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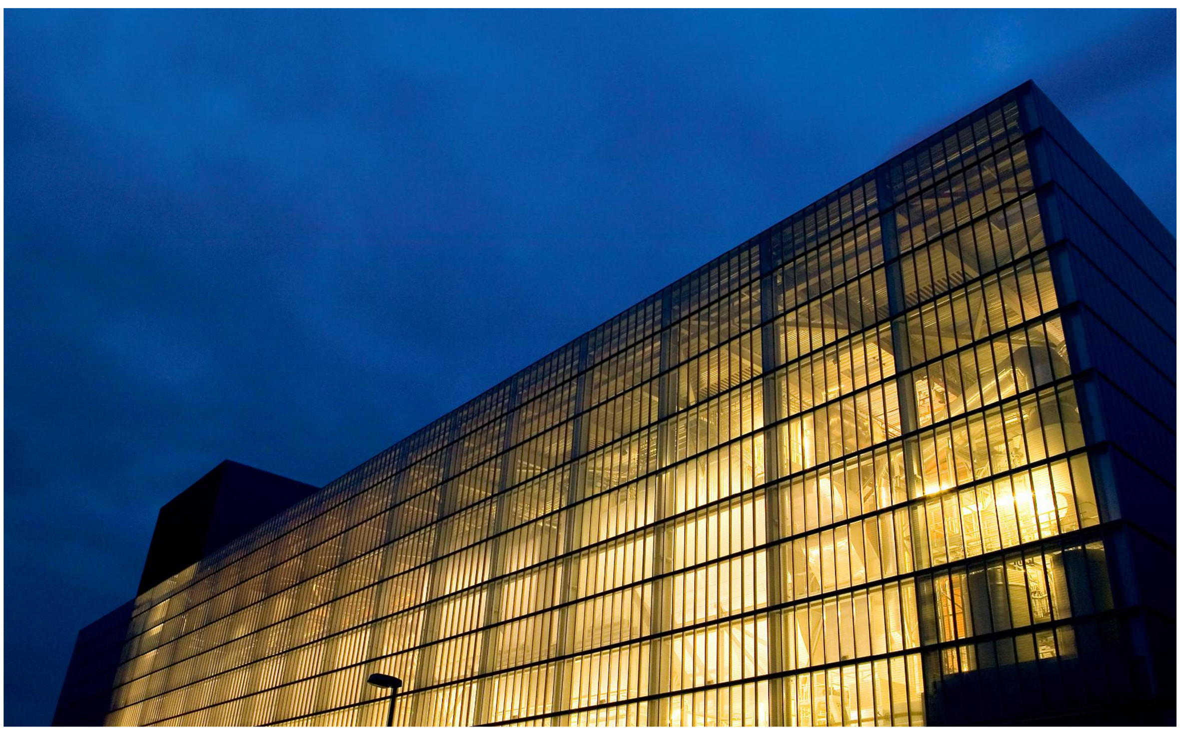
WASTE TREATMENT OPTIONS ASSESSMENT



WASTE TREATMENT OPTIONS ASSESSMENT

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0. EXECUTIVE SUMMARY

Gibraltar is committed to waste handling in compliance with EU regulation and the Government of Gibraltar has instructed Ramboll to carry out a high level assessment of available waste management and disposal options.

In the EU the municipal waste is regulated principally by the Waste Directive (2008/98/EC) and the Landfill Directive (1999/31/EC). The EU Waste Directives promote high quality recycling. For 2015 the aim is 'separate collection of paper, metal, plastic and glass – where technically, environmentally and economically practicable'. By 2020 the member states are expected to have taken the necessary steps to achieve a recycling target of 50%.

The EU Landfill Directive states that the maximum amount of biodegradable waste that shall be sent to landfill in 2016 is 35% of the amount produced in 1995. This means that at least 65% of the biodegradable municipal waste is to be treated through composting, anaerobic digestion or thermal treatment.

Therefore, Gibraltar faces a number of challenges with regard to the future handling of municipal waste – especially due to the limited available footprint for a waste treatment facility and the limited space at households for source collection of individual waste fractions. The main challenges of waste collection and treatment for Gibraltar are illustrated in figure 1.

Figure 1 – Challenges for Waste Management in Gibraltar

A broad range of potential waste treatment technologies has been screened, those that meet the requirements of a minimum of three reference facilities treating similar waste and of similar scale as that required for Gibraltar are then evaluated further. This approach ensures that only well-proven and reliable technologies are carried on to the next stage.

Screening of technologies
Dry recyclables (glass, metal, paper and plastics) can be recovered from unsorted or sorted MSW via Material Recovery Facilities (MRF). The equipment at MRFs is dependent on the required level of automation or the overall output requirements. Overall, these types of facilities pass the criteria.

The separated organic fraction of waste can be treated in either an in-vessel composting facility or an anaerobic digester for biogas production. However, it is noted that the capacity of an anaerobic digestion facility for Gibraltar will be around ten times lower than the minimum capacity for a facility considered as commercially viable in Europe. It is possible that co-digestion - with the sewage sludge generated within Gibraltar - will improve the financial viability of this option.

Only one of the four thermal treatment methods evaluated – grate fired thermal treatment - met the pass-fail criteria where a significant number of facility lines have been successfully installed and operated in Europe. A number of reference plants, of similar capacity and waste type as Gibraltar, have been operating successfully for more than 5 years. These facilities can treat municipal waste without any pre-treatment. This technology can also treat sewage sludge – subject to certain parameters.

Thermal gasification plants for municipal waste are operating in Asia – mainly Japan. In Europe a number of plants have been shut down due to poor performance. Historically, the main driver in Japan has been a requirement within the environmental permits for vitrified bottom ash. Vitrified bottom ash is produced from thermal gasification plants because the bottom ash is subjected to higher temperature compared to grate fired thermal treatment. The energy efficiency for thermal gasification is much lower than grate fired technology and the majority of new thermal treatment plants in Japan now seem to be based on grate fired technology.

Biodiesel production from municipal waste has never been implemented on a commercial scale. Ramboll is not aware of any successful pilot scale projects using municipal waste. Therefore, it did not pass the screening criteria.

Summary of the technology evaluation is found in Appendix A, which is found after this 'Executive Summary'.

A summary of findings within the technology screening:

- The following treatment technologies passed the screening process:
  - In-vessel composting
  - Anaerobic digestion
  - Grate fired thermal treatment

- Biodiesel production from municipal waste has not been proven on a commercial scale.

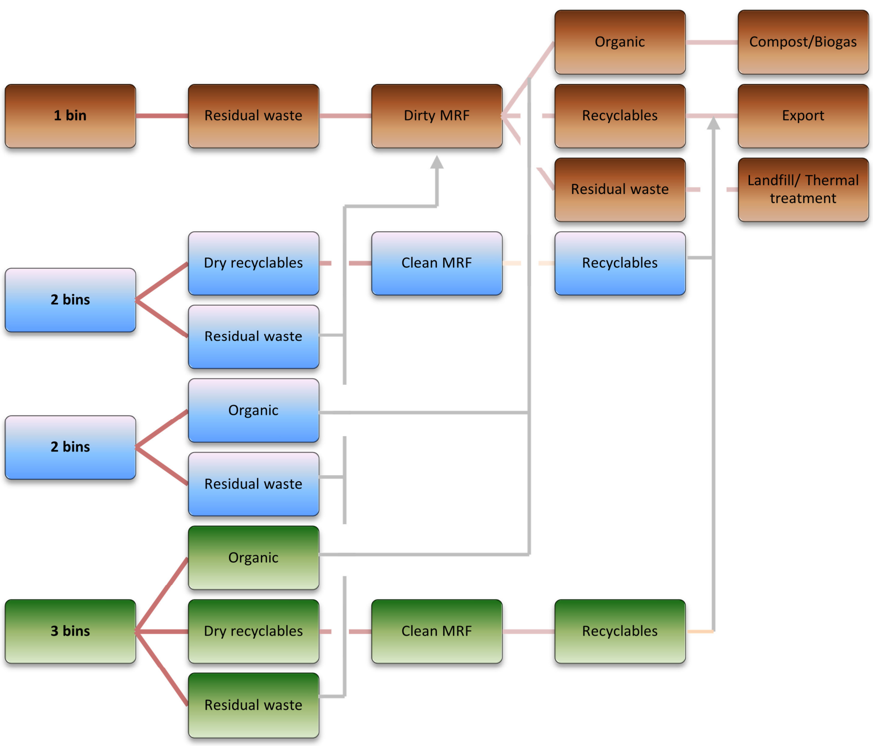
<u>Evaluation of scenarios</u>

Technologies that passed the screening process were evaluated under a number of waste management scenarios. Different levels of household source separation were included in the waste management scenarios to evaluate the impact on the scenario performance (such as quality and quantity of recyclables and organic material) by collection of source separated dry recyclables or organic waste.

A total of 16 waste management scenarios were established based on combinations of collection systems and treatment technologies.

The scenario development is illustrated in figure 2. The figure shows how the mixed waste from a '1 bin' system can be sorted into different waste types. The separate collection of organic waste and/or dry recyclables at the household gives waste fractions with less cross-contamination from other waste streams. The remaining residual waste can be further sorted at a materials recovery facility for mixed waste (dirty MRF).

Figure 2 – Concept for Development of Waste Management Scenarios



Conclusions

A broad range of waste management scenarios utilizing proven technology have been assessed.

The EU regulation on recycling targets and ban on untreated organic waste sent to landfills presents a significant challenge for Gibraltar and a further iteration of waste management scenarios will be required to obtain the best fit.

Therefore, it is recommended to continue work with two of the scenarios developed in this project:

- One scenario that fulfils the EU requirements with regard to the collection system and recycling level, treatment of the organic fraction and landfills the remaining residual waste (Scenario 4)
- One scenario that includes source collection of dry recyclables and recovers energy from the residual waste (Scenario 7).

It is proposed that the next phase will focus on further developing the feasibility of the two scenarios. This may include:

- Feasibility study
- Energy sale study
- Available area for waste treatment facilities on Gibraltar
- Environmental assessment
- Combining sewage sludge treatment with MSW treatment.

Appendix A – Overview of the Evaluated Technologies (Technology Screening Process)

Technology	Waste treated	Advantages	Disadvantages	Pass/fall criteria	Comments
Sorting system					
Material recovery facility (dirty)	Mixed waste	- No requirement of source separation at households	- Lower quality of recyclables (compared to source separated recyclables) - Non-source separated organic material may be contaminated with a relatively high content of other waste types. This may cause process problems and produce compost of lower quality	✓	Many variants of technical concepts. The concepts vary from semi-automatic systems to a more manual approach based on hand pickers
Material Recovery facility (Clean)	Source separated recyclables	- High quality of recyclables	- Requires an additional bin for recyclables	✓	As above
Organic treatment					
Open air windrows	Organic waste	- Technically simple process - Nutrients are recycled if compost is used for beneficial purpose	- Only suitable for garden waste. Kitchen waste is to be treated in accordance with the EU Animal By-product regulation. The directive specifies a minimum treatment temperature for given amount of time. This can't be guaranteed for open windrows.	(✓)	Many facilities are operating in Europe with good experience
In-vessel composting	Organic waste	- All types of organic waste are acceptable - Nutrients are recycled if compost is used beneficially	- No energy is recovered from the waste	✓	Many facilities are operating in Europe with good experience
Anaerobic digestion	Organic waste (option to include sewage sludge)	- Energy production - Nutrients are recycled if digestate is used beneficially	- Technical complexity	✓	Many facilities are operating in Europe with good experience. The minimum capacity of commercial viable EU facilities is typical minimum 40,000 tpa. For comparison the organic fraction is only around 4,000 tpa for Gibraltar.
Autoclave facility	Organic waste	- The heating process makes it easier to remove plastic and metal objects from the organic fraction before further treatment	- High energy consumption to heat the waste to around 130 °C - Limited number of operational plants - Reference plants have much larger capacity compared to the requirements for Gibraltar	✗	The original idea of the autoclave facilities was to produce 'fibres' from the organic waste. These fibres were to be used for production of MDF wood. This idea has been now been abandoned and the process now serves are pre-treatment before the final organic treatment process.
Thermal treatment					
Grate fired technology	All residual waste (option to include some sewage sludge and other waste)	- High level of energy recovery - No pre-treatment of municipal waste is required	- Bottom ash to be disposed on landfill or alternatively recycled, if possible - Flue gas treatment residue to be disposed at hazardous landfill - Impact from clean emissions of stack to be assessed further due to the relatively close proximity of buildings	✓	By far the most common thermal treatment method in Europe. The concept is well-proven and robust. In Europe bottom ash is classified as non-hazardous waste. Some countries recycle the bottom ash - after metal removal, maturation and crushing – as base material in road construction.
Fluidised bed	All residual waste (option to include some sewage sludge and other waste)	- The boiler system can potentially by designed with higher temperature/ pressure compared to grate fired facilities	- Pre-treatment for size reduction of waste and removal of metals - The high velocity of fluidisation air will significantly increase the ratio between the fly ash fraction and the bottom ash fraction. This will increase operational costs as fly ash is classified as hazardous waste whereas bottom ash is non-hazardous waste.	✗	Most plants in Europe are based on a RDF feedstock (mainly paper and plastic derived from waste). Few are combusting solely municipal waste. In practise similar steam parameters are chosen for fluidized bed as for grate fired technology.
Thermal gasification	All residual waste (option to include some sewage sludge and other waste)	- Production of a syngas for use in a gas engine with high electrical efficiency - Vitrification (melting) of the bottom ash may reduce potential leaching of metals - Reduce concentration of NOx, HCl and SO_2 in raw flue gas (However, grate fired technology and thermal gasification have similar low level of pollutants after the flue gas treatment of the respective systems)	- Significant pre-treatment of the waste may be required - Less energy efficient compared to grate fired technology due to the very high temperature required to melt the inert fraction of the waste	✗	Thermal gasification is mainly used in Japan as vitrification of the bottom ash may be a requirement in the environmental permit. No European based service organisation as operating plants are located in Asia, mainly Japan.
Plasma technology	All residual waste	- Vitrification of residues	- Very high electrical consumption for the electrical arch used to heat the combustion air to several thousand degrees Celsius.	✗	Performance data of pilot plants does doesn't appear public available
Biodiesel production	All residual waste	- Biodiesel can be stored	- High energy loss within the conversion process into a diesel product	✗	No commercial plants have been established to treat municipal waste

✓ = Fulfilled, ✗ = Not fulfilled and (✓) = Fulfilled under conditions.

Appendix B – Overview of the Scenario Performance

Scenario number	Scenario description	Number of bins	Recycling level (estimate)	Energy production (GJ /year)	Advantages	Risks	EU legislation			
							Collection systems	Recycling level	Renewable energy	Limited organic material to landfill
Scenarios based on- Export of waste after limited handled in Gibraltar										
0	Export of waste	One bin (Mixed waste)	(0%)	0	- Simple collection system (as today)	- Reliance of third party for offtake of mixed waste - Difficult to monitor whether the waste is treated in accordance with agreement	✘	✘	✘	(✓)
9	'Solid fuel production' of residual waste for export	One bin (Mixed waste)	3%	0	- Limited pre-treatment in Gibraltar	- Reliance of third party for offtake of 'fuel' - It may be difficult to negotiate an attractive contract due to limited potential off-takers - Significant footprint of waste drying facility	✘	✘	✘	✓
Scenarios based on – Disposal of residual waste on landfill after various levels recycling and/or treatment of organic fraction										
1A/B	Sorting of residual waste into recyclables, organic fraction (to compost or biogas) and a remaining fraction (to landfill)	One bin (Mixed waste)	34%	≈ 5,000 (Scenario B - biogas)	- Simple collection system (as today)	- Lower recovery rate of recyclables from mixed waste - Lower quality recyclables may have limited off-takers - Lower quality of compost/digestate from non-source separated organic waste *General comments for all scenarios that landfill residual waste (Scenario 0-4):* - *Residual waste may have to be treated - prior to disposal at landfill - in order to stabilize the organic content. This is due to EU regulations.* *General comments for all 'B' scenarios:* - *Biogas plant is technically complex* - *Small scale plant will have relatively high 'gate fee'* - *Produced electricity will be used as own consumption for the plant. Only limited export of electricity.* - *Potential of co-treatment with sewage sludge*	✘	✘	✘	(✓)
2A/B	Dry recyclables collected separately. Sorting the remaining waste into an organic (to compost or biogas) and a residual fraction.	Two bins (Recyclables + residual waste)	43%	≈ 4,000 (Scenario B - biogas)	- High recycling efficiency - Good quality recyclables from source separated material	- Lower quality of compost/digestate from non-source separated organic waste - Large footprint of facilities	✓	(✓)	✘	(✓)
3A/B	Organic waste collected separately. The remaining waste is split into recyclables, organic (to compost or biogas) and a residual fraction.	Two bins (Organic waste + residual waste)	46%	≈ 8,000 (Scenario B - biogas)	- High overall recycling efficiency (however, limited recycling rate of paper plastic, glass ad metals) - Good quality of compost/digestate	- Lower recovery rate of recyclables from mixed waste - Lower quality recyclables may have limited off-takers - Large footprint of facilities	✘	✓	✘	(✓)
4A/B	Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic (to compost or biogas) and a residual fraction.	Three bins (Recyclables + organic waste + residual waste)	63%	≈ 7,000 (Scenario B - biogas)	- High recycling efficiency - Good quality recyclables - Good quality of compost/digestate	- Challenges with physical constraints of collection system and whether public engages in the project	✓	✓	✘	(✓)
Scenarios based on – Thermal treatment of residual waste after various levels of recycling and/or treatment of organic fraction										
5	All residual waste treated by thermal treatment	One bin (Mixed waste)	3%	≈ 190,000 (steam)	- Simple collection system (as today) - Maximum energy recovery - Certainty that available area is sufficient for plant - Limited human contact with waste	- Bottom ash and fly gas treatment residue to landfill - Not in line with EU's recycling aim	✘	✘	✓	✓
6A/B	Residual waste is split into recyclables, organic fraction (to compost or biogas) and a remaining fraction for thermal treatment.	One bin (Mixed waste)	31%	≈140,000 (steam) ≈ 5,000 (Scenario B - biogas)	- Simple collection system (as today) - High level of energy recovery	- Lower recovery rate of recyclables from mixed waste - Lower quality recyclables may have limited off-takers - Lower quality of compost/digestate from non-source separated organic waste - Overall treatment cost will be higher per tonnes compared to Scenario 5	✘	✘	✓	✓
7	Dry recyclables collected at household. Remaining fraction for thermal treatment.	Two bins (Recyclables + residual waste)	32%	≈ 120,000 (steam) ≈ 5,000 (Scenario B - biogas)	- Medium recycling efficiency - Good quality recyclables - Medium level of energy recovery	- Removal of plastic and paper from the waste stream will lower the calorific value of the waste - Lower capacity of the incineration facility increase treatment cost per tonne waste	✓	✘	✓	✓
8A/B	Organic waste collected at household (to compost or biogas). Remaining residual waste for thermal treatment.	Two bins (Organic waste + residual waste)	17%	≈180,000 (steam) ≈ 5,000 (Scenario B - biogas)	- High level of energy recovery - Good quality of compost/digestate	- Overall treatment cost will be higher per tonnes compared to Scenario 5	✘	✘	✓	✓

✓ = Fulfilled, ✘ = Not fulfilled and (✓) = Fulfilled under conditions.

1. INTRODUCTION

The implications of EU Directive 2008/98/EC on Waste include the need to achieve a significant increase in recycling subject to certain factors. Gibraltar is committed to compliance with this Directive and its Government has contracted Ramboll to undertake a high level assessment of available waste management and disposal options.

Following a kick-off meeting held in May 2012, Ramboll was asked to look at a broad range of waste management and disposal options for Gibraltar. The review considered performance of these options against a number of agreed technical, environmental and commercial elements. This performance was benchmarked against waste type, quantity and government objectives. For each option Ramboll has indicated the type of waste collection system required, products and residues that arise. These are important factors in the overall selection.

A shortlist of options was agreed at a meeting with the Government of Gibraltar. The subsequent analysis and conclusions are also provided in this report.

2. BACKGROUND

The challenges faced in Gibraltar are similar to those faced on islands, and island-like locations, and mainly arise from the higher degree of self-sufficiency required for resource management. Therefore, it is recognised that there is a need to modernise current practice, with a particular focus upon the delivery of a sustainable waste management system. There are a broad range of waste technologies available. However, not all are compatible with the scale and other specific constraints in Gibraltar.

2.1 EU Directive on Waste

Of particular importance to Gibraltar is the need to improve the environmental performance of its waste management practice. This can be achieved, for example, by increasing the level of recycling to make it compliant with EU Directives.

Article 11 of Directive 2008/98/EC on Waste, regarding re-use and recycling, requires measures to promote high quality recycling derived from separate collections of waste where technically, environmentally and economically practical, to meet the necessary quality standards.

By 2015, separate collection of paper, metal, plastic and glass will be required. By 2020, recycling of such waste from households, and possibly other similar origins, shall increase to a minimum of 50% by weight.

The implications of the Directive include the need to:

- Undertake a fresh high level assessment of the possibilities that exist for Gibraltar in terms of refuse disposal, and
- Establish the potential parameters of waste treatment systems.

2.2 Waste in Gibraltar

The Department of the Environment is responsible for waste and it will ensure:

- compliance with all local and applicable EU Environmental Legislation,
- Creation of a self-sufficient and sustainable environmental management and monitoring strategy,
- increased public awareness of environmental issues,
- monitoring with a view to ensuring environmentally friendly behaviour and compliance with legislation from individuals as well as industry.

The strategy for waste management within Gibraltar has concentrated on the preference to handle and manage waste locally. Historically, this was realised through the operation of a municipal solid waste incinerator. However, following the closure of the facility in 2000, an alternative waste treatment and disposal system had to be put in place.

At present all of Gibraltar's municipal waste is sent to Sur Europa, a landfill site in Los Barrios, Spain. Sur Europa opened a new environmental park in 2003. This employs a range of manual and automated separation and sorting processes to recover paper, plastics and metals from the incoming waste stream, with the organic fraction being composted in a covered shed to provide a 'saleable' compost product. The residual waste is removed by separate conveyor to a baling plant, before being disposed of to a newly developed landfill adjacent to the facility.

The complete termination of current disposal arrangements may give rise to further challenges should any new system fail to operate as intended. Therefore, it is essential that the assessment properly describes the likely robustness and reliability that can be expected. It must also consider options to continue to utilise neighbouring facilities.

2.3 Recycling in Gibraltar

Sorting with the aim of recycling is carried out locally for a number of waste streams. For example, wood and metal, principally arising from commercial wastes, are sorted at the site of the previous incinerator at Michael Dobinson Way.

The Government also provides a separate Civic Amenity Site, presently at Buena Vista, which is operated by personnel from Gibraltar General Support Services. At this facility, households are able to dispose of their bulky timber items, white goods, electrical and electronic goods, mattresses and scrap metal. These materials are then treated or recycled at appropriate plants. Other items that are currently being collected for recycling include batteries, plastics, cans, tetra bricks, glass paper and cardboard.

3. WASTE ARISING IN GIBRALTAR

The total waste arising on Gibraltar can be divided into the following categories:

- Municipal waste from residents
    - Refuse (unsorted municipal waste)
    - Bulky waste (timber pallets, white goods, furniture etc.)
- Industrial waste
    - Paints, solvents, batteries, electrical equipment etc.
    - Medical waste
    - Bilge oils
    - Construction and demolition waste (hazardous)
- Construction and demolition waste (non-hazardous)

The annual tonnage of these waste streams is listed in Table 1. The flows are based on data published by the Government in its report 'The Environment Matters, Annual Report 2010'.

The annual generation of 18,111 tonnes corresponds to around 616kg per capita per year. The equivalent figure in the UK or France is around 525kg per capita per year[1]. The 'refuse' stream for Gibraltar includes waste generated by tourists, which may explain the comparatively high refuse production rate.

While this report focuses principally on the handling of the refuse fraction of municipal waste, the ability to treat other waste types is considered in the options assessment methodology.

Table 1 – Waste Flow Data for 2010

Municipal waste fractions	Annual tonnage (tonne/year)
Refuse	18,111
Bulky waste	10,579
Bilge oils	4,225
Other oil wastes	78
Construction and demolition waste (hazardous)	10,500
Construction and demolition waste (non-hazardous)	66,000

3.1 Refuse Waste Stream

A fairly accurate estimate of the refuse waste fraction composition is important, as it can significantly impact the evaluation of a given waste management scenario. High energy content may give a thermal treatment solution a relative advantage whereas high content of recyclable fractions in the waste may give a recyclable focused solution an advantage.

3.1.1 Composition

In 2006 a waste characterisation was carried out for Gibraltar. The survey results are modified to fit the type of waste fraction categories normally used in UK. This makes the waste composition more easily comparable with other waste surveys. The modified values are shown in Table 2.

A weighted average waste composition – based on the assumed fraction of the total waste arising in the different areas - is also shown in Table 2.

[1] http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-11-031/EN/KS-SF-11-031-EN.PDF

Table 2 – Data from the Gibraltar Waste Characterisation Survey, 2006

Fraction	Upper town (residental) %	Main street (commercial) %	Devil road tower %	Shipwaste %	Weighted average %
Paper	12.7	17.3	8.0	9.8	12.4
Cardboard	9.3	41.9	20.5	23.9	19.5
Plastic film	14.1	7.6	8.6	6.5	11.0
Dense plastic	8.1	9.1	7.9	9.7	8.4
Textiles	2.6	1.3	8.3	9.3	4.2
Wood	0	0	0	0	0
Disposable nappies	0	0	0	0	0
Glass	4.9	3.2	5.1	4.3	4.5
Organic kitchen waste	38.2	13.1	31.1	11.6	29.1
Garden waste	0	0	0	0	0
Ferrous metal	4.6	2.3	3.2	4.0	3.8
Non-ferrous metal	1.1	0.6	0.8	1.0	0.9
WEE	0	0	0	0	0
Other combustible	2.2	1.1	3.0	0,0	1.9
Other non-combustible	1.4	1.1	1.4	0,0	1.2
Special municipal waste	0.8	1.5	2.1	19.9	3.1
Weighting	50%	20%	20%	10%	

Comparison of the Gibraltar waste composition with a similar UK survey – in Table 3 - illustrates two notable differences:

- Total plastic content is 19.4% for Gibraltar compared to 10% for the UK.
- Garden and wood waste is 0% for Gibraltar compared to 17.8% (3.7% + 14.1%) for the UK.

The relatively high plastic content may be explained by the increased amount of packaging required for an 'island like' community.

A very low content of garden waste/ wood in the Gibraltar waste is expected from household refuse due to the limited footprint of the average private garden area on Gibraltar. Secondly, it is likely that the wood fraction for Gibraltar is included in the bulky waste fraction.

The relatively high content of plastics in the Gibraltar waste results in an increased energy content within the waste. The calorific value of the waste (MJ/kg) is calculated in Table 4 and compared to values for municipal waste in Europe in the text.

Table 3 – Composition of Municipal Waste in Gibraltar and in UK

Fraction	Gibraltar (weighted average) %	Typical UK Composition[2] %
Paper	12.4	16.7
Cardboard	19.5	6.0
Plastic film	11.0	(included in 'dense plastic')
Dense plastic	8.4	10.0
Textiles	4.2	2.8
Wood	0	3.7
Disposable nappies	0	2.5
Glass	4.5	6.6
Organic kitchen waste	29.1	19.5
Garden waste	0	14.1
Ferrous metal	3.8	4.3
Non-ferrous metal	0.9	(included in 'ferrous metal')
WEE	0	2
Other combustible	1.9	≈4.2
Other non-combustible	1.2	≈7.6
Special municipal waste	3.1	0

3.1.2 Mass Flow and Energy Content

The mass flow of each waste fraction is calculated in Table 4. The energy content of each waste fraction is included in Table 4 to illustrate which waste fractions embed the greatest energy. It shows that plastic fractions in the waste are responsible for around 50% of the overall energy content of the waste.

The average calorific value of the Gibraltar refuse is estimated at 13.0MJ/kg, which is a very high value for typical unsorted municipal waste. Similar calculation for the UK waste composition – as listed in Table 3 - gives a lower calorific value of 10.8MJ/kg. The typical range for refuse in the EU is around 9.5 – 11.5MJ/kg.

An Entec report - completed prior to the Gibraltar waste characterisation study in 2006 - estimated a lower calorific value between 6.5 and 11MJ/kg. A design value of 9MJ/kg was chosen.

It is recommended to conduct an additional waste survey at a later project stage in order to provide better data on waste composition.

[2] *http://www.defra.gov.uk/statistics/environment/waste/wrfg18-compostion/*

Table 4 – Mass of Waste Fractions and Energy Content of the Gibraltar Refuse

Waste fraction	Mass (tonne/year)	Specific calorific value (MJ/kg)	Energy content in specific fraction (% of total energy)
Paper	2,247	12.5	12%
Cardboard	3,536	11.1	17%
Plastic film	1,984	34	29%
Dense plastic	1,521	36.5	24%
Textiles	752	18.5	6%
Wood	0	17.2	
Disposable nappies	0	11.9	
Glass	822	0	
Organic kitchen waste	5,270	4.6	10%
Garden waste	0	8	
Ferrous metal	685	0	
Non-ferrous metal	171	0	
WEE	0	0	
Other combustible	346	22	3%
Other non-combustible	216	0	
Specific municipal waste	561	0	
Calorific value	**-**	**13.0**	-

4. DEVELOPMENT OF WASTE MANAGEMENT SCENARIOS

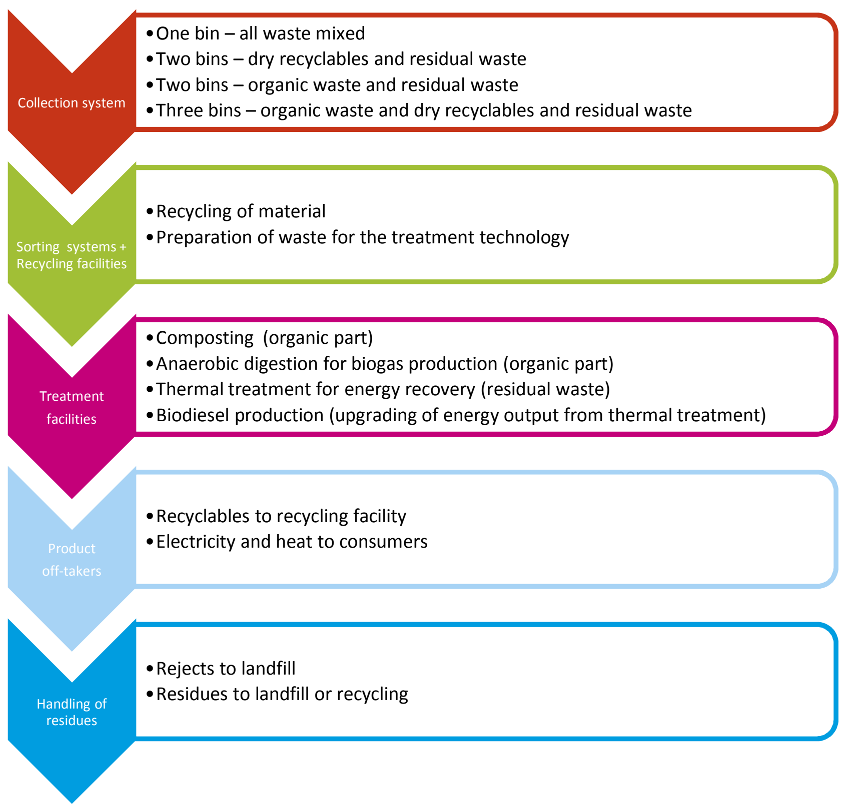
Municipal waste is a non-homogeneous material that contains a significant number of fractions such as; paper, cardboard, glass, different types of plastics, metals, organic wastes as well as various smaller fractions as listed in Table 2.

Municipal waste fractions can be grouped into three main categories with regard to choice and method of waste handling:

- Recyclable fraction (paper/cardboard, glass, plastics and metals)
- Organic fraction (kitchen, garden and wood waste)
- Residual fraction (remaining waste after pre-sorting)

Figure 3 illustrates the main steps to consider when configuring the technical concept for a waste management system.

Figure 3 – Steps in Design a Waste Management Systems



The total number of possible waste management scenarios is very high because the steps above can be combined in numerous ways.

An initial screening of the potential treatment technologies is performed to ensure that the selected waste management scenarios are based on proven technologies with a number of reference facilities.

5. WASTE MANAGEMENT SCENARIOS

The overall concept for the waste management scenarios were agreed at a meeting with the Government of Gibraltar. These are shown in Table 5 below. The scenarios are grouped into two main categories; one focuses on a landfill based concept and the other a thermal treatment concept. Both concepts also include a range of recycling and separate organic treatment options.

Table 5 – Waste Management Scenarios

		Main technology solution	Collection method
	0	Export of all residual waste (baseline)	A – One bin All waste mixed
Landfill of residual waste after recycling and/or pre-treatment	1A	Sorting of residual waste into recyclables, organic fraction (to compost) and a remaining fraction (to landfill).	A – One bin All waste mixed
	1B	Sorting of residual waste into recyclables, organic fraction (to biogas) and a remaining fraction (to landfill).	A – One bin All waste mixed
	2A	Dry recyclables collected separately. Sorting the remaining waste into an organic fraction (to compost) and a residual fraction (to landfill)	B - Two bins Dry recyclables + Residual waste
	2B	Dry recyclables collected separately. Sorting the remaining waste into an organic fraction (biogas) and a residual fraction (to landfill)	B - Two bins Dry recyclables + Residual waste
	3A	Organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)	C - Two bins Organic waste + Residual waste
	3B	Organic waste collected separately. The remaining waste is split into recyclables, organic fraction (biogas) and a residual fraction (to landfill)	C - Two bins Organic waste + Residual waste
	4A	Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)	D - Three bins Dry recyclables + Organic waste + Residual waste
	4B	Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic fraction (biogas) and a residual fraction (to landfill)	D - Three bins Dry recyclables + Organic waste + Residual waste
Thermal treatment	5	All residual waste treated by thermal treatment	A – One bin All waste mixed
	6A	Residual waste is split into recyclables, organic fraction (compost) and a remaining fraction for thermal treatment.	A – One bin All waste mixed
	6B	Residual waste is split into recyclables, organic fraction (biogas) and a remaining fraction for thermal treatment.	A – One bin All waste mixed
	7	Dry recyclables collected at household. Remaining fraction for thermal treatment.	B - Two bins Dry recyclables + Residual waste
	8A	Organic waste collected at household (compost). Remaining residual waste for thermal treatment.	C - Two bins Organic waste + Residual waste
	8B	Organic waste collected at household (biogas). Remaining residual waste for thermal treatment.	C - Two bins Organic waste + Residual waste
Fuel	9	Fuel production for export (Preparation of fuel by removal of metals and drying of remaining waste through aeration).	A – One bin All waste mixed

6. POTENTIAL WASTE TREATMENT TECHNOLOGIES

This chapter gives an overview of commercially available technologies – ranging from emerging technologies to well-proven technologies with numerous reference facilities.

The criteria to pass the screening process are defined in Chapter 7.

6.1 Collection System

The collection systems at Gibraltar are based on collection of waste bins and waste bags on streets by refuse compactor vehicles. All collected refuse is mixed.

Advanced collection solutions are unlikely to be attractive. For example, a central vacuum system is not attractive due to limited space and blocking risk.

The future collection system can therefore be assumed to be similar to the present operation except that the collection system may be based on a 2 or 3 bin system. The sorting efficiency achieved at household level will be dependent upon the uptake by, and continued engagement of, the public.

6.2 Sorting Systems and Recycling System

There are numerous commercial suppliers of sorting systems and various technical configurations for these sorting facilities.

This screening process will only evaluate the general sorting concept as the development of optimised designs is more relevant during later project stages.

Table 6 – List of Potential Sorting Systems

Sorting treatment facility
Material Recovery Facility (Dirty – for mixed municipal waste)
Material Recovery Facility (Clean – for presorted dry recyclables)

It is assumed that the recyclables produced are exported. The technologies for recycling of metals, glass, paper, cardboard and certain types of plastics are considered well-proven and will not be discussed further at this project stage.

Actual facilities that may recycle the material from Gibraltar are not identified and evaluated at this project stage.

6.3 Treatment Technology

The treatment technologies are divided into methods targeting the:

- Organic fraction
- Residual waste (thermal treatment).

6.3.1 Organic Treatment

The range of technologies to treat the organic fraction include concepts ranging from simple open-air windrows (where the main part of the bio-degradable material is converted to carbon dioxide, water and heat) to more advanced anaerobic processes where energy from the biologically degraded waste is transferred to the produced biogas (typically containing 50 to 60% methane).

There are a number of usages of the biogas, such as:

- Combustion in a boiler
- Combustion in a reciprocating engine for electricity and heat production
- Upgrading to a gas similar to natural gas.

However, the screening process only focuses on the technical concept for the anaerobic digestion process and the overall energy content in the produced biogas.

An autoclave facility takes the fine fraction from a dirty MRF facility, and heats it by 120-130°C steam for 1 to 2 hours. The result is a relatively homogeneous and 'sterile' biomass, as the structure of vegetables is broken down in the heating process. This biomass is refined by removal of remaining plastic/glass/metals etc before further processing of the organic fraction, such as composting or anaerobic digestion.

Table 7 – List of Potential Organic Treatment Facilities

Organic treatment facilities
Open air windrows
In-vessel composting or enclosed composting
Anaerobic digestion
Autoclave facility

6.3.2 Thermal Treatment

Numerous types of thermal technologies – or variants thereof – are currently being promoted. This screening process evaluates the technologies listed in Table 8.

Biodiesel production is referring to the upgrading process of the gas produced from the gasification process. It is therefore not an individual thermal treatment technology in itself. It is included because the combination of gasification and biodiesel production is promoted by a number of companies.

Table 8 – List of Potential Thermal Treatment Facilities

Thermal treatment facilities
Grate firing technology (typical WtE facility)
Fluidised bed technology
Thermal gasification
Plasma technology
Biodiesel production (upgrading of gas from gasification process)

6.4 Product Off-takers

At this stage it is assumed that there are off-takers for the products.

6.5 Handling of Residues

It is assumed the residues can be handled in Gibraltar or exported for disposal.

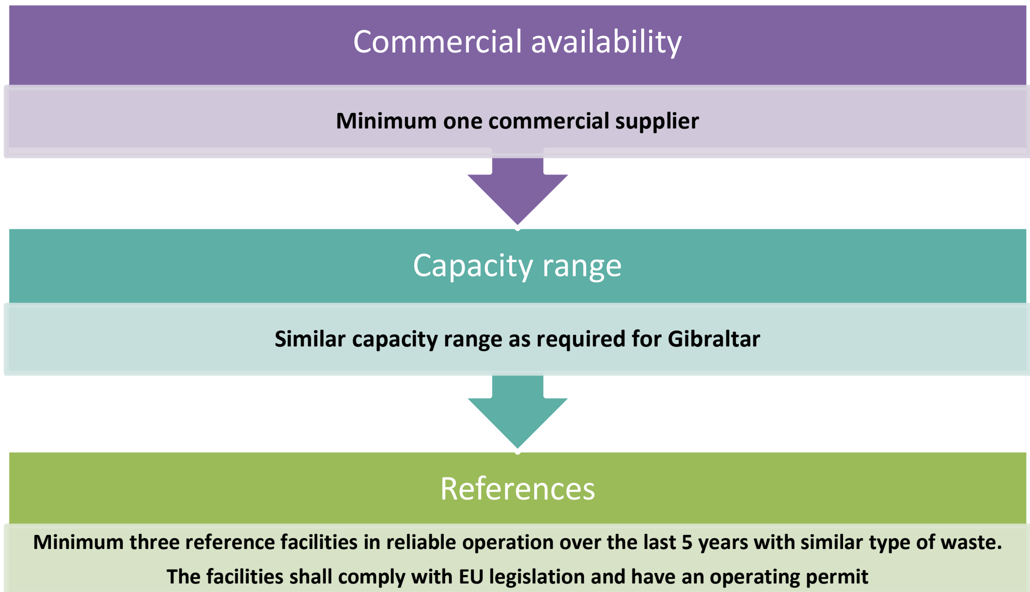
7. INTIAL SCREENING OF POTENTIAL TECHNOLOGIES

The potential technologies – listed in Chapter 6– are outlined and assessed against the selected pass/fail criteria in chapter 7.1.

7.1 Pass/Fail Criteria

The screening process serves to identify proven technologies with acceptable references. The selected minimum requirements are listed in Figure 4.

Figure 4 – Pass/Fail Criteria of Technologies



7.2 Evaluation of Organic Treatment Technologies

'In-vessel composting', 'Enclosed composting' and *'Anaerobic digestion (biogas)'* can fulfil the pass/fail criteria.

See Table 9, Table 10 and Table 11 for further information.

It should be noted that anaerobic digestion facilities of this size are typically run on research basis rather than commercial basis as facilities with much larger capacity - typically greater than 30-50,000 tonnes per year - are built in Europe to offer competitive gate fees. For comparison the amount of organic waste in the 'Refuse' on Gibraltar is only around 5,000 tonnes per year.

'*Windrow composting'* is not considered suitable for organic kitchen waste due to the requirements of the EU Animal By-Product Regulations, the risk of emissions of odour, and the potential attraction of vermin.

7.3 Evaluation of Thermal Treatment Technologies

'Grate fired' technology is the only thermal treatment technology that fulfils the pass/fail criteria.

See Table 12, Table 13, Table 14, Table 15 and Table 16 for further information

'Fluidised bed' technology can be used for mixed refuse. However, the waste must be prepared as a fuel. Secondly, no reference facility – of similar capacity as required for Gibraltar – has been identified.

'Thermal gasification' facilities are mainly located in Japan, as European facilities have suffered difficulties and hence operations have ceased or have been unreliable. No reference facility – of similar capacity as required for Gibraltar – has been identified.

'Plasma technology' is a variant of thermal gasification. A couple of reference plants – with somewhat similar plant capacity – have been identified. However the reference plants do not fulfil the pass/fail criteria as no information on plant performance is available.

7.4 Screening of Organic Treatment Technologies

Table 9 – Assessment of Open Air Windrows

Technology assessment – Organic treatment		
Open air windrow		
Historical background:	Open air windrow is a long pile of material and is a traditional method to produce fertilizer/peat from garden waste and some organics from households. In the EU this method is not permitted for household kitchen waste and catering waste, due to animal by-products Regulation (ABPR). The ABPR e.g. states the required minimum temperature and time to ensure pathogens are killed. This temperature is very difficult to control in open air windrows. Waste containing meats may attract vermin or similar and it is likely to emit strong odour.	
Technology development:	The technology is well-proven with numerous installations in Europe.	
Technical Description:	Windrow composting is a relatively simple process. The waste is shredded and mixed, if needed, with some structure material such as wood chips. The prepared material is placed in long windrows on an impermeable surface. The windrow height is typically 1.5 - 2 metre. The windrows are turned on a regular basis to regulate temperature and the mix moisture. The C:N (carbon: nitrogen) ratio of the shredded and mixed waste should be monitored to ensure optimal biological conditions. The process takes around 16 weeks. The material is then screened to remove oversized material, metals and plastic. The compost is then graded and - depending on quality – used for agriculture, landscaping or top soil cover for landfills. Normally compost originating from a 'non-source separated' waste stream is used for landfill cover and similar applications.	
Illustration:		
Input Requirements:	Green waste only (no animal products)	
Input:	Diesel for machinery Structure material, if required Water sprinkling, if required	
Output:	Compost (quality depends on required output specifications e.g. BSI PAS 100)	
Commercial:	Commercial availability : Yes, but only suitable for green waste	(✓)
	Capacity range: No restriction	(✓)
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: Not listed, as technology is only suitable for green waste.	(✓)

Table 10 – Assessment of In-vessel Composting

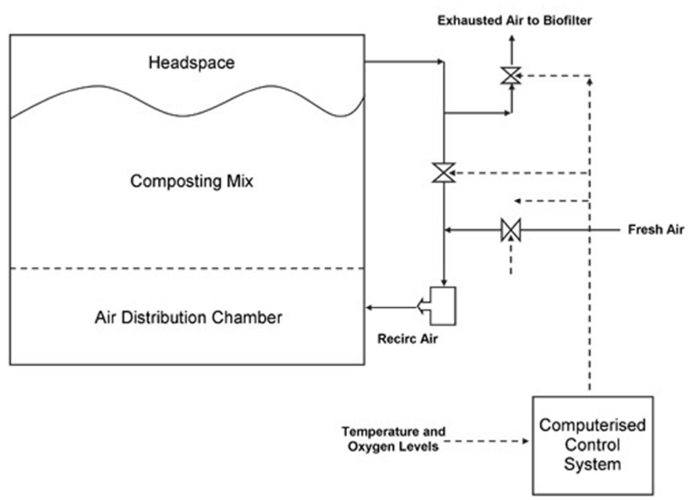
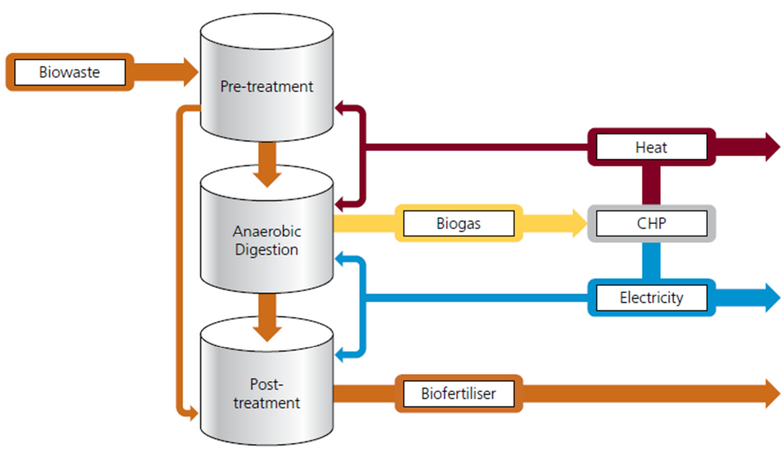
Technology assessment – Organic treatment		
In-vessel composting or enclosed composting		
Historical background:	In-vessel or enclosed composting has been commonly used since the Animal By-Products Regulations (ABPR) was introduced in 2003. These technologies fulfil the ABP regulations as the required temperature is reached for a given period in order to kill pathogens.	
Technology development:	The technology is well-proven with numerous installations in Europe.	
Technical Description:	In-vessel composting spans from simple windrow composting in enclosed halls to more advanced container systems or drums where moisture, temperature and oxygen is actively controlled. The process is often divided in 2 stages. The first stage aims to reach a temperature between 55-65°C (heat generated by bacteria) to kill pathogens and comply with the ABP regulation. This stage is typically 3 to 4 weeks. It is monitored so that the entire volume of the waste reaches the required temperature (e.g .60 °C for 48 hours). After the first stage the organic material is left to mature for 10-14 weeks. Finally the compost is screened for oversize material, metal and plastics. The compost can then - depending on quality – be used for agriculture, landscaping or top soil cover for landfills. Excess air from the process is treated through a bio-filter to reduce odour.	
Illustration:		
Input Requirements:	Pre-sorting and removal of metal, plastic etc. if required Shredding of waste	
Input:	Electricity to aerate waste and screening of waste/compost. Diesel for machinery Biofilter material	
Output:	Compost (quality depends on required output specifications e.g. BSI PAS 100)	
Commercial:	Commercial availability – Numerous large scale suppliers e.g. Agrivert, TEG and Veolia (Natural Recovery System)	✓
	Capacity range – No restriction, often built in modules.	✓
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar:	✓

Table 11 – Assessment of Anaerobic Digestion

Technology assessment – Organic treatment		
Anaerobic digestion		
Historical background:	In the 1920s the first anaerobic digesters were built for sewage sludge. In the late 1970s anaerobic digesters were built to handle manure from farmers. The first plants for treatment of organic waste from households were developed in the 1990s.	
Technology development:	The technology is well-proven with numerous installations in Europe.	
Technical Description:	The organic content of the waste is biologically converted - in an environment without oxygen - to generate the energy rich methane gas (CH_4) and the inert carbon dioxide gas (CO_2). The process typically converts around 40-60% of the organic carbon in the waste – the remaining carbon is found in the digestate from the process, which may be used as fertilizer or disposed at landfill. The biogas produced can, after pre-treatment, be fired in a reciprocating engine with a power efficiency around 38-41%. If the organic waste were to be thermally treated then energy would be required to evaporate the water content in the organic waste during the combustion process There are a number of technical concepts. These can be divided into a dry process (>30% dry matter) or a wet process (<10% dry matter) where the organic matter is pumpable. Dry systems are often used for organic waste from household whereas the wet process often is used if the organic waste is mixed with sludge or other industrial waste streams. The biological process can either take place at 37 °C (mesophilic) or 52 °C (thermophilic). The latter process is the fastest process, but also more difficult to control.	
Illustration:	 *Source: DEFRA 2011, Anaerobic Digestion, Strategy and Action Plan.*	
Input Requirements:	Organic waste without metal and plastics. It can be either household sorted organic waste or sorted organic matter from a sorting facility.	
Input:	Depends on technical concept, such as electricity, diesel, gas or heat.	
Output:	Depends on technical concept, such as biogas, electricity or heat. Typically around 40-60% of biogenic carbon is converted to biogas (depends on the organic material) Un-digested organic matter is typically matured under aerobic conditions	
Commercial:	Commercial availability – Numerous suppliers such as Haase, Kompogas, OWS, Ros Roca, Scmack and Valorga.	✓
	Capacity range - Typical range: 10.000 -150.000 tpa.	✓
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: Ludlow, UK (GreenfinchBiogen, 5000 tpa.), in operation since 2006, but scheduled to be closed in 2012 (funded project) A number of small non-commercial facilities exist.	✓

7.5 Screening of Thermal Treatment Technologies

Table 12 – Assessment of Grate Fired Incineration (Thermal Treatment)

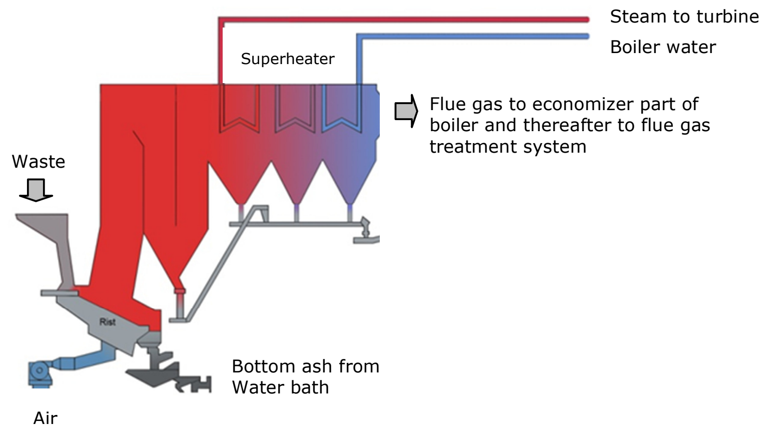
Technology assessment - Thermal treatment		
Grate fired		
Historical background:	Grate fired thermal treatment was developed in the 1930's. It is the most common technology to recover energy in waste.	
Technology development:	Over 300 grate fired lines (>8 t/h) have been installed in Europe. Over 100 grate fired lines with a capacity of between 2.5 – 8 t/h have been installed.	
Technical Description:	The residual waste is taken from the bunker by a crane and dropped into a chute. From the bottom of the chute the waste is mechanically pushed onto the grate. The waste is incinerated at a temperature of minimum 850°C - and up to 1050°C - on an inclined grate where air is injected from below. The waste is pushed forward on the grate and the bottom ash drops into a waterbath at the end of the grate. Complete gas phase combustion is reached by injection of secondary air above the grate. Auxiliary oil/gas burners ensure that a minimum temperature of 850 °C in minimum 2 seconds is reached (EU requirement) in the secondary combustion zone. The combustion energy is transferred to boiler system - with an efficiency of around 85% - for steam production. Steam parameters are typically 40bar and 400°C when the steam is used in a turbine for electricity production. The steam parameters can be lowered for heat-only plant. Many facilities are now being developed with much higher steam parameters (eg 60bar and 425°C). NOx is reduced by ammonia injection into the furnace. The flue gas from smaller plants is typically treated in a dry system, where hydrated lime/sodium bicarbonate is injected upstream of a large filter in order to absorb the acidic gases (HCl, SO_2 and HF). Activated carbon is added to adsorb heavy metal compounds, and dioxins. The residue from the filter requires hazardous waste disposal.	
Illustration:		
Input Requirements:	Residual waste - generally does not require pretreatment. Bulky waste - requires shredding Flexibility to handle changes input with regard to heating value, ash content and moisture.	
Input:	Fuel to auxiliary burners during normal operation - minimal. Ammonia water (25%) for deNOx - 4kg/tonne waste treated Lime for flue gas treatment - 10kg/t, Activated carbon – 0.5kg/t Electricity consumption – 100kWh/t (around 3% of the energy content in waste)	
Output:	Incinerator bottom ash - 200kg/t, Boiler ash - 15kg/t FGT residue - 30kg/t Steam – around 85% of the energy in the waste will be recovered.	
Commercial:	Commercial availability – Numerous large scale suppliers e.g. Babcock Wilcox Volund (Denmark), Fisia Babcock (Germany), Martin GmhB (Germany), Hitachi Zosen Inova (Japan), Vinci (France) and Keppel Seghers. Gibraltar scale suppliers – e.g. Babcock Wilcox Volund and Keppel Seghers.	✓
	Capacity range - Typical range: 8 - 30 tonne/hour per line, but some companies deliver down to 1.5 t/h as standard.	✓
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: Faro Island (2.5 t/h, supplied by - Bruun & Soerensen now Volund - in 1987) Bornholm, Denmark (2.5 t/h, supplied Bruun & Soerensen - now Volund - in 1991) Hammel, Denmark (4t/h, Volund - in 2002)	✓

Table 13 – Assessment of Fluidized Bed Technology (Thermal Treatment)

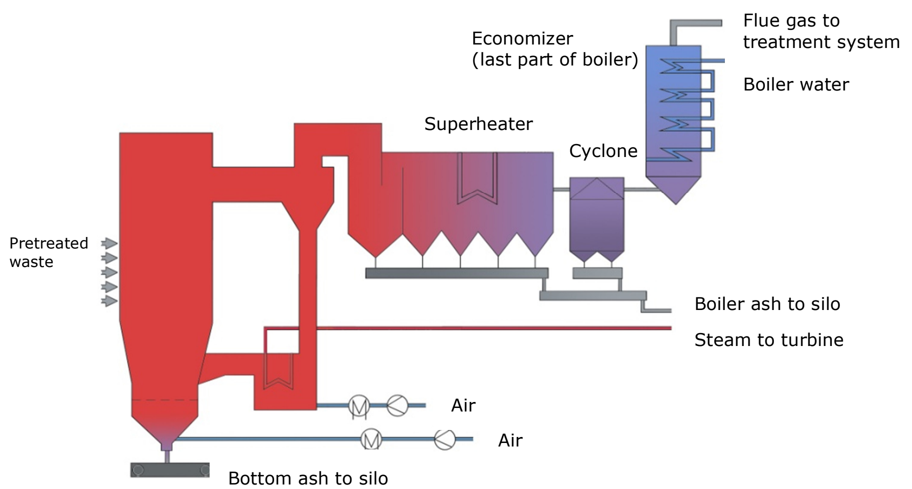
Technology assessment - Thermal treatment		
Fluidised bed		
Historical background:	The fluidised bed reactor was developed in the 1920's for coal combustion. It has later been successfully developed for the incineration of wood chips and sludge.	
Technology development:	Around 40 lines have been established in Europe. These lines are most often fed by RDF (refuse derived fuel, which is produced from municipal waste after sorting of metals and organic matter) and wood waste. Only a few lines treat a feedstock mainly consisting of residual waste – such as the Allington plant, UK.	
Technical Description:	The prepared residual waste (after removal metal and reduction of particle size) is transferred to the reactor chamber. The reactor chamber contains very hot sand, which is fluidised by an air steam from the windbox below. The incineration is very fast and primary combustion takes typically less than 30 seconds. The EU requirement of minimum 2 seconds of 850 °C in the secondary combustion zone is met. Energy is transferred to a boiler system similar to that used for a grate fired facility. Fluidised bed technology inherently produces low NOx emissions and it is often able to meet EU requirements without the use of any further DeNOx system. The remaining FGT system is similar as for a grate fired facility. Experience shows that the amount of fly ash will be significantly higher than for a grate fired facility due to the high air velocity which entrains more of the coarse fraction of the bottom ash in the air. This is important as fly ash often requires hazardous disposal, whereas bottom ash is considered non-hazardous.	
Illustration:		
Input Requirements:	Residual waste –shredding to particle size of 5 - 15 cm (and removal of aluminium) Bulky waste - requires shredding Restrictions on speed of input changes e.g. heating value, ash content and moisture.	
Input:	Fuel to auxiliary burners during normal operation - minimal. Ammonia water (25%) for deNOx – 0 to 2kg/t Lime for flue gas treatment - 10kg/t and activated carbon - 0.5kg/t Electricity consumption – 100kWh/t (around 3% of the energy content in waste) + minimum 50 kWh/t (and up to 400kWh/t) for the pretreatment.	
Output:	Incinerator bottom ash - 100kg/t, Boiler ash - 115kg/t and 20kg sand/t FGT residue - 30kg/t Steam – around 85% of the energy within the waste is recovered.	
Commercial:	Commercial availability – Several large scale suppliers, such as Metso (Finland) and Foster Wheeler (USA).	✓
	Capacity range - Typical range: Up to 40 tonnes/hour per line. Uncertainty of minimum capacity of commercially available fluidised beds.	?
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar No reference plant of similar capacity to Gibraltar – treating residual household waste - has been identified.	✗

Table 14 – Assessment of Thermal Gasification (Thermal Treatment)

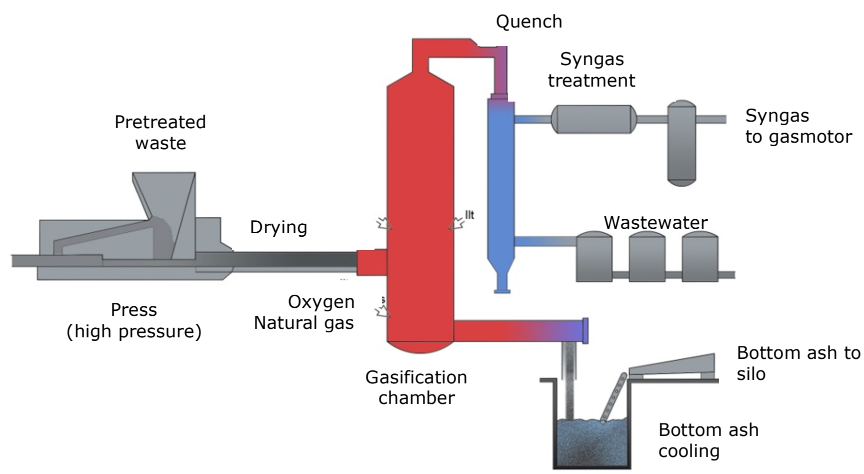
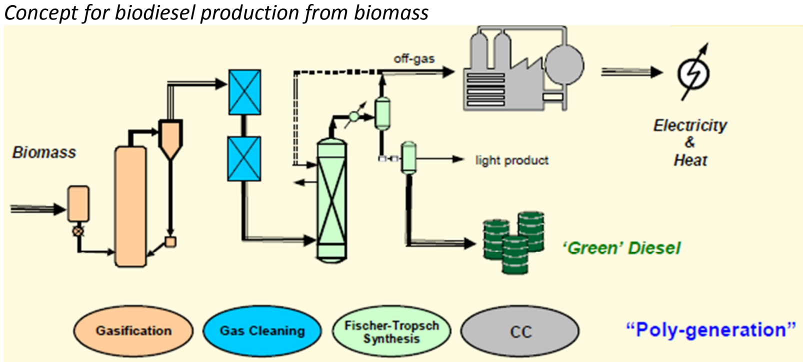
Technology assessment - Thermal treatment		
Thermal gasification (TTF3)		
Historical background:	Thermal gasification was invented in the 1800's to produce city-gas from coal. The technology is now commonly used in areas with large coal deposits to convert coal into a gas that can be used to produce diesel and oil.	
Technology development:	Gasification is common technology in Japan and the high operational temperature (up to 1600 -2000 °C) makes it possible to melt the bottom ash and fly ash into a clinker, which appears to be a requirement in the typical Japanese environmental permit. A couple of large gasification plants for treatment of municipal waste were built in the 1990's in Europe. Plants experienced operational problems and ceased operations. An example is the Thermoselect plant in Karlsruhe which was shut down in 2004 after 6 years of difficult operation.	
Technical Description:	The waste is indirectly exposed to a high temperature which causes the organic matter to crack and transfer into gases. Only limited oxygen is added to ensure that limited combustion takes place at this stage. The energy is therefore preserved in the syngas which may be used for energy recovery or other processes There are three main suppliers (Thermoselect, Ebara and Doosan Babcock) in Japan. The technical concept is dependent on the technology supplier. However, the general concept includes cooling of the hot flue gas prior to gas utilisation. Often the original idea was to use the gas in a reciprocating engine (with a net electricity efficiency up to 42% - compared to around 30% for steam turbine). However, at most plants the energy is now transferred to a boiler system with similar steam parameters as a grate fired or fluidised bed facility. The flue gas can be treated in a similar system as for grate fired facilities.	
Illustration:	*Thermoselect concept* 	
Input Requirements:	Residual waste – after shredding to particle size of around 15 cm Restrictions on input changes e.g. heating value, ash content and moisture.	
Input:	Fuel to auxiliary burners during normal operation - minimal. Ammonia water (25%) for deNOx <0-2kg/tonne waste treated Lime for flue gas treatment <10kg/t, Activated carbon <0.5kg/t Electricity consumption – unknown	
Output:	All residues melted into a relatively inert clinker. Net electricity is 0 and likely negative for some plants. (based on Ramboll site visits)	
Commercial:	Commercial availability – Thermoselect, Ebara, Doosan Babcock, Nippon Steel, Air Products	✓
	Capacity range - Typical range: 8 - 20 tonne/hour per line. No supplier of similar capacity to Gibraltar has been identified.	✗
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: No reference plant has been identified.	✗

Table 15 – Assessment of Plasma Technology (Thermal Treatment)

Technology assessment – Thermal treatment		
Plasma (gasification) (TTF4)		
Historical background:	Plasma gasification is a variant of thermal gasification. The energy source for the cracking of the organic matter is an ionized gas produced by emitting gas through an electrical arc, where the gas reaches a temperature up to 3500°C. The high temperature vitrifies the bottom ash into a glassy clinker.	
Technology development:	Plasma gasification is commercially available and at least two companies are promoting plasma gasification for treatment of residual waste - including AlterNRG and Plasco Energy Group. AlterNRG has two reference facilities – entered service in 2002/03 - according to the webpage of the company. Plasco Energy Group has one reference facility which entered service in 2007. No information regarding plant availability or energy efficiency was available from the company websites.	
Technical Description:	Similar to thermal gasification – except that a plasma torch (electrical arch) is used to reach the high temperature.	
Illustration:	*An example of plasma gasification reactor is shown below. The rest of the concept is similar to thermal gasification.*  *http://www.alternrg.com/plasma_technology/products_and_services/plasma_gasification*	
Input Requirements:	*Similar to thermal gasification*	
Input:	*Similar to thermal gasification, but additional high power consumption of the plasma torch.*	
Output:	*Similar to thermal gasification*	
Commercial:	Commercial availability – AlterNRG and Plasco Energy Group	✓
	Capacity range: 1 - 8 tonne/hour per line.	✓
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: The following 3 commercial reference plants for plasma technology are listed on the companies' websites. Mihama-Mikata, Japan (1t/h, residual waste and sludge) Plasco Trail Road (4t/h, municipal waste from landfill) Utashinai Japan (10t/h, auto shredder waste and residual waste) No operational data seems to be publicly available from any of the reference plants.	✘

Table 16 – Assessment of Biodiesel Production (Thermal Treatment)

Technology assessment – Thermal treatment		
Biodiesel (gasification) (TTF5)		
Historical background:	Biodiesel can be produced from the syngas – produced by a gasification plant – through the Fischer-Tropsch synthesis by building polymer chains of the H_2 and CO molecules. Some companies propose a technical concept with a 'mild' gasification where larger volatile organic molecules are produced - instead of CO and H_2. The idea is to distil these organic molecules and thereby skip the need of the more expensive Fisher-Tropsch synthesis.	
Technology development:	The Fisher-Tropsch synthesis is a well proven process. However, the Fischer-Tropsch process does not appear to have been used for the production of syngas from waste projects. It may not be economically attractive to produce bio-diesel especially compared to electricity/heat, due to the higher investment and increased operational costs. Distillation of gases from gasification of actual municipal has to Ramboll's knowledge not been in even pilot scale.	
Technical Description:	The syngas from the gasification process needs to be cleaned before the synthesis of biodiesel can begin. The Fischer-Tropsch process normally takes place at 150 - 300°C. A catalyst – e.g. the cobalt metal – is used to initiate the synthesis of: $(2n+1)\ H_2 + n\ CO \rightarrow C_nH_{(2n+2)} + n\ H_2O$	
Illustration:	*Concept for biodiesel production from biomass*  	
Input Requirements:	*Similar to thermal gasification*	
Input:	*Similar to thermal gasification and input inquired for the upgrading process.*	
Output:	*Biodiesel production*	
Commercial:	Commercial availability: Installations for the Fisher-Tropsch synthesis is commercially available.	✓
	Capacity range: A system can designed for this size of plant.	✓
	Minimum 3 reference plants of similar capacity and fuel as Gibraltar: No references on syngas from municipal waste.	✘

8. ABILITY TO TREAT OTHER WASTE STREAMS

This section describes whether the technologies passing the screening process are suitable or can be adapted to handle additional waste streams such as: non-hazardous bulky waste, oil sludge, bilge oil ('sullage') and wastewater treatment sludge.

The handling of one or more of these fractions is likely to be attractive from a number of points such as:

- Self-sufficient with regard to waste handling
- Increased energy production (which means less energy import)
- Lower waste handling costs.

The potential disadvantages of handling other waste streams include increased technical complexity of the project and the increased area of the facility.

The ability of selected treatment technologies ('composting', 'anaerobic digestion' and 'grate fired thermal treatment') to handle alternative waste streams is described below.

8.1 Introduction to Additional Waste Streams

The first step is to define the additional waste streams with regard to annual tonnage, expected average composition and the treatment cost in order to estimate the potential savings. The information for the waste streams of main interest is listed in Table 17.

Table 17 – Additional waste fraction

Waste fractions	Annual tonnage	Composition	Treatment cost
Non-hazardous bulky waste	10,000 – 12,000	No data - significant amount of timber pallets	£74/t[3]
Oil sludge + waste oil	13 – to be verified	Limited water content	£1280/t (exported to Spain)
Bilge oil	4,225	Average ratio between water and oil to be checked	To be checked
Wastewater treatment sludge	4,000 (25% dry matter)[4]	Water content depends on the chosen concept.	To be checked

8.2 Ability to Treat Other Waste Streams - Evaluation

The ability of 'Composting', 'Anaerobic digestion' and 'Grate fired technology' to treat other waste streams is described in Table 34, Table 35 and Table 36 in the appendixes.

The main conclusions of the evaluation are the following:

- 'Composting' facilities can use shredded timber waste as structure material for the organic material. This will improve the overall composting process. The amount of the timber that can be handled depends on the amount of timber chips that have to be returned to the composted process. There may be other restrictions on using chemically treated wood for this purpose.

- 'Anaerobic digestion' facilities could co-digest the wastewater sludge with the other organic streams. The facility could – if designed appropriately - handle all the wastewater sludge. The sludge should be fed continuously to minimize salinity swing due to the salts in the sludge.

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[3] *The average cost for collection, treatment and disposal of municipal waste is estimated to £73.55 in the Gibraltar Waste Management Plan 2011. The actual cost for transport and disposal of e.g. the waste wood within the 'non-hazardous bulky waste' is not stated.*

[4] *Sludge production is estimated to 1600tpa at 65% dry matter (after dryer). This corresponds to around 4000 tpa at 25% dry matter (after centrifuge)/Wastewater Treatment Works/Energy from Waste Facility, December 2005, Ramboll and Atkins*

- 'Grate fired thermal treatment' facility can technically be adapted to handle the listed additional waste streams. This adaption will be relatively expensive for a small plant. As a rule of thumb the facility can handle around 10% input of low calorific fraction (such as sludge with 25% dry matter and bilge oil with 80-90% water) if the remaining waste has a calorific value of 11 MJ/kg. The percentage can be increased for higher calorific value residual waste and similarly reduced for lower calorific residual value.

9. MODELLING PRINCIPLES

The waste model – designed in Excel - has an input sheet where the project assumptions for Gibraltar are set. This approach makes it easier to check the sensitivity of the input data to show, for example, a change in efficiency of recycling or performance of facility.

Where possible inputs are based on performance data extracted from an environmental life-cycle model called WRATE. This model has been established by the UK Environment Agency for waste management decision making. Performance data from actual facilities is found in Appendix 1.

The main input data is listed in Appendix 2.

The tonnage and composition of refuse to be treated is the same for all scenarios. Please refer to Table 4 for further details.

10. WASTE MODEL – RESULTS

The results of the waste model illustrate the expected technical performance of the different waste management scenarios.

For each scenario an overview table is produced showing the:

- Amount of recyclables/organic material collected separately at households
- Amount of recyclables/organic material sorted at treatment facility
- Change in the residual waste composition (and calorific value) due to recovery of materials from the waste stream
- Overall recycling rate including the amount of the different recyclables
- Overall energy consumption and production.

The model focuses on the waste treatment process and therefore excludes energy for transport such as the collection of waste and transport for disposal/recycling. Transport is in general found to have a low influence on life-cycle-analysis, but the additional handling may have significant future cost impacts.

An example of the performance overview of a given scenario is listed in Table 18. The overview of each scenario is found in Appendix 3.

Table 18 – Example of Scenario Overview

Scenario 4A — **Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)**

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	9.2	899	40	359	8.0	539
Cardboard	19.5	3,536	60	2,122	14.4	1,414	40	566	12.6	849
Plastic film	11.0	1,984	30	595	14.2	1,389	30	417	14.4	972
Dense plastic	8.4	1,521	40	608	9.3	913	40	365	8.1	548
Textiles	4.2	752	0	0	7.7	752	0	0	11.1	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	3.4	329	0	0	4.9	329
Organic kitchen waste	29.1	5,270	50	2,635	26.9	2,635	40	1,054	23.4	1,581
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.8	274	80	219	0.8	55
Non ferrous metal	0.9	171	60	103	0.7	69	80	55	0.2	14
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	3.5	346	0	0	5.1	346
Other non combustible	1.2	216	0	0	2.2	216	0	0	3.2	216
Special municipal waste	3.1	561	0	0	5.7	561	0	0	8.3	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			8,316		9,795		3,035		6,760
Overall recycling efficiency (in %)			46%				17%			
Lower calorific value (MJ/kg)		13.0				14.4				14.5

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		63%	Power usage	MWh/year	149
Amount of waste sent to recycling facility			Diesel usage	m^3/year	12
Paper	tpa	1,708	Steam - energy content	GJ/year	
Cardboard	tpa	2,687	Biogas - energy content	GJ/year	
Plastic film	tpa	1,012	**Products and residues**		
Dense plastic	tpa	973	Compost-like-material	tpa	1,845
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	630			
Non ferrous metal	tpa	158	Residual waste to landfill	tpa	6,760
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	3,689	Fly gas treatment residue (to haz landfill)	tpa	

10.1 Waste Model Results – Recycling

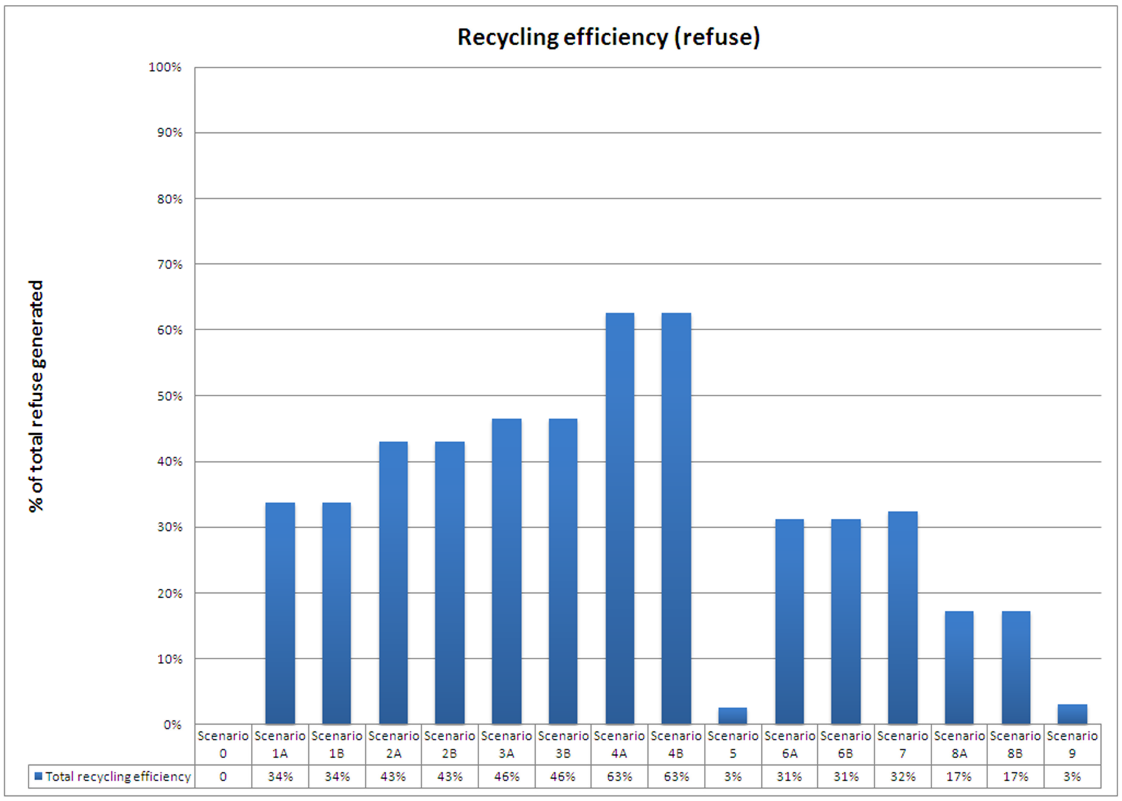
The overall recycling efficiency varies greatly between the scenarios as shown in Figure 5.

The recovery rate ranges from approximately 0% recycling in Scenario 0 (where it is assumed that all refuse is landfilled in Spain without any pre-treatment) to 63% in scenario 4A/B that includes a three bin system at households in combination with further sorting of residual waste.

All organic waste treated in composting or biogas facility counts as recycling. This means that a low grade compost used as topsoil for restored landfill as counted as recycling.

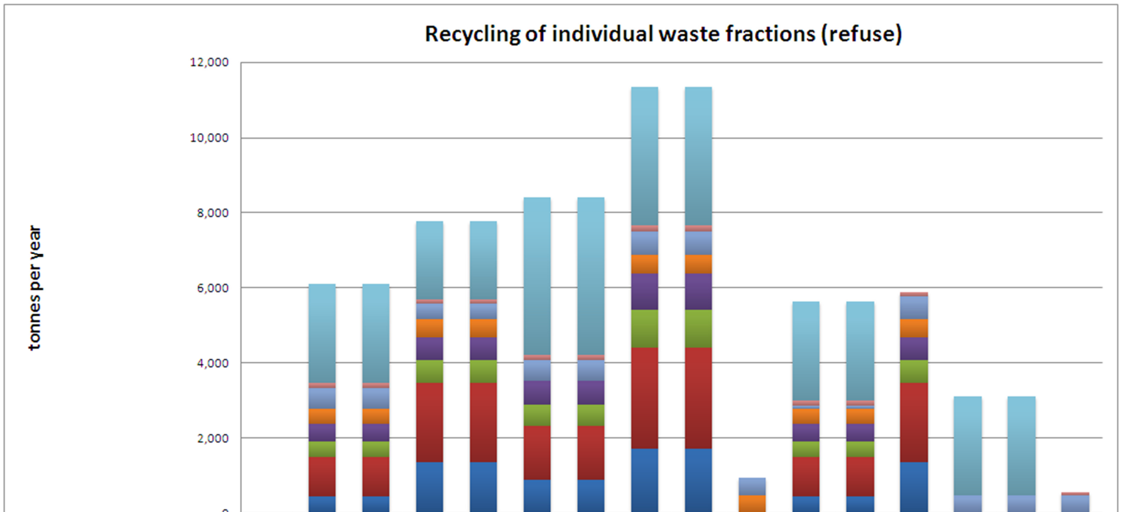
The recycling efficiency includes all recyclables sent to recovery including for example metals sorted from the incinerator bottom ash. Incinerator bottom ash is not included in the 'overall efficiency' even though it is often (after metal sorting, crushing and maturation in a stock pile) used as aggregate substitute for road construction.

Figure 5 – Scenario Recycling Efficiency



The type and amount of recyclables is illustrated in Figure 6. The figure shows that the majority of recyclables are cardboard/paper and the organic material for composting/anaerobic digestion.

Figure 6 – Recovered Recyclables and Organic Material



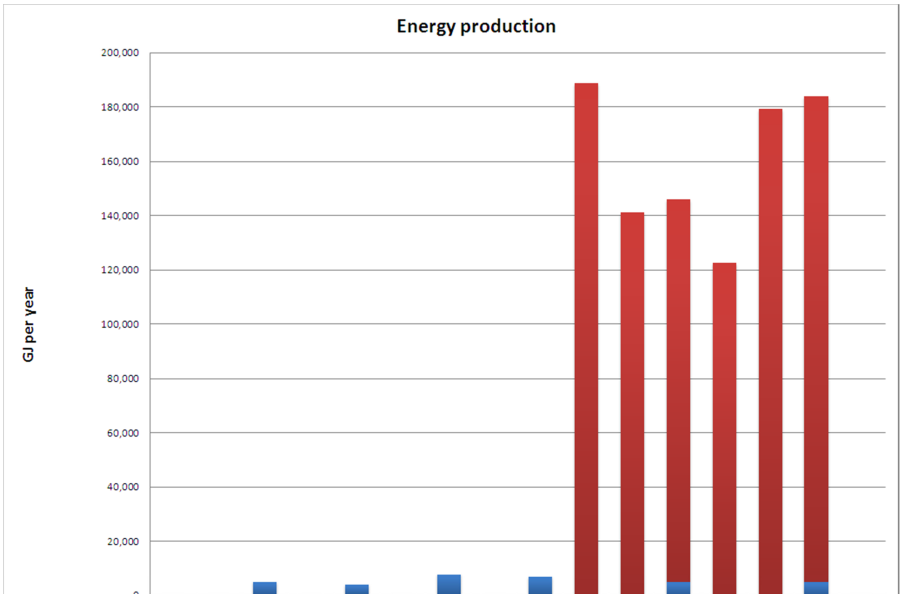
	Scenario 0	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B	Scenario 3A	Scenario 3B	Scenario 4A	Scenario 4B	Scenario 5	Scenario 6A	Scenario 6B	Scenario 7	Scenario 8A	Scenario 8B	Scenario 9
Organic material for treatment tpa	0	2,635	2,635	2,108	2,108	4,216	4,216	3,689	3,689	0	2,635	2,635	0	2,635	2,635	0
Non ferrous metal tpa	0	137	137	103	103	137	137	158	158	0	137	137	103	0	0	86
Ferrous metal tpa	0	548	548	411	411	548	548	630	630	480	96	96	603	480	480	480
Glass tpa	0	411	411	493	493	0	0	493	493	480	411	411	493	0	0	0
Textiles tpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense plastic tpa	0	456	456	608	608	608	608	973	973	0	456	456	608	0	0	0
Plastic film tpa	0	397	397	595	595	595	595	1,012	1,012	0	397	397	595	0	0	0
Cardboard tpa	0	1,061	1,061	2,122	2,122	1,414	1,414	2,687	2,687	0	1,061	1,061	2,122	0	0	0
Paper tpa	0	449	449	1,348	1,348	899	899	1,708	1,708	0	449	449	1,348	0	0	0

10.2 Waste Model Results – Energy Recovery

Energy recovery is stated as the energy transferred from the waste to the boiler system of the thermal treatment facility or as the total energy in the biogas.

Comparison of the energy output from the thermal treatment versus the produced biogas shows that the energy embedded in the organic fraction is relatively small compared to the overall energy content in the waste.

Figure 7 – Energy Recovery



	Scenario 0	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B	Scenario 3A	Scenario 3B	Scenario 4A	Scenario 4B	Scenario 5	Scenario 6A	Scenario 6B	Scenario 7	Scenario 8A	Scenario 8B	Scenario 9
Steam - energy content	0	0	0	0	0	0	0	0	0	188,851	141,124	141,124	122,576	179,153	179,153	0
Biogas - energy content	0	0	4,881	0	3,905	0	7,809	0	6,833	0	0	4,881	0	0	4,881	0

10.2.1 Use of energy

Biogas is most often converted to electricity in a reciprocating engine. The technology is well proven with many installations worldwide with electrical efficiencies greater than 38%. Approximately 30-40% of the energy can be recovered as heat.

Grate fired thermal treatment facilities normally transfer around 85% of the energy in the waste to the boiler. The steam produced can be used to drive a turbine to produce electricity or directly at industrial consumers. A turbine has a power efficiency of around 30%-35%, depending on turbine quality, steam parameters and cooling media/ambient temperature.

The annual electricity production from a turbine in scenario 5 will be around 10,000 – 12,000 MWh. This is equivalent to the annual consumption of 2,900 typical European households – assuming 4,000kWh per household. Assuming that all electricity produced can be fed to grid.

Turbines are expensive to purchase and installations require regular maintenance. A minimum facility tonnage is required to make a turbine installation commercially attractive. The minimum size is dependent on a number of parameters such as investment cost, operational cost, revenues from electricity sale and potential income from heat sale.

It is recommended that the utilisation of steam in desalination plants is investigated. Currently desalination plants are driven by electricity but it may be attractive to change these to steam supplied technology when they are upgraded in the future.

11. EVALUATION CRITERIA

The evaluation consists of an assessment of the technical performance, environmental performance, legislative compliance, affordability and other relevant factors.

The scenarios are scored against each criteria (a score of 1 to 3 is given, where 3 is the most attractive for Gibraltar/the environment).

The criteria are listed below.

Technical performance

- Constructability (Footprint, construction materials and construction period)
- Operability (waste/fuel requirements, staff number and expertise, operational range)
- Reliability and availability
- Ability to accept other waste (e.g. sewage sludge, bilge oil, bulky waste)

Environmental performance

- Environmental performance
- Energy production/usage
- Products/ Residues (including issues managing output and reliance on third party)

Compliance with legislation

- Ability to comply with legislative and regulatory requirements
- Ability to adapt to tougher regulations in future
- Planning and permitting issues
  (visual impacts and stack height etc.)

Affordability

- CAPEX (High/medium/low)
- OPEX (High/medium/low)

Other

- Compatibility with strategic aims (e.g. Recycling efficiency)
- Health and Safety

11.1 Technical Performance

Constructability relates to the complexity of construction including the required footprint and the construction period.

Scenarios based on limited pre-treatment before export of waste is scored high due to simplicity of the scenario. In-vessel composting is only scored relatively high as is relatively simple to construct but requires a large footprint. Grate fired thermal treatment will be the most complex facility to construct, but it requires a relatively small footprint compared to the capacity of plant.

A scenario with multiple facilities (such as the combination of dirty MRF for recyclables, anaerobic digestion of organic fraction and thermal treatment of residual fraction) will significantly increase the complexity of the scenario and the scenario will therefore be scored lower.

Operability evaluates the requirements of the input waste, operational range as well as the general required expertise of staff and number.

Scenarios based on limited pre-treatment before export of waste are scored high due to the limited manual input and the limited technical expertise required. MRF facilities requires less technical expertise for service of equipment but these facilities will on the other hand require a high staffing level of hand pickers of recyclables. Grate fired thermal treatment requires high expertise but the facility is less dependent on the input waste. Anaerobic digestion requires relatively high level technical expertise and the process is dependent on the quality of the input waste so scores low.

A scenario with multiple facilities will increase the requirement of technical expertise as well as the number of staff and is therefore scored lower.

Reliability and availability refers to the expected downtime due to maintenance and service of the facility. Grate fired thermal treatment can be designed with guaranteed annual availability of 8000 hours and one major stop per year. MRFs and anaerobic digestion can also be designed with high availability, but dirty MRFs will require regular cleaning.

Ability to accept other waste is listed in the table below. More detailed analysis is included in Appendix 4. Overall the grate fired thermal treatment can handle all the listed additional waste fractions – however with a limitation on the quantity. In-vessel composting and anaerobic digestion can handle readily biodegradable fractions, but waste fractions containing oil substances are not suitable.

	Non-hazardous bulky waste	**Oil sludge**	**Bilge oil**	**Wastewater treatment sludge**
Composting	(√)	x	x	√
Anaerobic digestion	x	x	x	√
Grate fired	√	√	√	√

11.2 Environmental Performance

Environmental performance is scored high for scenarios with high overall recycling rate and/or high potential energy recovery. A lower score is given to scenarios with a significant amount of residual waste disposed at landfill.

A detailed environmental performance evaluation can be carried out at later project stage. It will require assessment of how the recovered energy can be used (e.g. as steam to new desalination units) and information regarding the recycling facilities receiving the recovered recyclables.

Energy production/usage is scored high for scenarios that recover the energy in the waste, such as grate fired thermal treatment and anaerobic digestion. The energy production calculated by the waste model is stated as the energy in the produced steam or as energy in the produced biogas. The potential usage of produced energy – such as that from a steam turbine or gas engine – is evaluated at later project stage.

Products/ Residues is scored high for scenarios that produce a limited amount of product/residues that require export from Gibraltar and reliance on a third party.

Grate fired thermal treatment is scored low because bottom ash and flue gas treatment residues have to be disposed of safely. Dirty MRF facilities are scored low, because may be problematic to find an off-taker for the recovered recyclables due to impurities in the recyclables. In-vessel composting based on non-source separated organic is also scored lower impurities in the compost-like-material produced may make it difficult to find off-takers.

11.3 Compliance with Legislation

Ability to comply with legislative and regulatory requirements is referring to the scenario's ability to approach the recycling target set by EU. Scenarios with high overall recycling rate are given a high score. The Government of Gibraltar has set out a recycling requirement of 50% by 2020.

Scenarios including thermal treatment are also scored high, because the potential energy recovery will help Gibraltar reach the target of 15% energy from renewable sources by 2020. The Government of Gibraltar has set this target based on the EU directive 'Promotion of Use of Energy from Renewable Sources (2009/28/EC).

Ability to adapt to tougher regulations in future is scored high for all treatment facilities because these can be designed to meet tougher regulations although the ease of retrofit may vary. Stricter clean gas emissions from thermal treatment can be met by increasing chemical dosing and by installation of advanced NO_x abatement systems. Odour emissions from a MRF, in-vessel composting and anaerobic digestion facility can be reduced by installation of scrubber systems for process/ventilation air in addition to a bio-filter. More strict health and safety issues for e.g. hand-pickers in contact with waste are discussed under a separate evaluation criteria 'Health and Safety'.

Planning and permitting issues is scored high for scenarios only containing a transfer station, MRF or in-vessel composting facility because traditionally these can pass through the permitting process relatively easily compared to thermal treatment plants, which take longer to achieve planning permission in some countries.

CAPEX is scored high for the scenarios requiring limited investment in facilities, for example: transfer station and in-vessel composting. Thermal treatment facilities score low due to the high level of investment required for the facility.

Scenarios with multiple facilities are in general scored lower. A combined facility with thermal treatment and anaerobic digestion will have higher investment cost compared to a single thermal treatment plant with the same overall treatment capacity.

OPEX is - at this project stage - difficult to score because the facilities with high operational costs also have potential for a significant income from the recovered energy or high quality recyclables. Secondly the costs of handling residual products need to be quantified.

All scenarios are given the score 2 at this stage.

11.4 Other Criteria

Compatibility with strategic aims
This criterion is currently scored similar to 'Ability to comply with legislative and regulatory requirements'.

Health and safety is scored high for scenarios where personnel will have limited contact with waste during operation and maintenance. MRFs are scored where hand sorting is utilised.

11.5 Scoring of Scenarios

An overview of the scenarios is given in Table 19 and Table 20. Overall discussion of the scenarios can be found in Chapter 13.

Table 19 – Scoring of 'Technical Performance' and 'Environmental Performance'

	Technical Performance				Environmental Performance		
Scenario	Construct-ability	Operability	Reliability and availability	Ability to accept other waste	Environmental performance	Energy production/ usage	Products/ Residues
0	3	3	3	1	3	3	3
1A	3	2	2	2	3	2	2
1B	2	2	2	1	2	2	2
2A	3	3	3	2	3	3	3
2B	3	2	2	1	3	2	2
3A	3	3	2	2	3	3	2
3B	3	2	2	1	3	2	2
4A	3	2	2	2	3	2	2
4B	3	2	2	2	3	2	2
5	1	2	3	3	1	2	3
6A	2	2	2	3	2	2	2
6B	1	1	2	3	1	1	2
7	2	2	3	3	2	2	3
8A	2	2	3	3	2	2	3
8B	1	1	2	3	1	1	2
9	2	3	2	1	2	3	2

Table 20 – Scoring of 'Compliance with Legislation', 'Affordability' and 'Other'

	Compliance with legislation			Affordability		Other	
Scenario	Ability to comply with legislative and regulatory requirements	Ability to adapt to tougher regulations	Planning and permitting issues	CAPEX	OPEX	Compatibility with strategic aims	Health and safety
0	1	2	3	3	2	1	3
1A	1	2	3	3	2	1	1
1B	1	2	3	3	2	1	1
2A	3	2	3	3	2	3	2
2B	3	2	3	3	2	3	2
3A	2	2	3	3	2	2	1
3B	2	2	3	3	2	2	1
4A	3	2	3	3	2	3	1
4B	3	2	3	3	2	3	1
5	2	2	2	2	2	2	3
6A	2	2	2	2	2	2	1
6B	2	2	2	1	2	2	1
7	3	2	2	2	2	3	3
8A	2	2	2	2	2	2	3
8B	2	2	2	1	2	2	3
9	2	2	3	3	2	2	3

12. CONCLUSION

Final comments to each of the scenarios are listed in Table 21.

Please also refer to the chapter 'Executive Summary' for information about the most attractive scenarios and the proposed next steps.

Table 21 – Final comments to the selected scenarios

		Comments	Overall evaluation
	0	Export of refuse to Spain will require identification of suitable treatment facilities and continuous checking of the efficiency of the plant to ensure environmentally sound treatment. It is a disadvantage of the export solution that the recycling level for Gibraltar will be low and that the energy in the waste is not recovered and thereby does not contribute towards the target of 15% renewable in 2015.	✘
Landfill of residual waste after sorting and pre-treatment	1A	The recovery level of recyclables from mixed waste will be relatively low, as it is difficult to separate good quality recyclables from mixed waste. The recyclables may be difficult to sell due to increased level of contaminants in the recyclables. The compost derived from non-source separated organic material will contain traces of plastic, glass etc. and should only be used for certain applications such as cover for landfills. The organic matter in the residual waste sent to landfill will still be too high to fulfil the EU requirements due to the level of biological activity (ability to produce methane, which is a powerful greenhouse gas). The environmental benefit compared to Scenario 0 is evaluated as low compared to the investment.	✘
	1B	General comment as 1A. The energy produced from the biogas is low and can probably only cover the internal consumption of the treatment facility. Non-source separated organic material may cause operational problems due to contaminants such as plastics etc. A facility of this small capacity is more susceptible to stoppages due to the lighter equipment and smaller conveyors/chutes. It is generally not so economically attractive to build an anaerobic digestion plant of this size compared to the same size composting solution.	✘
	2A	Separate collection of dry recyclables will significantly increase the overall recycling rate. The partial removal of the organic material at source will further reduce the biological content in the residual waste. The compost will be of low quality.	(✓)
	2B	General comments as 2A. Comments with regard to anaerobic digestion as 1B.	✘

	3A	The recovery level of recyclables from mixed waste will be relatively low even though part of the organic material is collected separately. Separate collection of organic waste for composting will increase the quality level of the compost.	(✓)
	3B	The recovery level of recyclables from mixed waste will be relatively low even though part of the organic material is collected separately. Separate collection of organic waste for anaerobic digestion in combination with the organic matter separated from the residual waste will increase the waste flow to the anaerobic digester but the solution is most likely still not economically attractive compared to the composting solution.	✘
	4A	The collection of dry recyclables and source separated organic matter gives a high overall recycling efficiency. The main barrier is the requirement of three different bins at the households. This gives some challenges with regard to physical constraints of a collection system and whether the public engages in the project.	(✓)
	4B	As comments 4A. An anaerobic digestion plant will most likely not be economically attractive compared to the composting solution.	✘
Thermal treatment after potential sorting	5	Thermal treatment of the entire waste stream secures maximum energy recovery. The bottom ash (around 20% of the incoming waste) requires landfill for inert waste and the flue gas treatment residue (around 3.5% of the coming waste) is to be sent to hazardous waste landfill. The overall recycling efficiency will be low, as only metals will be recovered from the refuse waste stream. On the other hand energy is recovered that counts towards the renewable energy target.	✓
	6A	The recovery level of recyclables from mixed waste will be relatively low. The compost based on non-source separated organic material will have a low quality. The environmental benefit of sorting the mixed waste prior to thermal treatment is evaluated to be low – and possibly negative - compared to scenario 5. The additional facilities add technical risks will increase the investment and operational costs.	✘
	6B	Comments as 6A. It will not be economically attractive to build an anaerobic digestion plant when compared to thermal treatment of the organic waste alongside residual waste.	✘
	7	Separate collection of dry recyclables will increase the overall recycling efficiency. Whether this scenario has a better environmental performance than Scenario 5 depends on the actual use of the marginal recovered energy as well as the performance of the recycling facilities.	✓
	8A	Separate collection of organic material for composting will improve the compost quality, but reduce the energy content in the remaining waste. The overall recycling efficiency will be higher than Scenario 5, as the material sent to compost will count as recycling.	✘

		This scenario requires additional investment of a composting facility (compared to scenario 5) and implementation of a two bin system at households. The improved environmental impact - compared to Scenario 5 - is evaluated to be insignificant.	
	8B	Comments as 8A. The anaerobic digestion facility will increase investments compared to Scenario 8A as well as the technical complexity of the project. The environmental benefits are evaluated to be insignificant.	✘
SRF (Solid recovered fuel) production	9	Fuel production for export (by removal of metals and drying of remaining waste through aeration) requires a pre-treatment facility. Overall the scenario requires low investment and has low technical complexity. The main disadvantage is reliance on a third party. The fuel is a relatively low quality and can only be used in thermal treatment plants. The fuel should only – even though it is partly dried - be stored short-term due to bacterial activity. It is a disadvantage that the recycling level of Gibraltar will be low and that the energy in the waste is not recovered on the territory and thereby fails to count towards the target of 15% renewable in 2015.	(✓)

Appendix 1 – Actual Performance Data of Technologies (Passing the Screening Process)

Actual Performance Data of Technologies (Passing the Screening Process)

Examples of performance data from actual facilities are listed in this appendix. The performance data is extracted from a waste management lifecycle model (WRATE) which has been developed by the UK Environment Agency.

These case studies serve to back the used assumptions in the waste model. However, it is recognised that performance data varies between individual facilities – due to waste composition and variations of the technical concept.

Table 22 – Case Study – Material Recovery Facility (Handling Mixed Refuse)

Technology assessment	
Material recovery facility (sorting of mixed refuse)	
Case study	Material recovery facility (sorting of refuse). The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID 11130), which is a tool developed by the UK Environment Agency.
Capacity of plant	25,000 tpa
Input	Mixed refuse Power: 15 kWh/t (of incoming waste) Diesel: 0.3 litre/t Water consumption: No information
Output	Recycling efficiency: Dense plastic: 20 -32% Glass: 75% Ferrous metal: 95% Non-ferrous metal: 95% Cardboard: 25% Remaining paper: 90% is used for RDF fraction (fuel for other facility) Organic fraction: 60% is separated for composting. All other waste is sent to landfill.
Emissions	No data
Other technical details	
Plant area	0.26 ha
Investment cost	

Table 23 – Case Study – Material Recovery Facility (Handling Source Separated Recyclables)

Technology assessment	
Material recovery facility (sorting of dry recyclables)	
Case study	Material recovery facility (sorting of source separated dry recyclables). Manual sorting combined with infrared plastics separation. The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID12248), which is a tool developed by the UK Environment Agency
Capacity of plant	50,000 tonnes
Input	Dry recyclables collected separate at households. Power: 15 kWh/t (of incoming waste) Diesel: 1 litre/t – for mobile plants, e.g. forklifts and frontloaders. Water consumption: 0.1 l/t – dust suppression/odour control.
Output:	Recycling efficiency: On average 90% of the incoming waste was sorted in the following fractions: Plastic film, dense plastic, ferrous metal, non-ferrous metal and paper + cardboard. Approximately 10% reject to landfill
Emissions	No data
Other technical details	
Plant area	2.5 ha, including area for storage (Ramboll estimate)
Investment estimate	£10M for automated (Ramboll estimate)

Table 24 – Case Study – In-Vessel Composting

Technology assessment	
In-vessel composting	
Case study	Composting, in-vessel vertical flow by the TEG process The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID21270), which is a tool developed by the UK Environment Agency.
Capacity of plant	14,300 tonnes per year The facility is based on 24 modules.
Input	Source separated organic waste and green waste (It is operated with 50% organic waste and 50% garden waste). Power: 2 kWh/t (of incoming waste) Diesel: 1 litre/t Water consumption: 0.2 l/t (this seems unrealistic low)
Output:	Compost fulfilling 100 PAS quality requirement Output quantity ≈ 50% of input waste Stored in bunker or 'breathable' bags
Emissions	No data
Other technical details	There is no forced aeration, turning or agitation during the single pass composting process. This results in a low energy demand. Continuous temperature monitoring ensures the optimum working environment is maintained at all times, guaranteeing a pathogen-free product, which is stable, easy to store and handle. The contamination level of the incoming waste is reported to be 0.5% - consisting of mainly plastics. 42 days residence time. The water content of the waste should be 45% - 65%.
Plant area	0.58 ha
Investment estimate	

Table 25 – Case study – Anaerobic Digestion (Dry Process)

Technology assessment	
Anaerobic digestion (dry process)	
Case study	Typical dry anaerobic digestion plant (DRANCO supplied by Organic Waste System) The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID11312), which is a tool developed by the UK Environment Agency.
Capacity of plant	51,000 tonnes per year
Input	Source separated organic waste and green waste (It is operated with 53% garden waste, 30% food waste and 17% paper/cardboard) Power – own consumption (when gas-motor is down): 65 kWh/ t (of incoming waste) Natural gas: 0.6 Nm^3/tonne (33% for production of process steam and 67% to support the gas-engine if methane content of biogas is low) Diesel: 0.1 litre/t Water consumption: 0.2 l/t
Output:	Net power to grid: 280 kWh/t (of incoming waste) (ranging from 170 - 350 kWh/t) This corresponds to 85 Nm^3 of methane per tonne when assuming an electricity efficiency of 40%, 10 kWh/Nm^3 methane and own consumption of 65 kWh/t.. Digestate is used for agriculture ≈ 50% of input waste Wastewater volume is not stated.
Emissions	No data
Other technical details	The contamination level of the incoming waste is reported to be 5.5%. 42 days residence time. The water content of the waste should be 45% - 65%.
Plant area	0.8 ha
Investment estimate	

Table 26 – Case Study – Anaerobic Digestion (Wet Process)

Technology assessment	
Anaerobic digestion (wet process)	
Case study	Typical small scale 'wet' anaerobic digestion plant (BIOGEN GREENFINCH, Ludlow) The plant was built as part of the New Technologies Demonstrator Project in UK. The plant is expected to close in late 2012 after 6 years of operation. The reason is not stated in detail. http://www.resource.uk.com/article/Latest/Biocycle_AD_plant_Coder_Road_Ludlow_close-2158 (The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID11036), which is a tool developed by the UK Environment Agency.
Capacity of plant	7,500 tonnes per year
Input	Source separated organic waste and green waste (It is operated with 25% garden waste, 50% food waste and 25% paper/cardboard) Power – own consumption (when gas-motor is down): 15 kWh/t (of incoming waste) Natural gas: None Diesel: 0.9 litre/t Water consumption: 0.2 l/t
Output:	Net power to grid: 100 kWh/t (of incoming waste) (ranging from 75 – 100 kWh/t) Heat: 0.8 GJ/t Liquid digestate is used as fertilizer for agriculture ≈ 80% of input waste Fibres ≈ 5% of input waste Wastewater: None
Emissions	No data
Other technical details	The contamination level of the incoming waste is reported to be 1%. 56 days residence time.
Plant area	0.15 ha (seems rather low) ≈ 1 ha for a 45.000 tpa plant (Ramboll: around 75 x 150 meters. Including 3 weeks storage area for the centrifuge separated solid fraction of digestate)
Investment estimate	Ramboll estimate: £10 million for a 30 tpa plant (with all civil works prepared for 45 ktpa) Supplier estimates: Investment stated on TEG's Investor presentation 2010. Perth AD project:£4 million – 16,000 tpa plant (handover of facility in 2011) Dagenham (London): £15 million - 50,000 tpa plant (contract price 2012) *Information retrieved 10th of October 2012 from the web:* *http://www.theteggroup.plc.uk/images/upload/pdf/investor_presentation_march_2011_5282.pdf*

Table 27 – Case Study – Thermal Treatment (Grate Fired)

Technology assessment	
Thermal treatment (grate fired)	
Case study	Typical small scale grate fired plant (Chineham) The information is based on extracted information from WRATE (Waste and Resources Assessment Tool for the Environment) (Process ID12300), which is a tool developed by the UK Environment Agency.
Capacity of plant	95,000 tonnes per year
Input	Mixed municipal waste Power – 80 kWh/tonne (estimated) Natural gas: None Diesel: 1.5 litre/t Water consumption: subject to flue gas treatment system
Output:	Net power to grid: 20.1% of the energy in the waste is converted to electricity Heat: No heat production Incinerator bottom ash (IBA): 20% Flue gas treatment residue (including fly ash): 35 kg/tonne Wastewater: None
Emissions	Well below the limits stated in the EU Industrial Emission Directive.
Other technical details	Ramboll comment: A plant with the anticipated capacity as for Gibraltar normally produces heat (if there are any off-takers) as a turbine is relatively expensive for a small plant. The Danish plant in Hammel incinerates 29,500 tpa and sells 65,000 MWh of district heating. This corresponds to that 75% of the energy in the waste is sold
Plant area	1.4 ha
Investment estimate	≈ £80-100 million for a turnkey project including building and auxiliary equipment. However, the overall cost depends on the steel prices, supplier appetite for this capacity of plant and technical requirements to control monitoring systems etc. It is estimated that the investment cost for a turnkey plant of a capacity of 20,000 tpa is around £25 million. This budget price is based on a modern plant, but with some adjustments such as less advanced control and monitoring system.

Appendix 2 – Modelling Assumptions

Efficiency of Refuse Collection Systems

The expected efficiency of source separation – at households - of recyclables and organic waste is shown in Table 28.

Taking 'paper' for example, the table below illustrates that in a two bin system, 60% of the paper in the waste stream is recovered for recycling.

The values reflect the 'net' material recovery. It is assumed that rejects from final sorting of the dry recyclables are returned to the mixed residual waste.

Table 28 – Efficiency of Collection Systems

Collection efficiency of specific waste fractions	1 bin system	2 bin system		3 bin system
Fraction	%	Dry recyclables (+residual waste) %	Organic waste (+residual waste) %	Dry recyclables and organic waste (+ residual waste) %
Paper	0	60	0	60
Cardboard	0	60	0	60
Plastic film	0	30	0	30
Dense plastic	0	40	0	40
Textiles	0	0	0	0
Wood	0	0	0	0
Disposable nappies	0	0	0	0
Glass	0	60	0	60
Organic kitchen waste	0	0	50	50
Garden waste	0	0	0	0
Ferrous metal	0	60	0	60
Non ferrous metal	0	60	0	60
WEE	0	0	0	0
Other combustible	0	0	0	0
Other non combustible	0	0	0	0

Efficiency of Sorting Systems for Collected Refuse
A number of the selected scenarios are based on separation of the collection of the remaining refuse before further treatment. The sorting is done within a 'Material recovery facility' (MRF).

The values in Table 29 show the assumed material recovery rate from the remaining refuse after the household source separation.

An example – The gray shaded area in the Table 29 indicates that 20% of the paper fraction in the residual waste – after upstream removal of paper at household – can be recovered in a dirty MRF. If the total paper stream is 50 kg paper per tonne municipal waste then 10 kg can be recovered at the dirty MRF.

Table 29 – Efficiency of Material Recovery Systems

Sorting efficiency of remaining mixed refuse	**1 bin system**		**2 bin system (with dry recyclable collection)**	
Fraction	Recyclables %	Organic fraction %	Recyclables %	Organic fraction %
Paper	20	0	10	0
Cardboard	30	0	20	0
Plastic film	20	0	10	0
Dense plastic	30	0	20	0
Textiles	0	0	0	0
Wood	0	0	0	0
Disposable nappies	0	0	0	0
Glass	50	0	30	0
Organic kitchen waste	0	50	0	60
Garden waste	0	0	0	0
Ferrous metal	80	0	50	0
Non ferrous metal	80	0	50	0
WEE	0	0	0	0
Other combustible	0	0	0	0
Other non combustible	0	0	0	0
Sorting efficiency of remaining mixed refuse	**2 bin system (with organic collection)**		**3 bin system (with dry recyclables and organic collection)**	
Fraction	Recyclables %	Organic fraction %	Recyclables %	Organic fraction %
Paper	40	0	30	0
Cardboard	40	0	30	0
Plastic film	30	0	20	0
Dense plastic	40	0	30	0
Textiles	0	0	0	0
Wood	0	0	0	0
Disposable nappies	0	0	0	0
Glass	0	0	0	0
Organic kitchen waste	0	40	0	40
Garden waste	0	0	0	0
Ferrous metal	80	0	50	0
Non ferrous metal	80	0	50	0
WEE	0	0	0	0
Other combustible	0	0	0	0
Other non combustible	0	0	0	0

Assumptions for Treatment Technologies

Table 30 – Assumptions of Material recycling facility

Material recycling facility	Unit	Value
Power usage (Sorting recyclables and organic)	kWh/t waste	15
Diesel usage (Sorting recyclables and organic)	l/t waste	1
Power usage (Sorting organic only)	kWh/t waste	5
Diesel usage (Sorting organic only)	l/t waste	0.5
Power usage (Sorting recyclables only)	kWh/t waste	10
Diesel usage (Sorting recyclables only)	l/t waste	0.5

Table 31 – Assumptions of Thermal Treatment (Grate Fired)

Thermal treatment (grate fired)	Unit	Value
Energy		
Energy-to-steam efficiency	%	80
Own power consumption	kWh/t	80
Residues/product		
Bottom ash content (incl. boiler ash)	kg/t waste	200
Flue gas treatment residue (incl. fly ash)	kg/t waste	35

Table 32 – Assumptions of Organic Waste Handling (In-Vessel Composting)

In-vessel composting	Unit	Value
Energy		
Diesel consumption	kg/t waste	1
Electricity consumption	kWh/t waste	2
Residues/product		
Compost	kg/t waste	500

Table 33 – Assumptions of Organic Waste Handling (Anaerobic Digestion)

Anaerobic digestion	Unit	Value
Energy		
Diesel consumption	l/t waste	1
Electricity usage (excl. energy production)	kWh/t	25
Dry matter in organic material	%	35
Ash content in dry matter	%	30
Anaerobic degradation rate	%	60
Biogas production (calculated)	Nm^3 methane/t waste	51
Residues/product		
Digestate	kg/t waste	500

Appendix 3 – Waste Model Scenario Results

Scenario 0 — Export of all residual waste (baseline)

	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	0	0	12.4	2,247
Cardboard	19.5	3,536	0	0	19.5	3,536	0	0	19.5	3,536
Plastic film	11.0	1,984	0	0	11.0	1,984	0	0	11.0	1,984
Dense plastic	8.4	1,521	0	0	8.4	1,521	0	0	8.4	1,521
Textiles	4.2	752	0	0	4.2	752	0	0	4.2	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	0	0	4.5	822
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	0	0	29.1	5,270
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	0	0	3.8	685
Non ferrous metal	0.9	171	0	0	0.9	171	0	0	0.9	171
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	1.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.2	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	3.1	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		0		18,111
Overall recycling efficiency (in %)			0%				0%			
Lower calorific value (MJ/kg)		13.0				13.0				13.0

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency	%	0	Power usage	MWh/year	
Amount of waste sent to recycling facility			Diesel usage	m^3/year	
Paper	tpa	0	Steam - energy content	GJ/year	
Cardboard	tpa	0	Biogas - energy content	GJ/year	
Plastic film	tpa	0	**Products and residues**		
Dense plastic	tpa	0	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	18,111
Ferrous metal	tpa	0			
Non ferrous metal	tpa	0	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	0	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 1A — Sorting of residual waste into recyclables, organic fraction (to compost) and a remaining fraction (to landfill).

	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	20	449	15.0	1,797
Cardboard	19.5	3,536	0	0	19.5	3,536	30	1,061	20.6	2,475
Plastic film	11.0	1,984	0	0	11.0	1,984	20	397	13.2	1,587
Dense plastic	8.4	1,521	0	0	8.4	1,521	30	456	8.9	1,065
Textiles	4.2	752	0	0	4.2	752	0	0	6.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	50	411	3.4	411
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	50	2,635	21.9	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	80	548	1.1	137
Non ferrous metal	0.9	171	0	0	0.9	171	80	137	0.3	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	2.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.8	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	4.7	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		6,095		12,016
Overall recycling efficiency (in %)			0%				34%			
Lower calorific value (MJ/kg)		13.0				13.0				14.7

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		34%	Power usage	MWh/year	277
Amount of waste sent to recycling facility			Diesel usage	m^3/year	21
Paper	tpa	449	Steam - energy content	GJ/year	
Cardboard	tpa	1,061	Biogas - energy content	GJ/year	
Plastic film	tpa	397	**Products and residues**		
Dense plastic	tpa	456	Compost-like-material	tpa	1,318
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	411	Exported waste	tpa	
Ferrous metal	tpa	548	**0**		
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	12,016
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 1B

Sorting of residual waste into recyclables, organic fraction (to biogas) and a remaining fraction (to landfill).

Scenario	**Total waste produced**			**Recycling - Household**				**Recycling - Waste handling facility**		
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	20	449	15.0	1,797
Cardboard	19.5	3,536	0	0	19.5	3,536	30	1061	20.6	2,475
Plastic film	11.0	1,984	0	0	11.0	1,984	20	397	13.2	1,587
Dense plastic	8.4	1,521	0	0	8.4	1,521	30	456	8.9	1,065
Textiles	4.2	752	0	0	4.2	752	0	0	6.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	50	411	3.4	411
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	50	2635	21.9	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	80	548	1.1	137
Non ferrous metal	0.9	171	0	0	0.9	171	80	137	0.3	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	2.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.8	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	4.7	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		6,095		12,016
Overall recycling efficiency (in %)			0%				34%			
Lower calorific value (MJ/kg)		13.0				13.0				14.7

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		34%	Power usage	MWh/year	338
Amount of waste sent to recycling facility			Diesel usage	m^3/year	21
Paper	tpa	449	Steam - energy content	GJ/year	
Cardboard	tpa	1,061	Biogas - energy content	GJ/year	4,881
Plastic film	tpa	397	**Products and residues**		
Dense plastic	tpa	456	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	411	Exported waste	tpa	
Ferrous metal	tpa	548			
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	12,016
			Digestate	tpa	1,318
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 2A

Dry recyclables collected separately. Sorting the remaining waste into an organic fraction (to compost) and a residual fraction (to landfill)

Scenario	**Total waste produced**			**Recycling - Household**				**Recycling - Waste handling facility**		
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	7.2	899	0	0	8.7	899
Cardboard	19.5	3,536	60	2,122	11.4	1,414	0	0	13.7	1,414
Plastic film	11.0	1,984	30	595	11.2	1,389	0	0	13.5	1,389
Dense plastic	8.4	1,521	40	608	7.3	913	0	0	8.8	913
Textiles	4.2	752	0	0	6.0	752	0	0	7.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	2.6	329	0	0	3.2	329
Organic kitchen waste	29.1	5,270	0	0	42.4	5,270	40	2,108	30.6	3,162
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.2	274	0	0	2.7	274
Non ferrous metal	0.9	171	60	103	0.6	69	0	0	0.7	69
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.8	346	0	0	3.4	346
Other non combustible	1.2	216	0	0	1.7	216	0	0	2.1	216
Special municipal waste	3.1	561	0	0	4.5	561	0	0	5.4	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			5,681		12,430		2,108		10,322
Overall recycling efficiency (in %)			31%				12%			
Lower calorific value (MJ/kg)		13.0				12.3				13.9

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		43%	Power usage	MWh/year	66
Amount of waste sent to recycling facility			Diesel usage	m^3/year	8
Paper	tpa	1,348	Steam - energy content	GJ/year	
Cardboard	tpa	2,122	Biogas - energy content	GJ/year	
Plastic film	tpa	595	**Products and residues**		
Dense plastic	tpa	608	Compost-like-material	tpa	1,054
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	411			
Non ferrous metal	tpa	103	Residual waste to landfill	tpa	10,322
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	2,108	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 2B

Dry recyclables collected separately. Sorting the remaining waste into an organic fraction (biogas) and a residual fraction (to landfill)

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	7.2	899	0	0	8.7	899
Cardboard	19.5	3,536	60	2,122	11.4	1,414	0	0	13.7	1,414
Plastic film	11.0	1,984	30	595	11.2	1,389	0	0	13.5	1,389
Dense plastic	8.4	1,521	40	608	7.3	913	0	0	8.8	913
Textiles	4.2	752	0	0	6.0	752	0	0	7.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	2.6	329	0	0	3.2	329
Organic kitchen waste	29.1	5,270	0	0	42.4	5,270	40	2,108	30.6	3,162
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.2	274	0	0	2.7	274
Non ferrous metal	0.9	171	60	103	0.6	69	0	0	0.7	69
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.8	346	0	0	3.4	346
Other non combustible	1.2	216	0	0	1.7	216	0	0	2.1	216
Special municipal waste	3.1	561	0	0	4.5	561	0	0	5.4	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			5,681		12,430		2,108		10,322
Overall recycling efficiency (in %)			31%				12%			
Lower calorific value (MJ/kg)		13.0				12.3				13.9

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		43%	Power usage	MWh/year	115
Amount of waste sent to recycling facility			Diesel usage	m^3/year	8
Paper	tpa	1,348	Steam - energy content	GJ/year	
Cardboard	tpa	2,122	Biogas - energy content	GJ/year	3,905
Plastic film	tpa	595	**Products and residues**		
Dense plastic	tpa	608	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	411	**0**		
Non ferrous metal	tpa	103	Residual waste to landfill	tpa	10,322
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	2,108	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 3A

Organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	14.5	2,247	40	899	13.9	1,348
Cardboard	19.5	3,536	0	0	22.8	3,536	40	1,414	21.9	2,122
Plastic film	11.0	1,984	0	0	12.8	1,984	30	595	14.3	1,389
Dense plastic	8.4	1,521	0	0	9.8	1,521	40	608	9.4	913
Textiles	4.2	752	0	0	4.9	752	0	0	7.8	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	5.3	822	0	0	8.5	822
Organic kitchen waste	29.1	5,270	50	2,635	17.0	2,635	60	1,581	10.9	1,054
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	4.4	685	80	548	1.4	137
Non ferrous metal	0.9	171	0	0	1.1	171	80	137	0.4	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.2	346	0	0	3.6	346
Other non combustible	1.2	216	0	0	1.4	216	0	0	2.2	216
Special municipal waste	3.1	561	0	0	3.6	561	0	0	5.8	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			2,635		15,475		5,783		9,692
Overall recycling efficiency (in %)			15%				32%			
Lower calorific value (MJ/kg)		13.0				14.5				15.2

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		46%	Power usage	MWh/year	194
Amount of waste sent to recycling facility			Diesel usage	m^3/year	9
Paper	tpa	899	Steam - energy content	GJ/year	
Cardboard	tpa	1,414	Biogas - energy content	GJ/year	
Plastic film	tpa	595	**Products and residues**		
Dense plastic	tpa	608	Compost-like-material	tpa	2,108
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	548			
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	9,692
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	4,216	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 3B

Organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	14.5	2,247	40	899	13.9	1,348
Cardboard	19.5	3,536	0	0	22.8	3,536	40	1,414	21.9	2,122
Plastic film	11.0	1,984	0	0	12.8	1,984	30	595	14.3	1,389
Dense plastic	8.4	1,521	0	0	9.8	1,521	40	608	9.4	913
Textiles	4.2	752	0	0	4.9	752	0	0	7.8	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	5.3	822	0	0	8.5	822
Organic kitchen waste	29.1	5,270	50	2,635	17.0	2,635	60	1,581	10.9	1,054
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	4.4	685	80	548	1.4	137
Non ferrous metal	0.9	171	0	0	1.1	171	80	137	0.4	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.2	346	0	0	3.6	346
Other non combustible	1.2	216	0	0	1.4	216	0	0	2.2	216
Special municipal waste	3.1	561	0	0	3.6	561	0	0	5.8	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			2,635		15,475		5,783		9,692
Overall recycling efficiency (in %)			15%				32%			
Lower calorific value (MJ/kg)		13.0				14.5				15.2

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		46%	Power usage	MWh/year	194
Amount of waste sent to recycling facility			Diesel usage	m^3/year	9
Paper	tpa	899	Steam - energy content	GJ/year	
Cardboard	tpa	1,414	Biogas - energy content	GJ/year	7,809
Plastic film	tpa	595	**Products and residues**		
Dense plastic	tpa	608	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	548			
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	9,692
			Digestate	tpa	2,108
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	4,216	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 4A

Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic fraction (compost) and a residual fraction (to landfill)

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	9.2	899	40	359	8.0	539
Cardboard	19.5	3,536	60	2,122	14.4	1,414	40	566	12.6	849
Plastic film	11.0	1,984	30	595	14.2	1,389	30	417	14.4	972
Dense plastic	8.4	1,521	40	608	9.3	913	40	365	8.1	548
Textiles	4.2	752	0	0	7.7	752	0	0	11.1	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	3.4	329	0	0	4.9	329
Organic kitchen waste	29.1	5,270	50	2,635	26.9	2,635	40	1,054	23.4	1,581
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.8	274	80	219	0.8	55
Non ferrous metal	0.9	171	60	103	0.7	69	80	55	0.2	14
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	3.5	346	0	0	5.1	346
Other non combustible	1.2	216	0	0	2.2	216	0	0	3.2	216
Special municipal waste	3.1	561	0	0	5.7	561	0	0	8.3	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			8,316		9,795		3,035		6,760
Overall recycling efficiency (in %)			46%				17%			
Lower calorific value (MJ/kg)		13.0				14.4				14.5

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		63%	Power usage	MWh/year	149
Amount of waste sent to recycling facility			Diesel usage	m^3/year	12
Paper	tpa	1,708	Steam - energy content	GJ/year	
Cardboard	tpa	2,687	Biogas - energy content	GJ/year	
Plastic film	tpa	1,012	**Products and residues**		
Dense plastic	tpa	973	Compost-like-material	tpa	1,845
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	630			
Non ferrous metal	tpa	158	Residual waste to landfill	tpa	6,760
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	3,689	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 4B

Dry recyclables and organic waste collected separately. The remaining waste is split into recyclables, organic fraction (biogas) and a residual fraction (to landfill)

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	9.2	899	40	359	8.0	539
Cardboard	19.5	3,536	60	2,122	14.4	1,414	40	566	12.6	849
Plastic film	11.0	1,984	30	595	14.2	1,389	30	417	14.4	972
Dense plastic	8.4	1,521	40	608	9.3	913	40	365	8.1	548
Textiles	4.2	752	0	0	7.7	752	0	0	11.1	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	3.4	329	0	0	4.9	329
Organic kitchen waste	29.1	5,270	50	2,635	26.9	2,635	40	1,054	23.4	1,581
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.8	274	80	219	0.8	55
Non ferrous metal	0.9	171	60	103	0.7	69	80	55	0.2	14
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	3.5	346	0	0	5.1	346
Other non combustible	1.2	216	0	0	2.2	216	0	0	3.2	216
Special municipal waste	3.1	561	0	0	5.7	561	0	0	8.3	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			8,316		9,795		3,035		6,760
Overall recycling efficiency (in %)			46%				17%			
Lower calorific value (MJ/kg)		13.0				14.4				14.5

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		63%	Power usage	MWh/year	173
Amount of waste sent to recycling facility			Diesel usage	m^3/year	47
Paper	tpa	1,708	Steam - energy content	GJ/year	
Cardboard	tpa	2,687	Biogas - energy content	GJ/year	6,833
Plastic film	tpa	1,012	**Products and residues**		
Dense plastic	tpa	973	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	630			
Non ferrous metal	tpa	158	Residual waste to landfill	tpa	6,760
			Digestate	tpa	1,845
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	3,689	Fly gas treatment residue (to haz landfill)	tpa	

Scenario 5

All residual waste treated by thermal treatment

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	0	0	12.7	2,247
Cardboard	19.5	3,536	0	0	19.5	3,536	0	0	20.1	3,536
Plastic film	11.0	1,984	0	0	11.0	1,984	0	0	11.3	1,984
Dense plastic	8.4	1,521	0	0	8.4	1,521	0	0	8.6	1,521
Textiles	4.2	752	0	0	4.2	752	0	0	4.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	0	0	4.7	822
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	0	0	29.9	5,270
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	70	480	1.2	206
Non ferrous metal	0.9	171	0	0	0.9	171	0	0	1.0	171
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	2.0	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.2	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	3.2	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		480		17,631
Overall recycling efficiency (in %)			0%				3%			
Lower calorific value (MJ/kg)		13.0				13.0				13.4

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		3%	Power usage	MWh/year	1,449
Amount of waste sent to recycling facility			Diesel usage	m^3/year	
Paper	tpa	0	Steam - energy content	GJ/year	188,851
Cardboard	tpa	0	Biogas - energy content	GJ/year	
Plastic film	tpa	0	**Products and residues**		
Dense plastic	tpa	0	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	480			
Non ferrous metal	tpa	0	Residual waste to landfill	tpa	17,631
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	3,622
Organic material for treatment	tpa	0	Fly gas treatment residue (to haz landfill)	tpa	634

Scenario 6A — Residual waste is split into recyclables, organic fraction (compost) and a remaining fraction for thermal treatment.

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	20	449	15.0	1,797
Cardboard	19.5	3,536	0	0	19.5	3,536	30	1,061	20.6	2,475
Plastic film	11.0	1,984	0	0	11.0	1,984	20	397	13.2	1,587
Dense plastic	8.4	1,521	0	0	8.4	1,521	30	456	8.9	1,065
Textiles	4.2	752	0	0	4.2	752	0	0	6.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	50	411	3.4	411
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	50	2,635	21.9	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	80	548	1.1	137
Non ferrous metal	0.9	171	0	0	0.9	171	80	137	0.3	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	2.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.8	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	4.7	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		6,095		12,016
Overall recycling efficiency (in %)			0%				34%			
Lower calorific value (MJ/kg)		13.0				13.0				14.7

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		31%	Power usage	MWh/year	1,233
Amount of waste sent to recycling facility			Diesel usage	m^3/year	0
Paper	tpa	449	Steam - energy content	GJ/year	141,124
Cardboard	tpa	1,061	Biogas - energy content	GJ/year	
Plastic film	tpa	397	**Products and residues**		
Dense plastic	tpa	456	Compost-like-material	tpa	1,318
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	411	Exported waste	tpa	
Ferrous metal	tpa	96			
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	2,403
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	421

Scenario 6B — Residual waste is split into recyclables, organic fraction (biogas) and a remaining fraction for thermal treatment.

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	20	449	15.0	1,797
Cardboard	19.5	3,536	0	0	19.5	3,536	30	1,061	20.6	2,475
Plastic film	11.0	1,984	0	0	11.0	1,984	20	397	13.2	1,587
Dense plastic	8.4	1,521	0	0	8.4	1,521	30	456	8.9	1,065
Textiles	4.2	752	0	0	4.2	752	0	0	6.3	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	50	411	3.4	411
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	50	2,635	21.9	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	80	548	1.1	137
Non ferrous metal	0.9	171	0	0	0.9	171	80	137	0.3	34
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	2.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.8	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	4.7	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		6,095		12,016
Overall recycling efficiency (in %)			0%				34%			
Lower calorific value (MJ/kg)		13.0				13.0				14.7

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		31%	Power usage	MWh/year	1,233
Amount of waste sent to recycling facility			Diesel usage	m^3/year	0
Paper	tpa	449	Steam - energy content	GJ/year	141,124
Cardboard	tpa	1,061	Biogas - energy content	GJ/year	4,881
Plastic film	tpa	397	**Products and residues**		
Dense plastic	tpa	456	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	411	Exported waste	tpa	
Ferrous metal	tpa	96			
Non ferrous metal	tpa	137	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	2,403
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	421

Scenario 7 — Organic waste collected at household (compost). Remaining residual waste for thermal treatment.

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	60	1,348	7.2	899	0	0	7.2	899
Cardboard	19.5	3,536	60	2,122	11.4	1,414	0	0	11.4	1,414
Plastic film	11.0	1,984	30	595	11.2	1,389	0	0	11.2	1,389
Dense plastic	8.4	1,521	40	608	7.3	913	0	0	7.3	913
Textiles	4.2	752	0	0	6.0	752	0	0	6.0	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	60	493	2.6	329	0	0	2.6	329
Organic kitchen waste	29.1	5,270	0	0	42.4	5,270	0	0	42.4	5,270
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	60	411	2.2	274	0	0	2.2	274
Non ferrous metal	0.9	171	60	103	0.6	69	0	0	0.6	69
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.8	346	0	0	2.8	346
Other non combustible	1.2	216	0	0	1.7	216	0	0	1.7	216
Special municipal waste	3.1	561	0	0	4.5	561	0	0	4.5	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			5,681		12,430		0		12,430
Overall recycling efficiency (in %)			31%				0%			
Lower calorific value (MJ/kg)		13.0				12.3				12.3

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		32%	Power usage	MWh/year	994
Amount of waste sent to recycling facility			Diesel usage	m^3/year	0
Paper	tpa	1,348	Steam - energy content	GJ/year	122,576
Cardboard	tpa	2,122	Biogas - energy content	GJ/year	
Plastic film	tpa	595	**Products and residues**		
Dense plastic	tpa	608	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	493	Exported waste	tpa	
Ferrous metal	tpa	603			
Non ferrous metal	tpa	103	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	2,486
Organic material for treatment	tpa	0	Fly gas treatment residue (to haz landfill)	tpa	435

Scenario 8A — Organic waste collected at household (compost). Remaining residual waste for thermal treatment.

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	14.5	2,247	0	0	14.5	2,247
Cardboard	19.5	3,536	0	0	22.8	3,536	0	0	22.8	3,536
Plastic film	11.0	1,984	0	0	12.8	1,984	0	0	12.8	1,984
Dense plastic	8.4	1,521	0	0	9.8	1,521	0	0	9.8	1,521
Textiles	4.2	752	0	0	4.9	752	0	0	4.9	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	5.3	822	0	0	5.3	822
Organic kitchen waste	29.1	5,270	50	2,635	17.0	2,635	0	0	17.0	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	4.4	685	0	0	4.4	685
Non ferrous metal	0.9	171	0	0	1.1	171	0	0	1.1	171
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.2	346	0	0	2.2	346
Other non combustible	1.2	216	0	0	1.4	216	0	0	1.4	216
Special municipal waste	3.1	561	0	0	3.6	561	0	0	3.6	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			2,635		15,475		0		15,475
Overall recycling efficiency (in %)			15%				0%			
Lower calorific value (MJ/kg)		13.0				14.5				14.5

Performance overview

Recycling			**Energy (excl. collection system)**		
Total recycling efficiency		17%	Power usage	MWh/year	1,238
Amount of waste sent to recycling facility			Diesel usage	m^3/year	
Paper	tpa	0	Steam - energy content	GJ/year	179,153
Cardboard	tpa	0	Biogas - energy content	GJ/year	
Plastic film	tpa	0	**Products and residues**		
Dense plastic	tpa	0	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	480			
Non ferrous metal	tpa	0	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	3,095
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	542

Scenario 8B — Organic waste collected at household (biogas). Remaining residual waste for thermal treatment.

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	14.5	2,247	0	0	14.5	2,247
Cardboard	19.5	3,536	0	0	22.8	3,536	0	0	22.8	3,536
Plastic film	11.0	1,984	0	0	12.8	1,984	0	0	12.8	1,984
Dense plastic	8.4	1,521	0	0	9.8	1,521	0	0	9.8	1,521
Textiles	4.2	752	0	0	4.9	752	0	0	4.9	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	5.3	822	0	0	5.3	822
Organic kitchen waste	29.1	5,270	50	2,635	17.0	2,635	0	0	17.0	2,635
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	4.4	685	0	0	4.4	685
Non ferrous metal	0.9	171	0	0	1.1	171	0	0	1.1	171
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	2.2	346	0	0	2.2	346
Other non combustible	1.2	216	0	0	1.4	216	0	0	1.4	216
Special municipal waste	3.1	561	0	0	3.6	561	0	0	3.6	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			2,635		15,475		0		15,475
Overall recycling efficiency (in %)			15%				0%			
Lower calorific value (MJ/kg)		13.0				14.5				14.5

Performance overview

Recycling			Energy (excl. collection system)		
Total recycling efficiency		17%	Power usage	MWh/year	1,238
Amount of waste sent to recycling facility			Diesel usage	m^3/year	
Paper	tpa	0	Steam - energy content	GJ/year	179,153
Cardboard	tpa	0	Biogas - energy content	GJ/year	4,881
Plastic film	tpa	0	**Products and residues**		
Dense plastic	tpa	0	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	480			
Non ferrous metal	tpa	0	Residual waste to landfill	tpa	
			Digestate	tpa	1,318
			Bottom ash (used as aggregate)	tpa	3,095
Organic material for treatment	tpa	2,635	Fly gas treatment residue (to haz landfill)	tpa	542

Scenario 9 — Fuel production for export (Preparation of fuel by removal of metals and drying of remaining waste through aeration).

Scenario	Total waste produced		Recycling - Household				Recycling - Waste handling facility			
	Composition	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*	*Recycling efficiency*	*Mass removed*	*New composition*	*Mass flow*
	%	tpa	%	t/year	%	t/year	%	t/year	%	t/year
Paper	12.4	2,247	0	0	12.4	2,247	0	0	12.4	2,247
Cardboard	19.5	3,536	0	0	19.5	3,536	0	0	19.5	3,536
Plastic film	11.0	1,984	0	0	11.0	1,984	0	0	11.0	1,984
Dense plastic	8.4	1,521	0	0	8.4	1,521	0	0	8.4	1,521
Textiles	4.2	752	0	0	4.2	752	0	0	4.2	752
Wood	0.0	0	0	0	0.0	0	0	0	0.0	0
Disposable nappies	0.0	0	0	0	0.0	0	0	0	0.0	0
Glass	4.5	822	0	0	4.5	822	0	0	4.5	822
Organic kitchen waste	29.1	5,270	0	0	29.1	5,270	0	0	29.1	5,270
Garden waste	0.0	0	0	0	0.0	0	0	0	0.0	0
Ferrous metal	3.8	685	0	0	3.8	685	0	0	3.8	685
Non ferrous metal	0.9	171	0	0	0.9	171	0	0	0.9	171
WEE	0.0	0	0	0	0.0	0	0	0	0.0	0
Other combustible	1.9	346	0	0	1.9	346	0	0	1.9	346
Other non combustible	1.2	216	0	0	1.2	216	0	0	1.2	216
Special municipal waste	3.1	561	0	0	3.1	561	0	0	3.1	561
Total (in %)	*100*				*100*				*100*	
Amount of waste (tpa)	18,111			0		18,111		0		18,111
Overall recycling efficiency (in %)			0%				0%			
Lower calorific value (MJ/kg)		13.0				13.0				13.0

Performance overview

Recycling			Energy (excl. collection system)		
Total recycling efficiency		3%	Power usage	MWh/year	
Amount of waste sent to recycling facility			Diesel usage	m^3/year	
Paper	tpa	0	Steam - energy content	GJ/year	
Cardboard	tpa	0	Biogas - energy content	GJ/year	
Plastic film	tpa	0	**Products and residues**		
Dense plastic	tpa	0	Compost-like-material	tpa	
Textiles	tpa	0	RDF (refuse derived fuel)	tpa	
Glass	tpa	0	Exported waste	tpa	
Ferrous metal	tpa	480			
Non ferrous metal	tpa	86	Residual waste to landfill	tpa	
			Digestate	tpa	
			Bottom ash (used as aggregate)	tpa	
Organic material for treatment	tpa	0	Fly gas treatment residue (to haz landfill)	tpa	

Appendix 4 – Ability to treat Other Fractions

Ability to treat other waste fractions

Table 34 – Composting – handling of additional waste fraction

Technology	Waste fractions	Advantages/ disadvantages	Suitability
In-vessel Composting	Non-hazardous bulky waste	- Wood chips improve the structure of the organic waste as it allows for better air transport into the compost matrix. - Restriction of maximum input of wood chips, as non-degraded chips are sieved from the compost of recycled unless the off-taker allow for wood chips (e.g. for landfill cover or similar) - Potential issues from the chemicals used to impregnate wood to be assessed.	(✓) (There are restrictions of the maximum input of wood waste. Roughly the organic waste and wood chips can be mixed in a ratio 1:1. Around 70-90% of the wood chips can assumed recycled)
	Oil sludge		✘ (The oil sludge not suitable for composting)
	Bilge oil		✘ (The bilge oil not suitable for composting)
	Wastewater treatment sludge	- Reduced disposal cost – Increase requirement for timber waste, if sludge is composted. - Co-treatment with sludge potential makes the compost less attractive, especially if organic food waste was collected separately. - Increased footprint of facility. - No energy recovery of the energy in the sludge or the additional wood waste used.	✓ (All sludge can probably be co-composted with the organic material).

Table 35 – Anaerobic digester – handling of additional waste fraction

Technology	Waste fractions	Advantages/ disadvantages	Suitability
Anaerobic digestion	Non-hazardous bulky waste		✘ (These fractions will not– even though that they are fully/partly organic –be significantly biodegradable in the anaerobic digester and therefore not produce additional biogas)
	Oil sludge		
	Bilge oil		
	Wastewater treatment sludge	- Reduced disposal cost - Increased energy production - Limited technical risks	✓ (All sludge can be co-digested with the organic waste as there is no min/max ratio between the organic waste and the sludge. Co-digestion is common for many plants in Europe).
		- The treatment with sludge may make it less attractive to use the digestate of fertilizer.	

Table 36 – Grate fired thermal treatment – handling of additional waste fraction

Technology	Waste fractions	Advantages/ disadvantages	Suitability
Grate fired thermal treatment	Non-hazardous bulky waste	- Increased energy production. - Minimizing fluctuation of thermal input, as wood waste can temporary stored. - Limited technical risks	✓ (No limits on amount of combustible bulky waste that can be mixed with refuse and incinerated – when facility is designed accordingly)
		- Shredder may be required - Additional area for sorting of bulky waste may be required	
	Oil sludge	- Reduction of disposal costs - Slightly increased energy production - Potentially reducing thermal fluctuations, as oil sludge can temporary stored and used to adjust the thermal input.	✓ (Preferable the oil sludge should be injected the furnace above the grate through lances. Potential pre-treatment and handling system is be evaluated)
		- Oil sludge handling equipment to be serviced and maintained - Technical risks for handling system - Potentially an additional requirements of PAH measurement of the bottom ash and of the cleaned flue gas.	
	Bilge oil	- Similar to 'Oil sludge'	✓ (Around 0.1 tonnes of bilge oil can be added per 1 tonne of municipal waste. However, above fraction is dependent on e.g. the calorific value of refuse and the oil content of the bilge oil)
		– Equipment may be required to concentrate bilge oil before treatment technology. (The first step is to mechanically separate as much water as possible. The second step may be concentrating the bilge oil through indirect heat transfer by use of boiler steam). - Similar to 'Oil sludge'	
	Wastewater treatment sludge	- Reduced disposal cost - Increased energy production	✓ (Around 0.1 tonnes of sludge can be added per 1 tonne of municipal waste)
		- Increased technical risks as it is relatively uncommon to co-incinerate sludge – especially it relatively small facility. Co-incineration is done in Zurich and Brescia. It can be either done by dropping the sludge onto the grate or by adding the sludge in the chute before entrance to the grate. It is most likely not attractive to dry sludge prior to incineration due to additional project complexity.	