure. |
| Advantages | Uses excess heat that would otherwise be emitted to the atmosphere through the plant cooling system.<br>Recent government policy has favoured heat network development. |
| Limitations | High capital costs mean long payback periods (15 to 20 years) that many commercial customers are not prepared to sign up for. Political intervention is normally needed to overcome this obstacle.<br>Needs a large commercial scale steam user in close proximity to the plant. |
| Reference plants | Linkoping, Sweden – supplies heat and steam to a car manufacturer, Roosendaal, Netherlands – supplies heat to greenhouses, Delfzijl, Netherlands – supplies process steam to 5 neighbouring companies. |
| TRL | 9 (Commercially proven) |

| District cooling network | |
|---|---|
| Type of technology | Supply of chilled water - Heat from combustion is converted to cooling |
| Technology name | District cooling network |
| Technical description | The heat or steam generated by an EfW plant can be used to power refrigeration units to provide chilled water for air conditioning and other cooling applications.<br>Steam can be used to drive a refrigeration compressor pump or waste heat can be used to operate a refrigeration absorption system. The overall energy efficiency of cooling systems is less than a system delivering heat energy, particularly refrigeration absorption.<br>Backup facilities are normally required to provide for EfW supply outages.<br>To date applications are limited, however one area of particular interest is data centres which have very high cooling requirements for banks of electrical equipment. |
| Typical application and feedstock | Air conditioning consumers and industrial cooling applications.<br>Data centres. |
| Feedstock characteristics | n/a |
| Technology scale and capacity | Even a small EfW plant generates large amounts of usable heat compared to the electrical energy produced so small or large scale district cooling installations are viable. |
| Process outputs | Chilled water or air |
| Advantages | Uses excess heat that would otherwise be emitted to the atmosphere through the plant cooling system. |
| Limitations | Is quite low efficiency compared with heating, so is only effective if heat really has no other useful purpose. |
| Reference plants | Barcelona Sant Marti, Spain |
| TRL | 9 (Commercially proven) |

# 6 Biological treatment of waste dashboard

| | Measure/Material | | | | | |
|---|---|---|---|---|---|---|
| | General information | Aerobic | Anaerobic Digestion | Advanced Anaerobic Digestion | Mechanical Biological Treatment | Technologies for distribution of heat and power |
| Examples | *Introduction* | *Open Windrow Composting* | *Overview* | *Overview of Advanced AD processes* | *Overview* | *Gas to Grid* |
| | | *In-vessel composting (IVC)* | *Dry Anaerobic Digestion* | | | *Gas to vehicle fuels* |
| | | | *Wet Anaerobic Digestion* | | | |
| | | | *Small scale AD* | | | |

## 6.1 Introduction to biological treatment

This section looks at forms of biological treatment that can be used to treat either source segregated organic material e.g. garden and / or kitchen waste and the mixed residual waste containing organic material. Figure 4 summarises the different biological treatment technologies.

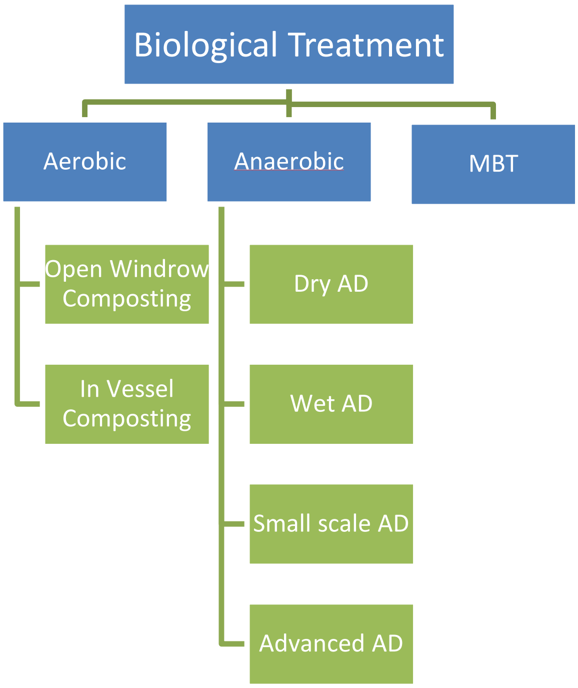



**Figure 4: Biological treatment of waste**

The biological treatment of waste can be divided into two main categories as follows:

- Aerobic composting i.e. the processing of waste in the presence of oxygen; and
- Anaerobic digestion (AD) i.e. the processing of waste in the absence of oxygen via dry or wet process depending on the dry solids content of the waste.

The treatment of source segregated organic material is more straightforward than that required for mixed residual waste containing organic material. This technology is relevant to consider in this context due to potential future regulatory drivers requiring food waste separation and given the potential for BCC to reduce the required scale of any future residual waste treatment facility as a result of diverting food and other highly biodegradable organic waste.

Treatment technology has developed over the last 15 years from predominantly open air windrow composting (OAWC), to a mixture of technologies including enclosed or in vessel composting (IVC) and wet and dry anaerobic digestion (AD). The most common form of digestion used is wet AD where the organic material is mixed with liquid to form a 'bioliquid' which can then be digested to generate biogas. The biogas can then be used to generate energy either as electricity or heat. This is one of the key advantages of AD – it is a net exporter of energy. The AD process has developed rapidly from lower technology 'farm type' systems to more technical 'industrial based' systems that are much more efficient at processing the organic material to generate biogas for conversion into energy. These industrial based or high rate AD processes have the following benefits:

- Reduced retention time in the digestion process.
- Efficient extraction of biogas.
- Smaller operating footprint.
- High levels of automation.
- More suited to 'urban' environments.
- Currently, access to attractive renewable energy incentives.

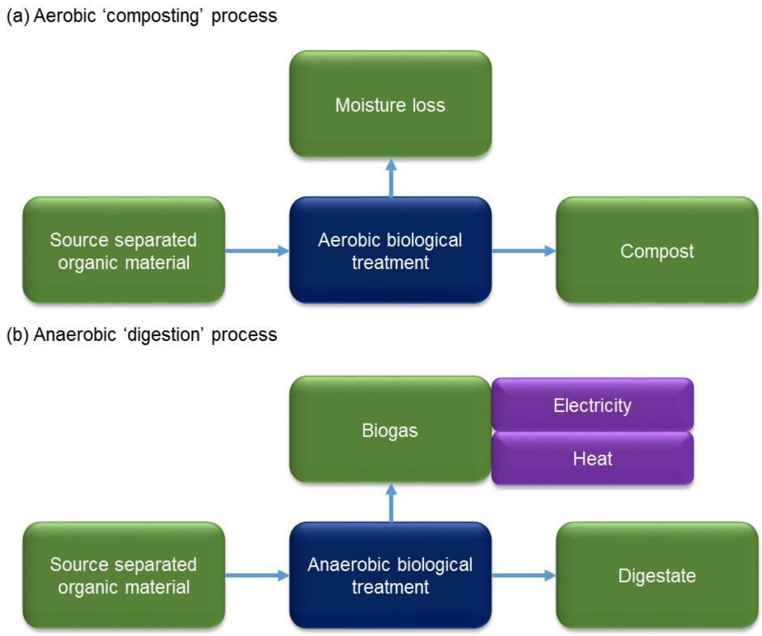



**Figure 5: Typical schematic for 'aerobic' (a) and 'anaerobic' (b) treatment of source separated organic waste with outputs highlighted.**

However, high rate wet AD processes are generally more expensive to build than the lower tech farm type systems. Sector developments show that it is this type of small footprint, highly efficient process that is being increasingly developed. This type of process is also best suited to a high food waste and low garden waste mix given the resultant moisture content and density of the feedstock. Ricardo Energy & Environment therefore expects that should BCC decide to construct its own treatment solution for the processing of source separated food waste in parallel to residual waste treatment, it will use AD rather than aerobic technology.

There would also be an opportunity to use the energy, either as electricity or heat.

## 6.2 Aerobic composting

| Open Windrow Composting | |
|---|---|
| Type of technology | Biological |
| Technology name | Open Air Windrow Composting (OAWC) |
| Technical description | This is an open process and is most typically used to treat source segregated household garden waste and farm wastes that do not contain Animal By Products (ABP) materials. The process typically operates at temperatures up to 70 degrees Celcius to ensure that sanitisation (pathogen kill) is completed. The process can be used on a micro (garden and community), medium (on farm composting or small centralised site) and large (industrial centralised site) scale. The process can be undertaken from a very low level up to a high level with specialist dedicated mechanical equipment to improve processing efficiency. Medium and large scale composting typically uses specialised machinery including shredders, screens and compost turning equipment to make the process more efficient, introduce greater process control and reduce costs through greater mechanisation.<br><br>On a medium and large scale the organic waste will be received at the composting site, will be inspected for compliance against waste acceptance criteria and then shredded to produce a more consistent material that will break down more readily. The shredded organic waste will then be placed either into windrows or blocks typically using a loading shovel, telehandler or excavator for composting. The windrows or blocks will be turned regularly to keep them aerated. They will be turned using loading shoevls, telehandlers, excavators or dedicated turning machines. Finally the compost will be screened to produce the required size grade and remove physical contaminants such plastics and metals.<br><br> |
| Type of recycling technology | The organic material is broken down in the presence of air which generates heat to remove pathogens and use available nutrients leaving a sanitised and stable compost which can be recycled back to land. The compost is used in agriculture, land restoration, horticulture and as a peat free or peat reduced retail product. |

| Open Windrow Composting | |
|---|---|
| Typical application and feedstock | Source segregated non ABP organic waste including commercial and household garden waste and farm wastes such as manure. |
| Feedstock characteristics | The feedstock must consist of a mixture of different types of soft and hard organic wastes to enable pathways for aeration to be formed. For example, if the organic waste consisted of just soft materials it would not aerate and would turn anaerobic. |
| Technology scale and capacity | The technology ranges from low tech through to high tech specialist equipment including shredders, turners and screens. The process can be used from small scale <1,000 tpa through to large scale >50,000 tpa. The key restriction is land area available for treatment and use of the products and any sensitive receptors in the vicinity. |
| Process outputs | Process outputs are $CO_2$, low grade heat and subsequent moisture and compost. Physical contaminants such as plastic and metal are removed from the compost. |
| Advantages | Is simple, robust, low cost and proven for treating source segregated non ABP commercial and household organic waste. |
| Limitations | Is space hungry for large scale processing and can be difficult to manage and control emissions such as odour meaning that is best undertaken away from urban areas or sensitive receptors. As it is an open process weather can hinder processing. It is suitable only for non ABP materials. |
| Reference plants | Numerous globally<br>UK examples include Jack Moody, West Midlands; Little Bushy Warren, Veolia, Hampshire; and Eco Composting, Dorset. |
| TRL | 9 - Global track record |

## 6.3 In Vessel Composting

| In-vessel composting (IVC) | |
|---|---|
| Type of technology | Biological |
| Technology name | Enclosed Composting via In Vessel Composting (IVC) |
| Technical description | This process can be used to treat source separated organic waste, such as food and green waste collected from households and businesses. The process is operated under controlled conditions with the composting commonly being undertaken either in a 'tunnel' or 'box' The process operates at temperatures up to 70-80 degrees Celcius and in compliance with the temperature regime as required for sanitising ABP materials. Due to the more capital intensive nature of the process it is typically undertaken at scales in excess of 5,000 tpa and can be found at sites treating 200,000 tpa. The process normally uses specialised machinery including shredders, screens and compost turning equipment to make the process more efficient, introduce greater process control and reduce costs through greater mechanisation.<br><br>The organic waste will be received at the site, will be inspected for compliance against waste acceptance criteria and then shredded to produce a more consistent material that will break down more readily. The shredded organic waste will then be loaded into the vessel either via a mechanised loading system or through using loading shovels or similar equipment.<br><br>The vessels are then closed and the process managed for a number of days before the material is removed. Typically, if the waste includes ABP materials it will be treated via a second set of vessels to ensure complete sanitisation and subsequent stabilisation and compost is typically then matured in an on-site OAWC process.<br><br>Finally the compost is mechanically screened to the required size grade for final use and to remove physical contamination such as plastic.<br><br><br><br> |

| In-vessel composting (IVC) | |
|---|---|
| Type of recycling technology | The organic material is broken down in the presence of air which generates heat to remove pathogens and use available nutrients leaving a sanitised and stable compost.<br>For compost produced from source segregated waste this may be used in agriculture, land restoration, horticulture and as a peat free of peat reduced retail produce. |
| Typical application and feedstock | Feedstock can consist of mixed household MSW and source segregated household, commercial and farm organic waste containing ABP materials. |
| Feedstock characteristics | The feedstock must consist of a mixture of different types of soft and hard organic wastes to enable pathways for aeration to be formed. For example, if the organic waste consisted of just soft materials it would not aerate and would turn anaerobic. |
| Technology scale and capacity | The technology includes both simple and sophisticated forms of vessels – boxes and tunnels. As the process is more capital intensive it is normally undertaken at a scale in excess of 5,000 tpa.<br>A typical system will process circa. 25,000 tpa. However, some systems that are part of MBT processes can treat up to 200,000 tpa. |
| Process outputs | Process outputs are CO2, low grade heat and subsequent moisture and compost. Physical contaminants such as plastic and metal are removed from the compost.<br>For compost produced from source segregated waste this may be used in agriculture, land restoration, horticulture and as a peat free of peat reduced retail produce.<br>There are only a couple of examples globally of the low grade heat being captured and reused back on site as this is not an efficient process. |
| Advantages | This is relatively simple, but robust and proven process for treating both mixed household MSW and source segregated household and commercial organic waste containing ABP materials. |
| Limitations | Is space hungry for large scale processing. |
| Reference plants | Numerous globally<br>Current UK based examples treating source segregated household and commercial organic waste containing ABP materials include: Jack Moody, West Midlands; Edmonton – NLWA, North London; Chipping Norton, Agrivert, Oxfordshire; and St Ives, Envar, Cambridgeshire. |
| TRL | Global track record |

## 6.4 Anaerobic Digestion

### 6.4.1 Anaerobic Digestion overview

Anaerobic digestion is a series of natural biological processes through which organic material is broken down without the presence of oxygen by micro-organisms and within an enclosed system to generate biogas (a mixture of methane and carbon dioxide) which can then be converted into energy (electricity and heat). A by-product of the process is digestate which is a stable, nutrient rich substance that can be used as a renewable fertiliser or soil conditioner when derived from source-separated waste or in e.g. land reclamation applications when derived from organics separated from residual waste

The AD process can be undertaken with the waste either in a ‘dry’ or ‘wet’ condition. Most AD technology in the UK uses the wet process with the organic material prepared into a liquid. Wet AD is however best suited to source separated waste with low contamination. Whist it is proven it has been problematic when used with the organic fraction extracted from mixed residual waste. High levels of physical contaminants including glass, grit, sands and plastics have caused higher than anticipated wear, blockages and process issues. In addition wet AD is susceptible to chemical contaminants causing the biological process to be disrupted. A number of advances have been made in the last 18 months which have been aimed at resolving these issues however it will be some time before the success of these developments is known.

| **Dry Anaerobic Digestion** | |
|---|---|
| Type of technology | Biological |
| Technology name | Dry Anaerobic Digestion |
| Technical description | This process can be used to treat source separated organic waste, such as food and green waste collected from households and businesses The process is operated under controlled conditions with the composting commonly being undertaken either in a ‘tunnel’ or ‘box’ Due to the more capital intensive nature of the process it is typically undertaken at scales in excess of 5,000 tonnes per annum and can be found at sites treating 200,000 tonnes per annum. The process normally uses specialised machinery including shredders, screens and compost turning equipment to make the process more efficient, introduce greater process control and reduce costs through greater mechanisation.<br><br>The organic waste will be received at the site, will be inspected for compliance against waste codes and then shredded to produce a more consistent material that will break down more readily. The shredded organic waste will then be loaded into the vessel either via a mechanised loading system or through using loading shovels or similar equipment.<br><br>The vessels are then closed the air removed to start the anerobic process and generate biogas. The process is managed for a number of days before the material is removed.<br><br>Finally the digestate is mechanically screened to the required size grade for final use and to remove physical contamination such as plastic.<br><br><br> |
| Type of recycling technology | The organic material is broken down without the presence of air which generates heat to remove pathogens and use available nutrients leaving a sanitised and stable compost. The process also generates biogas which is captured to be turned into renewable electricity or heat. |

| Dry Anaerobic Digestion | |
|---|---|
| | For digestate produced from source segregated waste this may be used in agriculture or land restoration as fertiliser. |
| Typical application and feedstock | Feedstock can consist of mixed household MSW and source segregated household, commercial and farm organic waste containing ABP materials. |
| Feedstock characteristics | The feedstock does not have to consist of a mixture of different types of soft and hard organic wastes. The key is to have the right nutrients present to enable the anaerobic digestion process to be undertaken effectively. |
| Technology scale and capacity | The technology includes both simple and sophisticated forms of vessels – boxes and tunnels. As the process is more capital intensive it is normally undertaken at a scale in excess of 25,000 tpa.<br>A typical system will process circa. 25,000 tpa. However, some systems that are part of MBT processes can treat up to 200,000 tpa. |
| Process outputs | Process outputs are biogas and digestate. Physical contaminants such as plastic and metal are removed from the compost. The biogas is captured cleaned and used to generate renewable electricity or heat.<br>For digestate produced from source segregated waste this may be used in agriculture and land restoration.<br>For digestate produced from mixed household MSW this is termed Compost Like Output (CLO) and may be used in land restoration projects. |
| Advantages | Robust process for anaerobically treating mixed household MSW and is relatively simple, but robust and proven process. |
| Limitations | Is space hungry for large scale processing, not as efficient as generating biogas as liquid anaerobic digestion plants. |
| Reference plants | Current examples treating source segregated household and commercial organic waste containing ABP materials include: Geent, Belgium; Lelystad, Orgaworld, Netherlands;<br>Current examples treating mixed household MSW as part of MBT processes include: BDR, Shanks; Valladolid, FCC, Spain; Leipzig, Germany; Kaiserslautern, Germany. |
| TRL | Extensive European track record. |

| Wet Anaerobic Digestion | |
|---|---|
| Type of technology | Biological |
| Technology name | Wet Anaerobic Digestion |
| Technical description | This process can be used to treat source separated organic waste such as green or food waste, or for oututs from a mechanical and biological treatment proces (MBT) or source segregated household and comemrcial organic waste which may contain ABP materials such as food waste. The process is operated under controlled conditions with the anaerobic digestion being undertaken within tanks. This is undertaken on a scale ranging from small farm based AD plants to large industrial AD plants. The range of technology also varys from simple systems to very sophisticated and highly mechanised and automated systems.<br><br>The process has not been deployed successfully for use in the treatment of mixed household MSW. Therefore, this section relates to its use in treating source separated household and commercial organic waste.<br><br>The organic waste will be received at the site, will be inspected for compliance against waste codes and then treated to remove packaging and / or prepare it for the wet AD process through the addition of liquid. The liquid feedstock is then mixed if required with ither liquids to produce the right blend before being pumped into the digestion tanks. The lqiuid is anaerobically digested in the tank over a period of time which generated biogas. The biogas is captured and used to produce renewable electricity or heat. Following the completion of the digestion process the digestate may be stored to allow stabilisation before being used either in liquid or dewatered form as a biofertiliser or soil improver on agrocultural land or land restoration.<br><br>More sophisticated high rate AD processes undertake the digestion process over a much reduced period of time.<br><br><br><br><br><br>**Depackaging** equipment is used to remove plastic, card and other packing before the digestion process. If the packaging remained it may block pipes or |

<table>
<tr><th colspan="2">Wet Anaerobic Digestion</th></tr>
<tr><td></td><td>prevent the release and capture of biogas reducing the effectivenss of the porcess.<br><br><br>Dewatering maybe undertaken to produce a more solid digestate which may be easier to transport and apply to land. Typically this is undertaken using centrifuges or belt presses.<br><br></td></tr>
<tr><td>Type of recycling technology</td><td>The organic material is broken down without the presence of air and use available nutrients leaving a stable liquid digestate. The process also generates biogas which is captured to be turned into renewable electricity or heat.<br><br>For digestate produced from source segregated waste this may be used in agriculture or land restoration as fertilising material.</td></tr>
<tr><td>Typical application and feedstock</td><td>Feedstock typically consists of source segregated household and commercial food waste and similar organic waste, farm wastes and specialist crops containing ABP materials. It is has not proved to be a successful process for treating mixed household MSW.</td></tr>
<tr><td>Feedstock characteristics</td><td>The feedstock needs to consist of soft tissue materials such as food waste and/or liquid wastes. The key is to have the right nutrients present to enable the anaerobic digestion process to be undertaken effectively.</td></tr>
</table>

| Wet Anaerobic Digestion | |
|---|---|
| Technology scale and capacity | The technology includes both simple and sophisticated forms ranging from farm based to highly industrialised systems. The process can be undertaken at both a small and large scale depending on the feedstock type and subsidy available. Small on farm plants generating <1MW will typically use an energy crop and/or some farm waste. Large industrial plants >1MW will normally treat household and commercial food and liquid wastes. |
| Process outputs | Process outputs are biogas and digestate. Physical contaminants such as plastic and metal are removed from the digestate. The biogas is captured cleaned and used to generate renewable electricity or heat.<br>For digestate produced from source segregated waste this may be used in agriculture and land restoration. |
| Advantages | Robust process for anaerobically treating source segregated food waste and liquid waste and generates high levels of biogas. |
| Limitations | The biology within the process can be susceptible to contaminants and must be monitored closely. Not successful at treating the organic fraction derived from mixed household MSW. |
| Reference plants | Current examples in the UK include: Cumbernauld, Energen Biogas, Scotland; Cassington, Agrivert; Westcott Park, Shanks, Buckinghamshire. |
| TRL | Extensive European track record. |

***Agrivert Cassington Anaerobic Digestion facility, Oxfordshire, UK, www.biogas.org.uk***

## 6.5 Small scale Anaerobic Digestion

There is a growing interest in in the use of small-scale and on-site AD plants which are designed to treat biodegradable residues close to where they are produced to make better use of unwanted resources. This applies not only to farm residues for which on-farm AD is relatively common, but also on food processing sites, and within communities with the benefits of generation of renewable energy.

| Small scale AD | |
|---|---|
| Location | London |
| Type of measure | Small scale AD |
| Target audience | Local householders and businesses |
| Type of waste | Food waste |
| Context | LEAP – (Local Energy ADventure Partnership) – is a cross-sector partnership seeking to support urban food waste management through the development of small-scale anaerobic digestion. The partnership was first funded by the London Borough of Camden in 2012, and has since been supported by the Technology Strategy Board and WRAP.<br>LEAP have developed a pilot community AD plant near King's Cross in London which consists of a:<br>• 0.6$m^3$ mill and pre-feed tank<br>• 2$m^3$ Methanogen digester<br>• 1.5$m^3$ gasholder<br>• digestate separator and storage<br>• Compressor and storage cylinders<br>• Ecogen CHP with microgen Stirling engine<br>Food is delivered to the pilot plant via bicycle, and consists mainly of food waste from local canteens and hotels.<br>The biogas is used during colder months to demonstrate electricity and heat generation using a micro CHP unit in partnership with Microgen, the makers of the Stirling engine in the Ecogen and several other units.<br>In warmer months, it is compressed into cylinders and used as a portable fuel for cooking and water heating.<br>Digestate is separated into liquid and solid fractions with the liquid fertiliser used on-site to support food-growing and a low cost hydroponics trial. The solid digestate fibre is added to compost heaps as a soil conditioner. |
| Objectives | The aims of LEAP is a cross-sector partnership developing micro anaerobic digestion (AD) to:<br>• Turn food waste into clean renewable energy and fertiliser<br>• Reduce carbon and methane emissions, air pollution and waste disposal costs<br>• Create green jobs and training opportunities for local people<br>• Support local food growing and urban greening projects |
| Outcomes | LEAP outline the benefits of the project as:<br>• managing food waste locally helps reduce pollution and greenhouse gas emissions associated with "waste miles", and generates onsite, clean renewable energy.<br>• Nutrient-rich digestate can be used to support local food growing, increasing community access to healthy organic produce. It can also be |

| Small scale AD | |
|---|---|
| | used for urban greening programmes to beautify urban areas and contribute to better air quality.<br>• Community-scale anaerobic digestion demonstrates a closed-loop system that offers excellent educational opportunities, helping people better understand the benefits of recycling. |
| Further information | http://communitybydesign.co.uk/ Accessed 15 December 2015 |

## 6.6 Advanced AD (AAD)

Advanced anaerobic digestion enhances the benefits of anaerobic digestion by separating and optimising the key process stages used in more conventional digestion systems. There are two main pre-digestion processes used in AAD in the UK, namely thermal hydrolysis (the Cambi process) or enzymatic hydrolysis (the Monsal process). Currently, there are examples of each in operation and under construction.

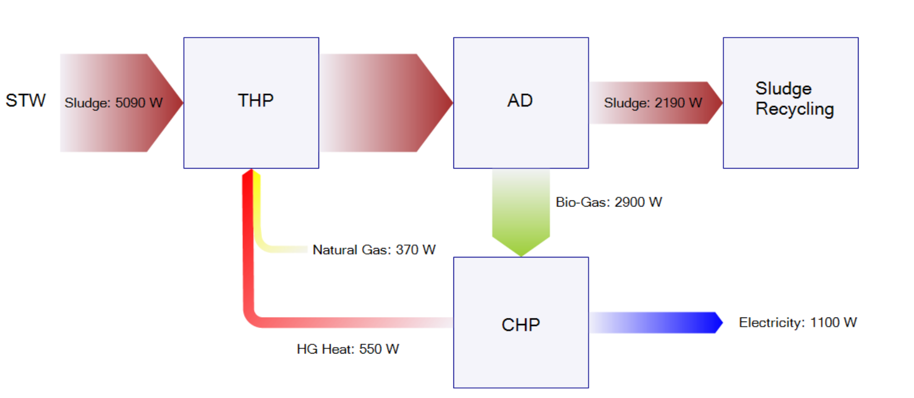
Regardless of which process is used, the key to the AAD process is a phase that significantly enhances the breakdown of organic materials by, for example, breaking down cell walls. With thermal hydrolysis this is achieved by an initial high temperature of 165°C combined with high pressure (6 Bar) for less than one hour, or with enzyme hydrolysis this is achieved by phasing an increased temperature from 42°C to 55°C over several days.

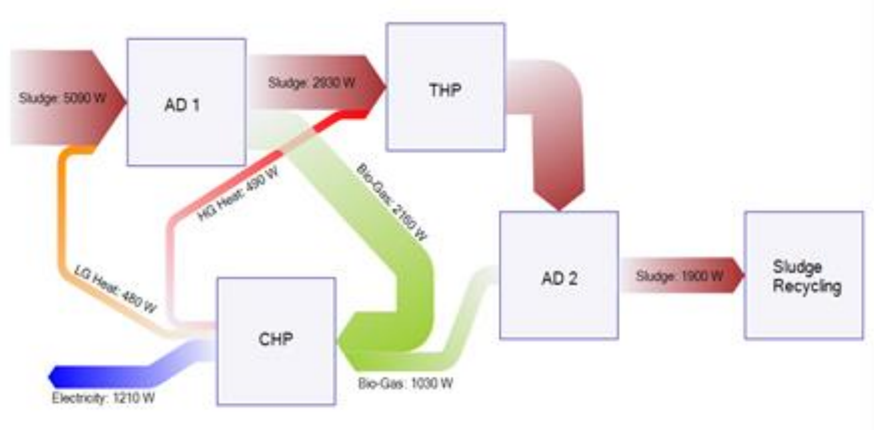
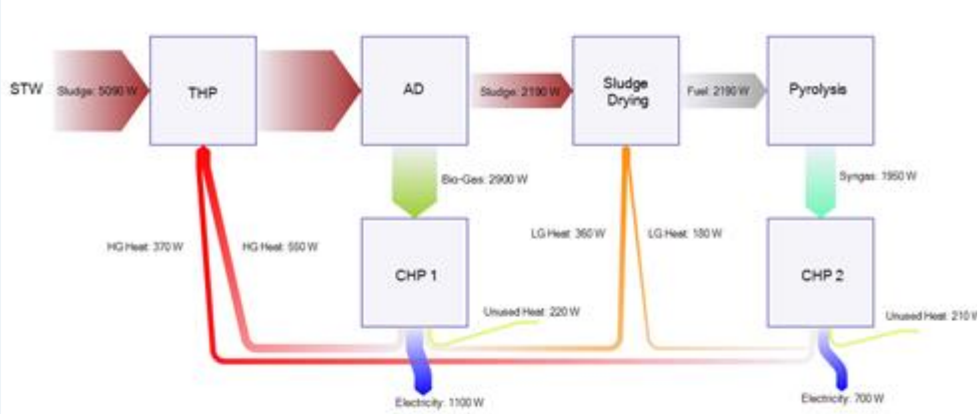
The intended result is enhanced conversion of organic matter into biogas when the material is transferred into the anaerobic digestion phase. Following this digestion phase, there is a 50% reduction in sludge volumes, combined with the additional biogas/CHP-derived energy being produced, and ultimately a better quality bio-solids fertilizer.

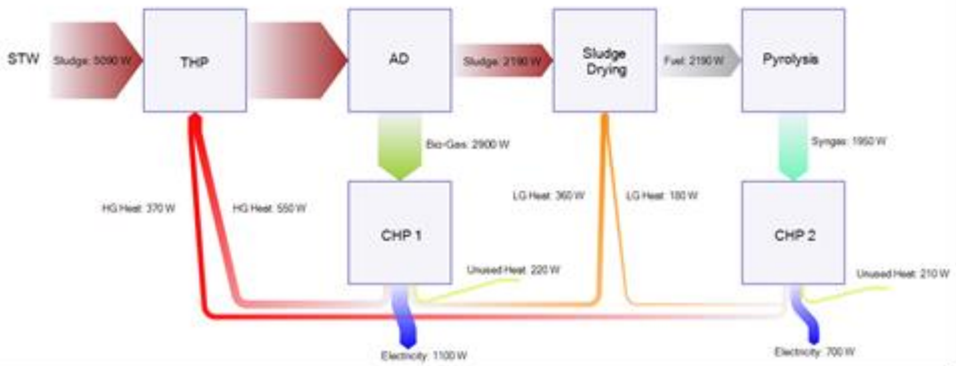
One of the major benefits of this, of course, is that energy from biomass, including sewage sludge, is classed as renewable and therefore contributes to meeting Britain's commitments to address climate change.

Using AAD reduces the mass of material which is required to be transported off site and offers the benefit of nutrient recovery from materials which are presently wasted. Indeed, some particularly difficult materials, such as food wastes under the Animal By-Products Order (ABPO), need the conditions of AAD to render them safe. AAD also has the benefit of reduced odour compared to conventional AD.

The table below summarises different AAD technologies and configurations.

| Overview of Advanced AD processes | |
|---|---|
| Sewage Sludge Advanced AD – THP | The Thermal Hydrolysis Process (THP) first dewaters the incoming sludge stream to 16.5% Dry Solids (DS) before the dried biomass enters a pressure vessel. Steam is added to the pressure vessel at roughly 12bar, degrading the biomass before high rate AD occurs. Conventional sewage sludge digestion achieves volatile solids destruction (VSD) of 40-50% which yields 300-350m3 of biogas per tonne of Dry Solids (DS) which translates to a 40% mass reduction.<br><br>Typical sites with THP achieve 60%VSD and produce 450m$^3$ biomass per tonne of dry solids, representing a 30 to 40% increase in gross energy output. However, insufficient high grade heat is produced by the process through CHP to meet all the THP process steam requirements, resulting in additional fuel being needed.<br><br><br> |

<table>
<tr><th colspan="2">Overview of Advanced AD processes</th></tr>
<tr><td>Sewage Sludge Advanced AD - ITHP</td><td>The Intermediate Thermal Hydrolysis Process (ITHP) locates THP in the middle of two digestion stages. In the first stage of digestion, a conventional digester generates biogas and forms a residual sludge from the readily available organic matter. Digested and concentrated sludge is then hydrolysed in a plant which reduces its size. In the second stage digester, which operates at a higher loading rate, more biogas is produced. The total biogas production of both phases is approximately 500m³/tDS, representing an 11% improvement on conventional THP. Final VSD is around 65%. Increased energy production and reduced THP size results in the process being self-sufficient in heat when combined with a CHP unit.<br>

</td></tr>
<tr><td>Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis)</td><td>Before the pyrolysis process, a dryer produces a solid fuel feed using biomass from either a THP sludge treatment process (as shown below) or an ITHP process. The pyrolysis process has been shown to reduce the mass of the biomass solids by 90%, liberating a pyrolysis gas with a high CV of 11 - 20MJ/m³ and leaving very little residual product for disposal.<br><br>The fuel gas from the pyrolysis process is then utilised in a second gas engine (CHP2). CHP1 is a gas engine running on biogas from the AD process. Both CHP units produce heat which is split into a high and low grade. The high grade heat (200°C) is used to raise steam for THP and low grade heat used for sludge drying. Unlike other THP processes there is no requirement for support fuel due to the combination of CHP units raising all of the steam for THP. Pyrolysis shows the most potential as a form of advanced energy recovery.<br>

</td></tr>
<tr><td>Sewage Sludge Advanced AD with Advanced Energy</td><td>A similar process to the above, with gasification replacing pyrolysis as the final stage of energy recovery from the sewage sludge stream. To sustain the conversion process, partial combustion of the syngas occurs during gasification of the dried biomass feedstock. The resulting syngas CV is lower than for pyrolysis, typically in the range of 4-8MJ/m³ as nitrogen is introduced with air,</td></tr>
</table>

| Overview of Advanced AD processes | |
|---|---|
| Recovery (Gasification) | diluting the syngas and some fuel. The gasification process is therefore not as efficient as the pyrolysis processes, with a 20% reduction in conversion efficiencies being expected between the two approaches.   |

## 6.7 Mechanical and Biological Treatment (MBT) overview

Mechanical Biological Treatment (MBT) uses a combination of mechanical and biological process steps to separate and treat waste and create a number of output materials which may include refuse derived fuel (RDF), biogas, recyclates or a compost like output (CLO). The mechanical element can either be used pre or post the biological treatment step. The biological treatment step can be used to broadly divide MBT processes into two main categories as follows:

- Aerobic treatment e.g. the processing of the waste in the presence of air i.e. via composting; and
- Anaerobic treatment e.g. the processing of the waste either as a liquid or solid in the absence of air i.e. via dry or wet AD.

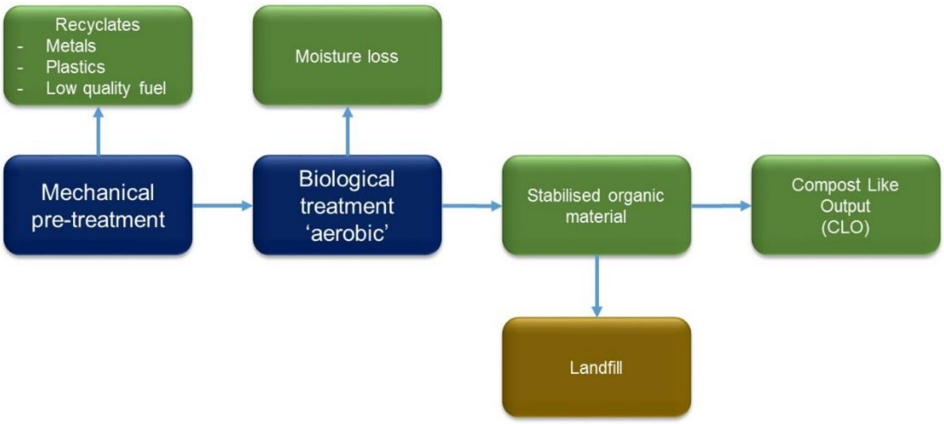
The use of aerobic treatment within MBT is the most widespread form of biological treatment and has been use for the longest period of time. More recently MBT processes with AD have been developed to generate biogas which can then be used to power and / or heat the facility. These are not yet as widespread as MBT processes with aerobic treatment but are starting to see increased use as focus is increased on energy consumption and sustainability.

The key benefit for the use of AD (either dry or wet) is the subsidy that is paid for the generation of renewable energy. This is either in the form of the ROC (for existing plants and those built by 2017), the Contract for Difference (CfD) for newer plants or the Renewable Heat Incentive (RHI). These subsidies provide valuable additional revenue that cannot be achieved through the use of aerobic technology. As AD can be used to generate electricity and heat from the biogas the plants can also be made to be much less reliant on external electricity and/or heat.

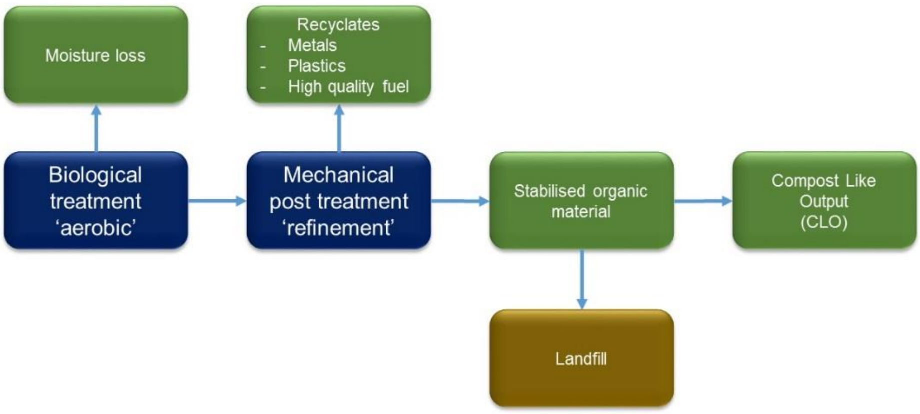
Typical examples of MBT with aerobic treatment are illustrated in the figure below.

**Figure 6: Typical configurations of MBT processes with aerobic treatment with (a) pre and (b) post mechanical treatment and outputs**

(a) Pre-treatment MBT example




(b) Post treatment MBT example

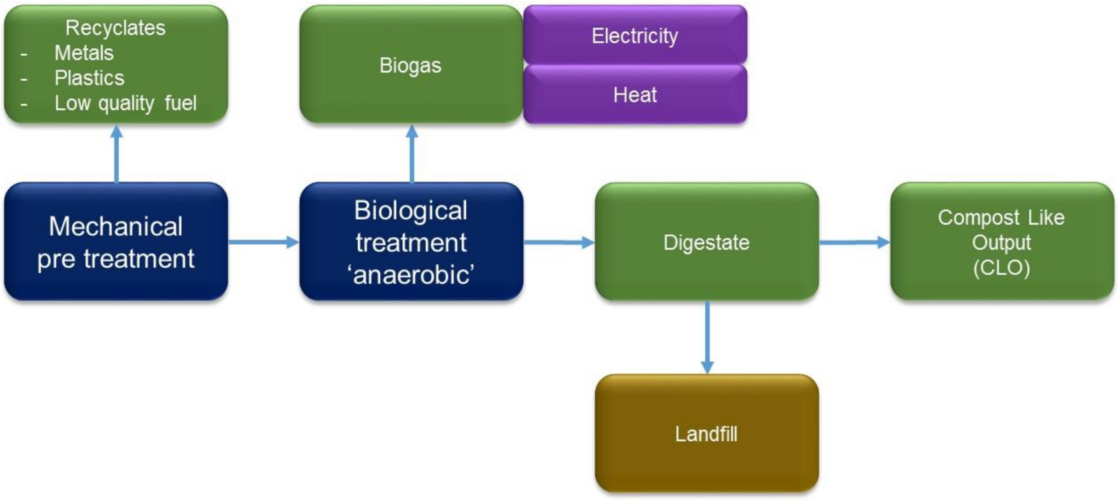


Understanding the composition of the waste to be processed and the specifics of the required outputs e.g. RDF, biogas, recyclates or CLO is critical in determining the most suitable MBT process to implement and its likelihood of operating successfully. Where these factors have not been carefully considered MBT plants have operated less effectively than expected including examples within the UK. Therefore, the key factors to address include as part of the selection include:

- Energy balance e.g. the consumption of energy v the generation of energy;
- Output specifications e.g. quality, quantity and type i.e. CLO, biogas or recyclates;
- Flexibility of the process to treat different compositions of residual waste over time; and
- Available footprint for the MBT process.

Assessing these factors will determine the most suitable biological process to be deployed as part of the MBT process i.e. aerobic or AD, see technologies described in Sections 6.2 and 6.4. This decision will also affect whether the mechanical treatment is pre or post the biological treatment. For example, if an aerobic process is deployed first this can enable the residual waste to first be 'biodried' (reduction in moisture content) making the material more suitable for refining into fuel and may enable a higher grade fuel (e.g. lower moisture and higher CV) to be manufactured. A higher quality fuel may enable additional off take options or more innovative uses which reduce costs or lead to new revenue streams. However, with the aerobic biological treatment first it typically means that most if not all of the residual waste is treated requiring a larger footprint. Conversely, mechanical pre-treatment will typically produce a lower quality fuel (e.g. higher moisture content and lower CV). This configuration of MBT processing typically removes a significant quantity of materials at the start of the process reducing the required footprint and energy required for the biological process.

**Figure 7: MBT AD example with pre mechanical treatment and highlighting the typical outputs**




Increasingly more novel uses are being sought for the recyclates and fuels (RDF/SRF) produced by MBT plants. Traditionally recyclates such as plastics and metals went to the same outlets and processes as 'clean' recyclates. However, as quality requirements and market conditions have changed MBT operators are looking at different outlets. For example, in some MBT plants plastic washing lines have been installed to clean and then prepare plastic flakes on site to increase their value. At other facilities the plastics have been used to produce synthetic liquid fuels, although this technology is in its relative infancy, see Section 5.7. These more novel approaches to the use of the recyclates will continue as operators seek to extract maximum value and apply the values of the circular economy to their business model.

# 6.8 Technology for the recovery of energy from biological treatment

## 6.8.1 Gas to grid or vehicle fuels

Biomethane produced from the anaerobic digestion of food waste and sewage sludge has the same composition as fossil-fuel derived methane and therefore is suitable for use as a substitute for natural gas via a gas to grid network. In an AD process, microorganisms biodegrade the organic feedstock in the absence of oxygen to produce methane rich biogas. The biogas is upgraded to biomethane and impurities such as $CO_2$ and $H_2S$ are removed by scrubbers and activated carbon filters. A small volume of propane is added to the methane to ensure the gas has the same natural gas quality, and then fed in to the local gas distribution network.

The 'upgrading' of biogas is necessary to meet quality standards necessary to permit the injection of gas into the natural gas network. The principal stages are $CO_2$ and $H_2S$ removal from the biogas, enrichment using propane to meet calorific value and Wobbe Index requirements and compression to meeting network pressure requirements. A number of separation technologies exist for the removal of carbon dioxide but the most commonly used a membrane separation and 'water wash'.

| Gas to grid, Geneco, Bristol | |
|---|---|
| Type of technology | Supply of biogas to gas grid |
| Technology name | Gas to grid |
| Technical description | Sewage sludge and food waste are heated to 32 – 42°C in digesters and retained there for 12 – 18 days. In the absence of oxygen, micro-organisms break down the biodegradable material to produce a methane rich biogas. At this point, the biogas contains around 60 % methane.<br><br>The methane-rich biogas produced by the digesters is then upgraded to biomethane (~98% methane; 1.5 % nitrogen).<br><br>Gaseous impurities such as carbon dioxide and hydrogen sulphide are then removed by a bioscrubber and activated carbon filters to produce virtually odour free emissions to air.<br><br>A small volume of propane is added to the biomethane to enrich the gas to natural gas quality and achieve the required calorific value. The biomehthane is then injected in to the gas grid. |
| Typical application and feedstock | Sewage sludge and food waste |
| Technology scale and capacity | The gas to grid plant at Bristol's Avonmouth sewage works produces up to 1,900$m^3$ of enriched biomethane an hour. |
| Process outputs | The volume of gas injected into the national gas grid is enough to supply 8,300 homes |
| Advantages | $CO_2$carbon dioxide released by the combustion of biomethane does not increase atmospheric $CO_2$; this is because the same amount of $CO_2$ is produced from natural decomposition of the organic matter that initially creates the biomethane.<br><br>Diverts biodegradable waste from landfill converts it in to a useful fuel. |
| Limitations | Requires access to gas grid |

| Gas to grid, Geneco, Bristol | |
|---|---|
| Reference plants | There are >200 biomethane products which are concentrated in Germany, the Netherlands and Sweden. Growth of this sector in the UK is anticipated. |
| TRL | 9 |
| Further information | http://www.geneco.uk.com/Biobug/gas-to-grid.aspx Accessed 18 January 2016 |

***Linköping Biogas to vehicle fuel plant, Sweden***

| **Gas to vehicle fuel, Geneco, Bristol** | |
|---|---|
| Type of technology | Conversion of biogas to vehicle fuel. |
| Technology name | Gas to vehicle fuel |
| Technical description | Sewage sludge and food waste are heated to 32 – 42°C in digesters and retained there for 12 – 18 days. In the absence of oxygen, micro-organisms break down the biodegradable material to produce a methane rich biogas. At this point, the biogas contains around 60 % methane. The biogas is then process to a higher purity in an upgrading process, which involves the removal of water, carbon dioxide, hydrogen sulphide, and other trace elements. |
| Typical application and feedstock | Sewage sludge and food waste |
| Process outputs | Biomethane from the Geneco Bristol plant fuels a 40-seat “Bio-Bus”, which can travel up to 186 miles on one tank of gas.<br><br> |
| Advantages | Diversion of organic waste from landfill.<br>Biomethane production uses 95% less $CO_2$ than diesel. The $CO_2$ emissions from biomethane vehicles is also 20-30% lower than the $CO_2$ emissions from diesel vehicles.<br>Improved emissions and air quality – use of biomethane provides a 97% reduction in dangerous particulate (PM2.5 and PM10) emissions; microscopic matter which can pass easily from the lungs into the bloodstream. There is also an 80 - 90 % reduction in nitrogen oxides (NOx). Suitable renewable fuel for HGVs. |
| Limitations | Infrastructure upgrades to clean biomethane<br>Infrastructure neededfor the liquefaction (LBM) or compression (CBM) of biomethane for vehicle use. |
| Reference plants | The use of biomethane as a vehicle fuel is a proven technology with the use of biomethane as a vehicle fuel is increasing across Europe. Sweden have been converting sewage in to transport fuel for years with over 36,000 trucks, 1,500 buses and 500 heavy-duty trucks in use, filling up at 130 public fuelling stations. |
| TRL | 9 |
| Further information | http://www.geneco.uk.com/Biobug/biobus.aspx |

# Appendices

# Appendix 1 – Evaluation of technologies

# Appendix 2 – Evaluation matrix

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# Appendix 2 – Technology Evaluation Methodology

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# 1 Methodology

The overall aim of evaluating recycling and recovery technologies is to enable Birmingham City Council to be an informed customer in the future procurement of a waste management contract/s, and to provide the council with the technical information and necessary evidence base to aid future decision making.

This document presents a high level overview of the technologies identified in the foresighting exercise. Each technology which has been reviewed in the technology foresighting exercise has been considered against:

- cost,
- risks,
- community benefits,
- impact on operations, and
- carbon reduction potential

This appraisal, has been used to complete the evaluation matrix (Appendix 2).

The information outlined for each technology reviewed enables the identification of high level environmental, economic, social and operational/technical impacts of each of the technologies. Under each of these key areas, a set of indicators was developed and refined with stakeholders and the BCC project team. These indicators have been used to evaluate each technology by evaluating each indicator using a Red/Amber/Green (RAG) scoring system. Where possible, evaluation of each technology has been made as a comparison to the current way in which a particular waste is managed. The aim of the scoring exercise is to be able to compare the overall impacts of each technology and not to discriminate against options that are innovative, low cost or small scale (or are different in other ways from more standard options).

As at this stage we do not know the importance, or weighting, of each criteria therefore it is not intended that the scores are used to conclude the best or preferred technologies against each criteria. This will be dependent on the importance and weighting assigned given to individual impacts when they are eventually evaluated as a solution for a specified waste contract. However, the RAG review will present a powerful and visual overview of the likely environmental, economic, social and technical/operational impacts of each technology option.

The scoring has also been informed by the level of information captured on each criteria in our technology review. For example, where limited information is available on certain technologies, there are more unknowns and more assumptions have needed to be made.

| Indicator: | |
|---|---|
| Not as good | (Red) |
| Similar | (Amber) |
| Better | (Green) |

If a technology is deemed to be better than the baseline for a specific criteria, a Green score has been applied. If the technology will be similar, an Amber score was applied. If a particular impact of a technology is worse than the baseline, a Red score was applied.

Where baseline data is not available, or is not applicable, an Amber rating has been applied.

The evaluation is assessed against the assumption that the technology will be procured or developed by BCC. For example, whilst cartons may be collected by BCC for treatment elsewhere, the evaluation considers the development of carton recycling technology within BCC.

# 2 Baseline assumptions

BCC Fleet and Waste department have provided information on the current waste management arrangements. These are not presented in detail here, but the management of key waste streams is summarised in the table below.

| | Current management or end destination |
|---|---|
| Household residual | Combusted at Tyseley EfW |
| Trade waste | Combusted at Tyseley EfW |
| Clinical waste | Dedicated incinerator at Tyseley |
| Construction & Demolition waste | Aggregate crushed and recycled at T&T aggregates (via Veolia) |
| Dry recyclables collected at kerbside | Paper (source separated in Paper Pod) – recycled at a paper mill<br>Mixed recycling (plastics, glass, cans) – processed at Veolia Four Ashes MRF. |
| Recyclables collected at recycling banks and at 5 Household Recycling Centres | Via transfer stations to Four Ashes MRF, or to reprocessors. |
| Food waste | Not currently separately collected. |
| Green waste | Open windrow composting |
| Mattresses | Not separately collected |
| Litter/Street Cleansing waste | Combusted at Tyseley EfW |
| Cartons | Collected only at Recycling Centres |
| Used Cooking Oil | Freedom Recycling (Ipswich) |
| Wood | A&A Recycling (Coventry), wood is processed for use in panelboard industry or for biomass |
| Tyres | Credential Environmental (Reprocessing of tyres for engineering schemes, or use a fuel) /Nottinghamshire Recycling |

# 3 Evaluation criteria and scores

| **Costs** | | | |
|---|---|---|---|
| Does the technology provide potential cost savings in terms of avoiding disposal costs, including exposure to taxation? | Costs increase | No potential cost savings | Potential cost savings |
| Does the technology provide potential cost savings in terms of avoiding natural gas use or electricity? | Costs increase | No potential cost savings | Potential cost savings |
| Does the technology provide potential cost savings in terms of avoiding transport and haulage where particular waste streams can be treated on-site or closer to the point of generation than current disposal or treatment options? | Costs increase | No potential cost savings | Potential cost savings |
| Does the technology offer potential revenue from fiscal measures and incentives for heat and/or power? | No potential revenue | Unknown/same as existing scenario | Potential revenue |
| Does the technology offer potential revenue from sale of outputs? | No potential revenue | Unknown/same as existing scenario | Potential revenue |
| Are the capital costs (purchase costs of technology and associated infrastructure) less than expanding the present services? | Higher capital costs | Unknown/No difference to capital costs | Capital costs less than expanding present |
| Are the operational costs likely to be less than the baseline? | Higher operationall costs | Unknown/No difference to operational costs | Operational costs less than expanding present |
| Does the technology present a funding opportunity through the attraction of inward investment? | No potential funding opportunities | Unknown/not applicable | Potential funding opportunities |
| **Risks** | | | |
| Does the technology have a demonstrable track record of delivery? | Limited or no track record | Unknown/some track record | Proven track record |
| Is the feedstock waste required for this technology (composition/ quantity) available? | Limited availability of feedstock | | Feedstock widely available |

| | | | |
|---|---|---|---|
| Does the technology offer similar operational risks to the present technology (for example availability, contingency?) | Higher operational risks | No change in operational risks | Fewer operational risks |
| Does the technology have similar site and planning risks to the present? | Higher site and planning risks | No difference in site and planning risks | Fewer site and planning risks |
| Is there evidence of examples of problems and risks experienced in similar schemes in the past, or extrapolations drawn from pilot schemes? | Strong evidence of problems and risks | Unknown | No evidence of problems or risks |
| Are there examples of other local authorities utilising the technology? | No examples of local authorities utilising technology | Some examples of local authorities utilising technology | Several examples of local authorities utilising technology |
| Is the typical site area (ha) building footprint and building height similar to the present technology? | Large footprint than present technlogy | Unknown/not applicable if technology not currently in use | Smaller footprint than present technology |
| Is the expected lifetime of facility (years) similar to the present technology? | Shorter lifetime | Similar lifetime to present technology/not applicable | Longer lifetime |
| Is the technology vulnerable to policy or legislative change? | Highly vulnerable to policy or legislative change | No change in vulnerability to policy or legislative change/not applicable | Unlikely to be vulnerable to policy or legislative change |
| What has been the technology's track record in public acceptability? | Significant record of poor public acceptability | Unknown/Not applicable | Limited issues with public acceptability |
| **Community impacts** | | | |
| Are actual impacts associated with traffic similar to the present technology? | Potential increase in traffic impacts | Unknown/Not applicable/Same as baseline | Potential reduction in traffic impacts |
| Are actual impacts associated with noise similar to the present technology? | Potential increase in noise impacts | Unknown/Not applicable/Same as baseline | Potential reduction in noise impacts |

| | | | |
|---|---|---|---|
| Are actual impacts associated with odour similar to the present technology? | Potential increase in odour impacts | Unknown/Not applicable/Same as baseline | Potential reduction in odour impacts |
| Are actual impacts associated with dust similar to the present technology? | Potential increase in dust impacts | Unknown/Not applicable/Same as baseline | Potential reduction in dust impacts |
| Are local and regional air pollution impacts similar to the present technology? | Potential increase in local and regional air pollution impacts | Unknown/Not applicable/Same as baseline | Potential reduction in local and regional air pollution impacts |
| Is the visual impact similar to the present technology? | Potential increase in visual impacts | Unknown/Not applicable/Same as baseline | Potential reduction in visual impacts |
| Are the health impacts similar to the present technology? | Potential increase in health impacts | Unknown/Not applicable/Same as baseline | Potential reduction in health impacts |
| Are the jobs created and skills requirements similar to the present technology? | Reduction in jobs and skills | No change in number of jobs/unknown | Increase number of jobs and upskilling |
| Will the technology have the potential to provide community incentives, i.e., local services, subsidised energy bills, community heating? | No potential for community incentives | No change in community incentives/unknown | Potential to provide community incentives |
| Will the technology particularly benefit citizens from deprived areas? | No specific benefits to deprived areas | No changes in deprived areas/unknown/not applicable | Specific benefits to deprived areas |
| Will the technology support third sector organisations? | No potential for third sector support | No changes /unknown/not applicable | Potential for third sector support |
| Will the technology contribute to behaviour change, e.g. engage with citizens/schools? | No potential for contribution to behaviour change | No changes /unknown/not applicable | Potential for contribution to behaviour change |
| Will the technology support/ contribute to the local supply chain? | No potential for contribution to local supply chain | No changes /unknown/not applicable | Potential for contribution to local supply chain |

| | | | |
|---|---|---|---|
| **Operations** | | | |
| Are the implications for waste collection the same as at present? | Significant implications for current waste collection | Unknown/not applicable | No implications for current waste collection |
| Does the option fit within current and future European, UK, English, regional & local policy? | Contradicts current and future policy | Unknown/not applicable | Complements current and future policy |
| Does the option move waste up the waste hierarchy compared to the present treatment method? | Waste moves down hierarchy | No change/not applicable | Waste moves up hierarchy |
| Does the option have a similar number of vehicle movements to the new technology? | Increased vehicle movements | No change/not applicable | Reduced vehicle movements |
| Is the technology flexible to accept municipal, commercial & industrial and other waste streams? | Inflexibility to accept range of waste streams | No change/not applicable | Flexibility |
| Is the technology flexible to accept changing waste composition and policies? | Inflexibility to accept changes in composition | No change/not applicable | Flexibility to accept changes in composition |
| Can the technology be developed using existing sites/ current locations? | New sites will be required | Not applicable | Potential to use existing sites |
| Does this technology complement current technology (as this is decommissioned/ phased out/ comes to the end of its life? | Does not complement current technology | No change/Not applicable | Complements current technology |
| **Carbon reduction and environmental** | | | |
| Does it offer a reduction in life cycle carbon impacts in comparison to the present technology? | Increased life cycle carbon impacts | No change/Not applicable | Potential reduction life cycle carbon impacts |
| Does it offer more opportunities for outputs to be utilised as a resource by current or emerging industries (e.g. bio refining, chemicals manufacturing) than the present technology | Decrease in opportunities to use waste as a resource | No change/Not applicable | Increase opportunities to use waste a resource |
| Does it offer links to transport technologies (e.g. provision of transport biofuels)? | No links to transport technologies | No change/Not applicable | Potential links to transport technologies |
| Can the technology provide combined heat and power (CHP), heating or | No potential to provide | No change/Not | Potential to provide |

| | | | |
|---|---|---|---|
| cooling? | CHP, heating or cooling | applicable | CHP, heating, or cooling |
| Can the technology provide opportunities for community energy schemes? | No potential for community energy | No change/Not applicable | Opportunity for community energy |

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| | |
|---|---|
| Recycling | Multi-material MRF<br>Advance Mixed Materials Sorting<br>Optibag<br>Pneumatic waste collection<br>Magpie plastics sorting<br>Mixed Plastic sorting<br>Water-free plastics recycling<br>Enzymatic depolymerisation<br>Tyre recycling<br>Advanced Glass Recycling<br>CRT Recycling<br>Street sweepings recycling<br>UCO - biodiesel<br>AHP Recycling<br>Carpet waste recycling<br>Mattress recycling<br>Gum-tec<br>Cigarette waste recycling<br>Dog waste digester<br>Dog waste wormery<br>Carton recycling |
| Thermal | Moving grate<br>Rotary kiln<br>Fluidised bed |
| ATT | Rodecs Pyrolysis<br>Pyrolysis<br>Flash pyrolysis<br>Gasification<br>Plasma gasification<br>Thermal depolymerisation<br>Hydrothermal Carbonisation<br>Thermal-Catalytic Reforming<br>Waste to biofuels |
| Energy recovery | Boilers<br>Turbine and generator set<br>Heat pump<br>Flue gas condensation<br>Cooling |
| Distribution | Private Wire Network<br>District Heating Network<br>High grade heat<br>District Cooling Network |
| Biological | Open windrow<br>IVC<br>Dry AD<br>Wet AD<br>Small scale AD<br>Advanced AD<br>MBT |
| Energy recovery | Gas to grid<br>Gas to vehicle fuel |

| | Recycling | Recycling | Recycling | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Evaluation Criteria | Multi-materia | Advance Mix | Optibag | Pneumatic wa | Magpie plasti | Mixed Plastic | Water-free pl | Enzymatic de | Tyre recycling | Advanced Glass | CRT Recycling | Street sweepi | UCO - biodies | AHP Recycling | Carpet waste | Mattress recy | Gum-tec |
| **Costs** | | | | | | | | | | | | | | | | | |
| Does the technology provide potential cost savings in terms of avoiding disposal costs, including exposure to taxation? | G | G | G | R | G | G | G | G | G | G | G | G | A | G | G | G | G |
| Does the technology provide potential cost savings in terms of avoiding natural gas use or electricity? | G | G | G | G | R | R | R | G | A | G | G | A | G | R | R | R | G |
| Does the technology provide potential cost savings in terms of avoiding transport and haulage where particular waste streams can be treated on-site or closer to the point of gene | G | G | G | G | R | R | R | R | A | G | G | G | G | G | G | G | A |
| Does the technology offer potential revenue from fiscal measures and incentives for heat and/or power? | R | R | R | R | R | R | R | R | R | R | R | R | G | R | R | R | R |
| Does the technology offer potential revenue from sale of outputs? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | A |
| Are the capital costs (purchase costs of technology and associated infrastructure) less than expanding the present services? | A | A | A | A | A | A | A | A | A | A | A | A | R | A | G | G | G |
| Are the operational costs likely to be less than the baseline? | A | A | A | R | A | A | A | A | A | A | A | A | R | R | A | G | G |
| Does the technology present a funding opportunity through the attraction of inward investment? | A | A | A | A | A | A | A | A | A | A | A | R | A | G | G | G | R |
| **Risks** | | | | | | | | | | | | | | | | | |
| Does the technology have a demonstrable track record of delivery? | G | G | G | G | G | A | R | R | G | G | G | G | G | A | G | G | A |
| Is the feedstock waste required for this technology (composition/ quantity) available? | G | G | G | G | G | A | R | R | G | G | G | G | A | G | G | G | G |
| Does the technology offer similar operational risks to the present technology (for example availability, contingency?) | G | G | G | G | A | A | R | R | G | G | G | G | G | A | G | G | G |
| Does the technology have similar site and planning risks to the present? | G | G | G | R | A | A | A | A | A | A | A | R | R | G | G | G | G |
| Is there evidence of examples of problems and risks experienced in similar schemes in the past, or extrapolations drawn from pilot schemes? | G | G | G | G | A | A | A | A | G | G | G | G | G | A | G | G | G |
| Are there examples of other local authorities utilising the technology? | G | G | G | G | G | G | R | R | A | A | A | G | G | G | G | G | G |
| Is the typical site area (ha) building footprint and building height similar to the present technology? | A | A | A | G | G | G | G | G | G | G | G | R | A | G | G | G | G |
| Is the expected lifetime of facility (years) similar to the present technology? | A | A | A | G | A | A | A | A | A | A | A | A | A | A | G | G | G |
| Is the technology vulnerable to policy or legislative change? | R | R | R | G | G | G | G | G | A | G | G | G | G | G | G | G | G |
| What has been the technology's track record in public acceptability? | G | G | G | G | G | G | R | R | G | G | G | G | G | G | G | G | G |
| **Community impacts** | | | | | | | | | | | | | | | | | |
| Are actual impacts associated with traffic similar to the present technology? | G | G | G | G | A | A | G | G | G | G | G | A | A | R | G | G | G |
| Are actual impacts associated with noise similar to the present technology? | G | G | G | G | G | G | G | G | G | A | A | A | A | A | G | G | G |
| Are actual impacts associated with odour similar to the present technology? | G | G | G | G | G | G | G | G | G | G | G | A | A | A | G | G | G |
| Are actual impacts associated with dust similar to the present technology? | G | G | G | G | G | G | G | G | G | G | G | A | A | G | G | G | G |
| Are local and regional air pollution impacts similar to the present technology? | A | A | A | A | A | A | G | G | G | G | G | A | A | A | G | G | G |
| Is the visual impact similar to the present technology? | G | G | G | G | G | G | G | G | G | G | G | A | R | G | G | G | G |
| Are the health impacts similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | A | G | G | G | G |
| Are the jobs created and skills requirements similar to the present technology? | G | G | G | A | A | A | A | A | A | G | G | G | A | A | A | G | A |
| Will the technology have the potential to provide community incentives, i.e., local services, subsidised energy bills, community heating? | R | R | R | R | A | A | A | A | A | R | R | R | G | G | A | G | G |
| Will the technology particularly benefit citizens from deprived areas? | R | R | R | A | R | R | R | R | R | R | R | R | A | A | A | G | R |
| Will the technology support third sector organisations? | R | R | R | R | A | A | A | A | A | R | R | R | A | A | A | G | A |
| Will the technology contribute to behaviour change, e.g. engage with citizens/schools? | A | A | A | A | A | A | A | A | R | R | R | R | A | G | A | A | G |
| Will the technology support/ contribute to the local supply chain? | G | G | G | R | A | A | A | A | A | G | G | A | A | G | G | G | R |
| **Operations** | | | | | | | | | | | | | | | | | |
| Are the implications for waste collection the same as at present? | R | R | R | R | R | R | R | R | G | G | G | G | A | R | R | A | R |
| Does the option fit within current and future European, UK, English, regional & local policy? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the option move waste up the waste hierarchy compared to the present treatment method? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the option have a similar number of vehicle movements to the new technology? | G | G | G | G | A | A | A | A | A | G | G | G | A | R | A | G | R |
| Is the technology flexible to accept municipal, commercial & industrial and other waste streams? | G | G | G | G | A | A | A | A | R | R | R | A | G | G | G | R | R |
| Is the technology flexible to accept changing waste composition and policies? | G | G | G | A | A | A | A | A | R | R | R | A | A | R | R | A | A |
| Can the technology be developed using existing sites/ current locations? | A | A | A | R | A | A | A | A | A | A | A | A | G | A | A | A | G |
| Does this technology complement current technology (as this is decommissioned/ phased out/ comes to the end of its life? | G | G | G | G | G | G | G | G | R | A | A | G | A | G | G | G | G |
| **Carbon reduction and environmental** | | | | | | | | | | | | | | | | | |
| Does it offer a reduction in life cycle carbon impacts in comparison to the present technology? | G | G | G | G | G | G | G | G | A | G | G | G | G | G | G | G | G |
| Does it offer more opportunities for outputs to be utilised as a resource by current or emerging industries (e.g. bio refining, chemicals manufacturing) than the present technology | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Does it offer links to transport technologies (e.g. provision of transport biofuels)? | A | A | A | R | G | G | R | R | R | R | R | R | G | R | R | R | R |
| Can the technology provide combined heat and power (CHP), heating or cooling? | R | R | R | R | R | R | R | R | R | R | R | R | A | R | R | R | R |
| Can the technology provide opportunities for community energy schemes? | R | R | R | R | R | R | R | R | R | R | R | R | A | R | R | R | R |

| | | | | | Thermal (Combustion) | | | Advanced Thermal Treatment | | | | | | | Product conversion | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Evaluation Criteria | Cigarette was | Dog waste dig | Dog waste wo | Carton recycl | Moving grate | Rotary kiln | Fluidised bed | Rodecs Pyroly | Pyrolysis | Flash pyrolysi | Gasification | Plasma gasific | Thermal depo | Hydrotherma | Thermal-Cata | Waste to bio |
| **Costs** | | | | | | | | | | | | | | | | |
| Does the technology provide potential cost savings in terms of avoiding disposal costs, including exposure to taxation? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the technology provide potential cost savings in terms of avoiding natural gas use or electricity? | R | R | R | R | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the technology provide potential cost savings in terms of avoiding transport and haulage where particular waste streams can be treated on-site or closer to the point of gene | A | G | A | G | A | A | A | A | A | A | A | A | A | A | G | A |
| Does the technology offer potential revenue from fiscal measures and incentives for heat and/or power? | R | R | R | R | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the technology offer potential revenue from sale of outputs? | A | R | R | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Are the capital costs (purchase costs of technology and associated infrastructure) less than expanding the present services? | G | G | G | A | R | R | R | R | R | R | R | R | A | A | A | A |
| Are the operational costs likely to be less than the baseline? | G | G | G | A | A | A | A | R | R | R | R | R | A | A | A | A |
| Does the technology present a funding opportunity through the attraction of inward investment? | R | R | R | G | G | G | G | G | G | G | G | G | G | G | G | G |
| **Risks** | | | | | | | | | | | | | | | | |
| Does the technology have a demonstrable track record of delivery? | R | A | A | G | G | G | G | A | A | A | A | A | R | R | A | A |
| Is the feedstock waste required for this technology (composition/ quantity) available? | G | G | G | G | G | G | G | G | G | G | G | G | A | A | R | G |
| Does the technology offer similar operational risks to the present technology (for example availability, contingency?) | G | G | G | G | G | G | G | R | R | R | A | A | A | A | A | A |
| Does the technology have similar site and planning risks to the present? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | A | A |
| Is there evidence of examples of problems and risks experienced in similar schemes in the past, or extrapolations drawn from pilot schemes? | A | A | A | G | G | G | G | R | R | R | R | R | R | A | A | R |
| Are there examples of other local authorities utilising the technology? | R | A | A | G | G | G | G | R | R | R | G | A | R | R | A | A |
| Is the typical site area (ha) building footprint and building height similar to the present technology? | G | G | G | G | A | A | A | G | G | G | G | G | G | G | G | G |
| Is the expected lifetime of facility (years) similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | A | A | A | A |
| Is the technology vulnerable to policy or legislative change? | G | G | G | A | A | A | A | A | A | A | A | A | A | A | A | A |
| What has been the technology's track record in public acceptability? | A | A | A | G | R | R | R | A | A | A | A | A | A | A | A | A |
| **Community impacts** | | | | | | | | | | | | | | | | |
| Are actual impacts associated with traffic similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | A | A | A | A |
| Are actual impacts associated with noise similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | A | A | A | A |
| Are actual impacts associated with odour similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | A | A |
| Are actual impacts associated with dust similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | A | A |
| Are local and regional air pollution impacts similar to the present technology? | G | G | G | G | A | A | A | G | G | G | G | G | G | G | G | G |
| Is the visual impact similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | G | A |
| Are the health impacts similar to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | A | A |
| Are the jobs created and skills requirements similar to the present technology? | A | A | A | G | G | G | G | A | A | A | A | A | A | A | A | A |
| Will the technology have the potential to provide community incentives, i.e., local services, subsidised energy bills, community heating? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Will the technology particularly benefit citizens from deprived areas? | R | R | R | R | A | A | A | A | A | A | A | A | A | G | G | A |
| Will the technology support third sector organisations? | A | A | A | A | R | R | R | R | R | R | R | R | R | R | R | R |
| Will the technology contribute to behaviour change, e.g. engage with citizens/schools? | G | G | G | G | R | R | R | R | R | R | R | R | R | R | R | R |
| Will the technology support/ contribute to the local supply chain? | A | A | A | G | A | A | A | A | A | A | A | A | A | G | G | A |
| **Operations** | | | | | | | | | | | | | | | | |
| Are the implications for waste collection the same as at present? | R | R | R | R | G | G | G | A | A | A | A | A | R | R | R | A |
| Does the option fit within current and future European, UK, English, regional & local policy? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Does the option move waste up the waste hierarchy compared to the present treatment method? | G | G | G | G | A | A | A | A | A | A | A | A | G | A | A | A |
| Does the option have a similar number of vehicle movements to the new technology? | R | R | G | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Is the technology flexible to accept municipal, commercial & industrial and other waste streams? | R | R | R | R | G | G | G | G | G | G | G | G | G | G | G | G |
| Is the technology flexible to accept changing waste composition and policies? | A | R | R | A | G | G | G | R | R | R | R | A | R | A | R | R |
| Can the technology be developed using existing sites/ current locations? | G | G | G | A | G | G | G | G | G | G | G | G | G | G | G | G |
| Does this technology complement current technology (as this is decommissioned/ phased out/ comes to the end of its life? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| **Carbon reduction and environmental** | | | | | | | | | | | | | | | | |
| Does it offer a reduction in life cycle carbon impacts in comparison to the present technology? | G | G | G | G | A | A | A | A | A | A | A | A | G | G | G | G |
| Does it offer more opportunities for outputs to be utilised as a resource by current or emerging industries (e.g. bio refining, chemicals manufacturing) than the present technology | G | G | G | G | A | A | A | G | G | G | G | G | G | G | G | G |
| Does it offer links to transport technologies (e.g. provision of transport biofuels)? | R | R | R | R | R | R | R | G | G | G | G | R | G | G | G | G |
| Can the technology provide combined heat and power (CHP), heating or cooling? | R | R | R | R | G | G | G | A | A | A | G | A | R | G | G | G |
| Can the technology provide opportunities for community energy schemes? | R | R | R | R | G | G | G | A | A | A | G | R | R | G | G | A |

| | Energy recovery (thermal) | | | | | Energy distribution | | | | Biological | | | | | | | Energy Recovery (biological) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Evaluation Criteria | Boilers | Turbine and g | Heat pump | Flue gas cond | Cooling | Private Wire | District Heati | High grade he | District Cooli | Open windrow | IVC | Dry AD | Wet AD | Small scale AD | Advanced AD | MBT | Gas to grid | Gas to vehicle fuel |
| **Costs** | | | | | | | | | | | | | | | | | | |
| Does the technology provide potential cost savings in terms of avoiding disposal costs, including exposure to taxation? | A | A | A | A | A | A | A | A | A | G | A | G | G | G | G | G | G | G |
| Does the technology provide potential cost savings in terms of avoiding natural gas use or electricity? | G | G | G | G | G | G | G | G | G | R | R | G | G | G | G | A | G | G |
| Does the technology provide potential cost savings in terms of avoiding transport and haulage where particular waste streams can be treated on-site or closer to the point of gene | A | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | G | G |
| Does the technology offer potential revenue from fiscal measures and incentives for heat and/or power? | G | G | G | G | G | G | G | G | G | A | R | G | G | G | G | G | G | G |
| Does the technology offer potential revenue from sale of outputs? | A | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | G | R |
| Are the capital costs (purchase costs of technology and associated infrastructure) less than expanding the present services? | A | A | R | A | R | R | R | R | R | A | R | R | R | R | R | R | A | A |
| Are the operational costs likely to be less than the baseline? | A | A | A | A | R | R | R | R | R | A | R | R | R | R | R | R | A | A |
| Does the technology present a funding opportunity through the attraction of inward investment? | G | G | G | G | G | G | G | G | G | A | G | G | G | G | G | G | G | G |
| **Risks** | | | | | | | | | | | | | | | | | | |
| Does the technology have a demonstrable track record of delivery? | G | G | A | G | G | G | G | G | G | G | G | G | G | A | A | G | G | G |
| Is the feedstock waste required for this technology (composition/ quantity) available? | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | G | A | A |
| Does the technology offer similar operational risks to the present technology (for example availability, contingency?) | A | A | A | A | R | R | R | R | R | G | G | G | G | G | A | A | G | G |
| Does the technology have similar site and planning risks to the present? | A | A | A | A | R | R | R | R | R | G | G | G | G | G | A | G | G | G |
| Is there evidence of examples of problems and risks experienced in similar schemes in the past, or extrapolations drawn from pilot schemes? | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| Are there examples of other local authorities utilising the technology? | G | G | A | G | A | G | G | G | A | G | G | G | G | A | G | G | G | G |
| Is the typical site area (ha) building footprint and building height similar to the present technology? | A | A | A | A | R | R | R | R | R | A | A | R | R | G | A | R | A | A |
| Is the expected lifetime of facility (years) similar to the present technology? | A | A | A | A | G | G | G | G | G | A | A | A | A | G | A | A | A | A |
| Is the technology vulnerable to policy or legislative change? | A | A | A | A | A | A | A | A | A | G | G | G | G | G | A | A | A | A |
| What has been the technology's track record in public acceptability? | A | A | A | A | A | A | G | A | A | G | G | G | G | G | G | G | G | G |
| **Community impacts** | | | | | | | | | | | | | | | | | | |
| Are actual impacts associated with traffic similar to the present technology? | A | A | G | G | G | G | G | G | G | A | R | R | R | R | R | R | A | A |
| Are actual impacts associated with noise similar to the present technology? | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Are actual impacts associated with odour similar to the present technology? | A | A | A | A | A | A | A | A | A | A | R | R | R | R | R | R | R | R |
| Are actual impacts associated with dust similar to the present technology? | A | A | A | A | A | A | A | A | A | A | R | A | A | A | A | A | A | A |
| Are local and regional air pollution impacts similar to the present technology? | A | A | A | A | A | A | A | A | A | A | R | A | A | A | A | A | A | A |
| Is the visual impact similar to the present technology? | A | A | A | A | A | A | A | A | A | A | R | R | R | R | R | R | A | A |
| Are the health impacts similar to the present technology? | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Are the jobs created and skills requirements similar to the present technology? | A | A | A | A | G | G | G | G | G | A | G | G | G | G | G | G | G | G |
| Will the technology have the potential to provide community incentives, i.e., local services, subsidised energy bills, community heating? | G | G | G | G | G | G | G | G | G | A | G | G | G | G | G | A | G | G |
| Will the technology particularly benefit citizens from deprived areas? | A | A | A | A | G | G | G | A | G | A | A | A | A | G | A | A | G | G |
| Will the technology support third sector organisations? | A | A | A | A | A | A | A | A | A | A | A | A | A | G | R | A | R | R |
| Will the technology contribute to behaviour change, e.g. engage with citizens/schools? | A | A | A | A | A | A | A | A | A | A | A | A | A | G | R | A | A | A |
| Will the technology support/ contribute to the local supply chain? | A | A | A | A | G | G | G | G | G | A | G | G | G | G | G | G | A | A |
| **Operations** | | | | | | | | | | | | | | | | | | |
| Are the implications for waste collection the same as at present? | A | A | A | A | A | A | A | A | A | A | R | R | R | R | R | R | R | R |
| Does the option fit within current and future European, UK, English, regional & local policy? | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | A | G | G |
| Does the option move waste up the waste hierarchy compared to the present treatment method? | A | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | G | G |
| Does the option have a similar number of vehicle movements to the new technology? | A | A | A | A | A | A | A | A | A | A | R | R | R | G | A | R | A | A |
| Is the technology flexible to accept municipal, commercial & industrial and other waste streams? | A | A | A | A | A | A | A | A | A | A | G | G | G | G | A | G | G | G |
| Is the technology flexible to accept changing waste composition and policies? | A | A | A | A | A | A | A | A | A | A | A | R | R | R | A | A | G | G |
| Can the technology be developed using existing sites/ current locations? | G | G | G | G | R | R | R | R | R | A | G | A | A | A | G | A | G | G |
| Does this technology complement current technology (as this is decommissioned/ phased out/ comes to the end of its life? | A | A | A | A | R | R | R | R | R | A | G | G | G | G | G | G | G | G |
| **Carbon reduction and environmental** | | | | | | | | | | | | | | | | | | |
| Does it offer a reduction in life cycle carbon impacts in comparison to the present technology? | A | A | G | G | G | G | G | G | G | A | G | G | G | G | G | G | G | G |
| Does it offer more opportunities for outputs to be utilised as a resource by current or emerging industries (e.g. bio refining, chemicals manufacturing) than the present technology | A | A | A | A | A | A | A | A | A | A | G | G | G | G | G | G | G | G |
| Does it offer links to transport technologies (e.g. provision of transport biofuels)? | R | R | R | R | R | R | R | R | R | R | R | G | G | A | G | G | G | G |
| Can the technology provide combined heat and power (CHP), heating or cooling? | G | G | G | G | G | G | G | G | G | R | R | G | G | A | G | G | G | G |
| Can the technology provide opportunities for community energy schemes? | A | A | A | A | G | G | G | G | G | R | R | G | G | G | G | G | G | R |