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Memorandum

To:	Jay Heaman Manager, Strategic Initiatives	**From:**	Mark Sungaila, Ben Arnold SLR Consulting
Company:	Oxford County		
cc:		**Date:**	August 4, 2017
Subject:	**ASSESSMENT OF WASTE REDUCTION AND RECOVERY TECHNOLOGIES TECHNICAL MEMORANDUM 1A: STAGE 1 - SETTING THE SCENE**		

1.0 INTRODUCTION

Oxford County operates a very successful municipal solid waste management program having achieved a ranking of 6th out of 230 Ontario municipalities for diverting residential waste from landfill, as well as a ranking of 1st in diversion for municipalities within its grouping[1]. The County has also embarked on an ambitious program to achieve two significant long term Sustainability goals, being 1) achievement of 100% renewable energy by 2050[2], in accordance with the County's June 2015 resolution; and, 2) achievement of Zero Waste, as articulated in the September 2016 draft Zero Waste Plan[3]. Oxford County's renewable energy commitment provides a mechanism for linking the two goals outlined above and recognizes that residual waste can form a useful feedstock for generating energy from waste. As part of its program toward achieving Zero Waste and other related goals, OC has undertaken this ***Assessment of Waste Recovery and Reduction Technologies*** (the Project). The Project is being undertaken amidst the development of recent climate change and waste management legislation (and related policies, strategies, and emerging programs), intended to dramatically reduce waste generation and disposal, and intended to drive the 'Circular Economy'.

The County has retained the consulting team of SLR Consulting (Canada) Ltd., in association with Love Environment to assist them in carrying out the Project, which will consist of five main tasks described in following **Sections 1.1** through **1.5.**

[1] Full Report County of Oxford Waste Management Strategy, Oxford County, August 2014.

[2] Draft 100% Renewable Energy Plan, Oxford County, June 22 2016.

[3] Draft Zero Waste Plan, Oxford County, September 22, 2106.

1.1 Task 1: Assessment of Existing Waste Recovery Technologies

Task 1 is a comprehensive review of existing approaches to the reduction of residual waste, leading to identification of technologies that are relevant to Oxford County. This will be undertaken in three stages:

- *Stage 1: Setting the Scene*: This is an analysis of the current waste management situation in Oxford County aimed at characterising the County's waste management situation in terms of scale, current approach, types of waste, barriers and opportunities.

- *Stage 2: Technology Options (Inclusive List).* Stage 2 is identification of a long list of technology suppliers under each material type and technology class. This long list would subsequently be screened against a set of criteria which would be agreed with the County.

- *Stage 3: In-depth Evaluation.* Stage 3 is a more in-depth analysis of the individual technologies using the County's Multi Criteria Analysis Tool (MCA).

1.2 Task 2: Case Studies of Implemented Technologies

Task 2 will result in the documentation of case studies of technologies implemented in other jurisdictions, as well as highlighting of those technologies which have been successfully implemented and which have highest likelihood of successful implementation in Oxford County.

1.3 Task 3: Review of New and Emerging Technologies

This task will be the documentation of new and emerging technologies as identified in Task 1, as supplemented by gathering of additional data as required and prepare meaningful commentary.

1.4 Task 4: Relationship of EPR and Resource Recovery with Current Waste Stream

Task 4 will examine and assess the impacts of recent climate change and waste management legislation, namely:

- Bill 151 – the *Waste Free Ontario Act* which includes both *Resource Recovery and Circular Economy Act* and the *Waste Diversion Transition Act;*
- The *Strategy for a Waste Free Ontario* (through which topics like the future of organics, disposal bans, new material designations and ICI diversion are prominent); and,
- The *Ontario Climate Change Action Plan* (and it potential impact on municipal waste operations).

This legislation will be examined in the context of several key questions, including the County's role in the delivery of waste management services in areas where producer responsibility is significantly changing, and the County's role in ensuring that expanded EPR programs that are implemented are well integrated with the overall waste management system.

1.5 Task 5: Economic Potential of Full Resource Recovery

This task will seek to identify the net economic benefits of implementing the preferred technology solutions identified in Task 1, considering the outline Capex and Opex costs of technologies, and accounting for the value within recovered materials, the potential sale of power and/or heat from certain categories of technology, and avoided costs of landfilling and long-term management of impacts.

1.6 Study Documentation

Documentation generated during this study will be presented in technical memoranda covering each task. Following review and agreement by the County, the technical memos will be combined into a final report with an overarching introduction and conclusion section.

2.0 DOCUMENT OBJECTIVES AND ORGANIZATION

This document is **Technical Memorandum 1a (TM1a)**, which summarizes Task 1, Stage 1 work. The content of TM1a is based on Oxford County's Task 1 scope definition contained in their Request for Proposal (RFP), as further informed by discussions with OC since commencement of the Project.

3.0 PROJECTED WASTE GENERATION IN OXFORD COUNTY

3.1 Baseline Waste Generation

The most recent Waste Management Strategy for Oxford County (OC) was issued in 2014 and has been provided to SLR for review[4]. The most comprehensive waste data within this document is the GAP waste flow analysis for 2010 and this has been used in conjunction with the County's latest available population projection data, to derive a figure for the waste generation per capita. The data is summarized in **Table 3-1.** As shown, in 2010 the County managed a total of 39.1kt of residential waste, equating to a generation rate of approximately 363kg per person[5]. 42.2% of this total was garbage with the remainder being comprised of a combination of source or depot-segregated organics, blue box and other recyclable materials. (In OC, organics comprise only yard, leaf and brush waste). For 2010, a diversion rate of 54.1% was achieved.

[4] Full Report County of Oxford Waste Management Strategy, Oxford County, August 2014.

[5] Population in 2010 estimated to be approximately 107,860.

Table 3-1 Waste Collected and Processed in 2010

Material Category		Tonnes Collected			Tonnes Processed	
		Curbside	Depot	Total	Diverted	Disposed*
Recyclables	Printed Paper & Packaging	7,370.44	-	7,370.44	6,927.14	443.30
	Wine and Spirits Containers	-	566.19	566.19	566.19	-
Other Recyclables	Textiles	-	-	0.00	3,529.32	863.18
	Bulky Goods	-	-	0.00		
	Scrap Metal	34.14	473.71	507.85		
	Dry Wall	-	203.67	203.67		
	Wood	-	686.36	686.36		
	Brick and Concrete	-	0.00	0.00		
	Other C&D Recyclables	75.37	2,852.73	2,928.10		
	Tires	-	66.52	66.52		
Organics	Leaf and Yard Waste	8,275.32	-	8,275.32	8,193.01	82.31
	Grasscycling	-	372.39	372.39	372.39	-
	Backyard Composting	-	1,292.30	1,292.30	1,292.30	-
Other Diversion	MHSW	69.43	93.10	162.53	146.77	15.76
	WEEE	-	171.87	171.87	137.50	34.37
Garbage		13,928.65	2,599.05	16,527.70	-	16,527.70
Total		29,753.35	9,377.89	39,131.24	21,164.62	17,966.62
				Current Diversion Rate		54%
				Material Disposed		46%
				Recyclables Diverted		28%
				Organics / Other Diverted		26%

Further basic composition data are presented in the 2014 Waste Strategy and in the 2015 Waste Diversion Year End Report[6], but they do not provide the level of compositional detail presented in the 2010 GAP analysis. Further detailed audit of OC's residual garbage forms part of new work which is currently being carried out by AET, with initial results expected to be made available in the early summer.

3.2 Forecasting Methodology

Key factors determining future rates of generation of residential waste are:

- growth in the overall generation of residential waste due to increased population; and

[6] 2015 Blue Box Waste Management System Annual Report, Oxford County, March 23, 2016.

- changes in rates of separation and segregation of waste materials for reuse, recycling and composting, due to changing behaviour and/or changing collection systems.

Projecting potential future behaviour change is very difficult, therefore for the purpose of this review, we have made the conservative assumption that levels of overall residential waste generation per resident in OC will remain relatively constant. Making this assumption, any increased tonnage of residential waste generated in Oxford will be driven by population growth. In projecting waste generation, population projections published in the Waste Management Strategy for 2014 are assumed. The population projections for OC equate to a compound annual growth rate of 0.5% between 2010 and 2041. We have assumed that in the absence of other guidance, the population remains static from 2041-50.

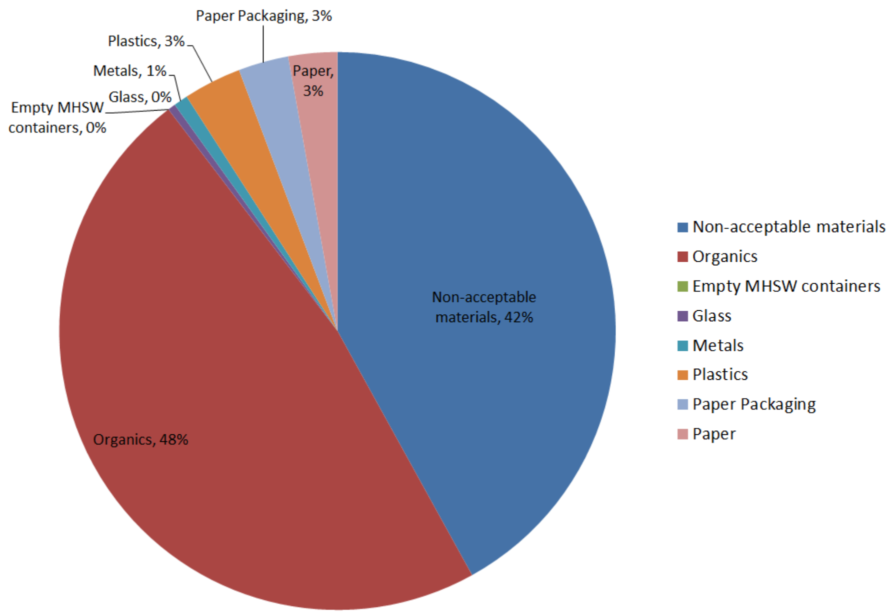
Materials separated for reuse, recycling and composting must be deducted from the total projected residential waste arising to establish the remaining quantity of residual waste (garbage and non-accepted recyclables) requiring treatment / disposal. As noted above, in 2010 Oxford County diverted 54.1% of the residential waste generated. The 2015 Waste Diversion Year End Report indicates that diversion has increased steadily to around 59% in 2015.

OC has embarked upon a programme of moving towards Zero Waste, although this does not yet have any specific targets set, against which to measure their achievement. This will include development of various new initiatives for the collection and processing of waste material. The potential impacts of these initiatives cannot be known at this time, but it is already clear that the County has already significantly exceeded the 2030 level of diversion recently proposed by the Ontario Ministry of Environment and Climate Change (MoECC).

In order to assess the potential shape and size of future waste and recycling we have sought other compositional information in the public domain. Although this is very limited, the CIF Ontario Single Family Curbside Audit report published in 2014 is useful. In discussion with the reports' authors, AET, it is considered that the Small Urban and Urban Regional municipalities could be reasonably comparable to OC (given that data for the two Rural Regional municipalities featured will be skewed by their relatively high proportion of seasonal dwellings in comparison to OC).

At the time the waste audits were conducted, the Urban Regional municipality had a green bin programme in place for the collection of curbside organic materials. As OC does not have such a programme in place, in drawing parallels from the waste study, it is assumed that the material presented in the green bins would otherwise be in the garbage for the case of Oxford. **Figure 3-1** presents a chart showing the derived composition, excluding blue box materials.

Figure 3-1 Indicative Waste Composition (excluding Blue Box)



In **Figure 3-1**, "organics" are assumed to comprise yard wastes and "non-acceptable materials" are assumed to include all food wastes.

For the purpose of modelling, we have derived a high-level compositional breakdown for all waste and other materials in 2012/13, as follows:

- Dry Recyclables 40%;
- Yard organics 31%;
- Food waste 14%;
- Non-recyclables 14%.

We have then derived a series of assumed capture rates from which overall future waste diversion figures are calculated. This has included the estimation of capture rates for 2010 and 2012/13 which would give the actual diversion rates achieved in OC, as shown in **Table 3-2**.

Table 3-2 – Assumed Capture Rates

Material	**Composition (2012/13)**	**Baseline (2010)**	**2015**	**2020**	**2030**	**2040**	**2050**
Dry recyclables	40%	72%	85%	85%	85%	93%	100%
Yard organics	31%	80%	80%	80%	80%	90%	100%
Food	14%	0%	0%	50%	75%	88%	100%
Non-recyclables	14%	0%	0%	0%	0%	0%	0%
Total	**100%**						
Combined diversion rate		**54.0%**	**59.2%**	**66.4%**	**69.9%**	**77.8%**	**85.8%**

These assumed capture rates for each material type have then been applied to the modelled population growth estimates to derive projected tonnages of collected material streams at key dates.

In developing projections for waste generation and diversion, the following scenarios have been considered:

- Scenario A – no change; and
- Scenario B – gradual increase in capture rate of recyclables, food and yard organics to a capture rate of 100% in 2050.

3.3 Forecasted Recycling and Residual Waste

Accounting for waste growth and recycling assumptions outlined above, **Table 3-3** illustrates the projected arising of residential waste collected in OC.

Table 3-3 - Residential Waste Generation Summary

Scenario		2020	2030	2040	2050
A	Total Waste Generated (tonnes)	41,627	44,000	45,495	45,604
	Dry recyclables diverted (tonnes)	14,305	15,120	15,634	15,671
	Yard organics diverted (tonnes)	10,355	10,946	11,317	11,344
	Food diverted (tonnes)	0	0	0	0
	Non-recyclables disposed (tonnes)	16,967	17,934	18,543	18,588
B	Total Waste Generated (tonnes)	41,627	44,000	45,495	45,604
	Dry recyclables diverted (tonnes)	14,305	15,120	17,013	18,437
	Yard organics diverted (tonnes)	10,355	10,946	12,732	14,181
	Food diverted (tonnes)	2,963	4,699	5,668	6,493
	Non-recyclables disposed (tonnes)	14,004	13,236	10,081	6,493

As shown, with the introduction of as yet unspecified future reuse/recycling/composting initiatives, the expectation is for:

- a marginal increase in recyclables collected up to 2020, 2030 and 2050 to meet the diversion targets for both scenarios;
- an ongoing gradual increase in residential waste collected in line with population growth; and
- a significant decline in total waste going to landfill.

Over the period 2020 to 2050 for the scenarios considered:

- the overall annual residential waste (garbage and recycling combined) tonnage increases from 41.6kt, to 45.6ktpa; and

- the overall annual residential tonnage of diversion increased from 24.6ktpa to between 27.0ktpa and 39.0ktpa.

3.4 Additional Comments

As part of the review of the data available, SLR has compared the total residential waste generation presented in the Oxford Waste Strategy Report against those presented in the Waste Diversion Year End Report for 2015. For 2011 through to 2013, the total residential waste that is reported to have been collected is considerably lower in the 2015 Year End Report than it is in the 2014 Waste Strategy Report. This difference could be explained by the fact that the C&D tonnages have not been included in the 2015 Year End Report as this material is collected at the C&D material depot and is recycled separately by the County's contractor.

It is reported that in 2015 the County diverted approximately 7,300 tonnes of C&D material from landfill. Assuming a comparable tonnage was also collected in the preceding years, this would bring the two reports to within +/-5% of each other for 2011 and 2013. The difference is greater for 2013; however, it is possible that more C&D material was collected in that particular year.

A further comparison was carried out to assess whether the figures presented in the 2015 Year End Report were aligned with the figures presented in SLR's high level projections. It is reported that approximately 43,510 tonnes of material were collected by the County in 2015 (inclusive of IC&I and C&D material). In contrast, SLR's high level forecast for the 'no change' scenario projected a tonnage of approximately 40,270 tonnes for the same period – a difference of approximately 8%. Again, this difference could be attributed to the annual variation in the generation of some material streams, such as C&D material which rather than being a function of population growth alone, may be linked to other factors such economic growth.

It should be noted that the ability of the County to capture further recyclable materials will be constrained by a number of issues including:

- The effectiveness of any communication campaign in influencing residents to improve the segregation of residential waste and recycling at source; and
- The ability of any new sorting/pre-treatment technology employed to achieve the capture rates required to enable the authority to meet its diversion targets.

Furthermore, as more recyclables are recovered from the garbage stream, the remaining proportion of recyclables will become increasingly difficult to recover.

4.0 INITIAL TECHNOLOGY CONSIDERATIONS

The projected changes in recycling targets and residual waste stream will impact on the selection of technology types and capacities, the size of facility and particularly the economic viability of MRF and WtE options. A broad description of waste treatment technologies is provided in **Appendix A**.

Based on the projections made herein and SLR's industry experience, the following initial technology class considerations are presented:

- Conventional combustion Waste to Energy (WtE) is generally not viable at throughputs of less than 40 kpta – 60 ktpa, and is therefore likely not viable for OC's waste stream on its own.

- Advanced thermal treatment technologies such as gasification/pyrolysis are generally not viable below a throughput of 5ktpa to 10ktpa, and may therefore be viable for OC's projected waste stream, depending upon the waste generation scenario considered.

- 'Complex' MRF technologies are not generally not viable below throughputs of 15kpta to 25ktpa etc., and may therefore be viable for OC's projected waste stream, depending upon the waste generation scenario considered.

- Ultimately the viability of any given technology class depends on jurisdiction-specific factors including land cost, energy prices, renewable tariffs, landfill prices, etc.

5.0 NEXT STEPS

On the basis of the composition and quantity of the residual waste stream over time that has been derived in Stage 1, a long-list of technology suppliers under each material type and technology class will be prepared in Stage 2. This long list would subsequently be screened against a set of criteria which would be agreed with the County. Issues to be considered in evaluating technologies at Stage 2 could include:

- Operability at the required scale;
- Commercial success;
- Geographical spread;
- Revenue potential;
- Ability to produce useful outputs;
- Robustness of plant; and,
- Capital cost.

At Stage 3, a more in depth analysis of the individual technologies will be conducted, including assessment using the County's Multi Criteria Analysis Tool (MCA).

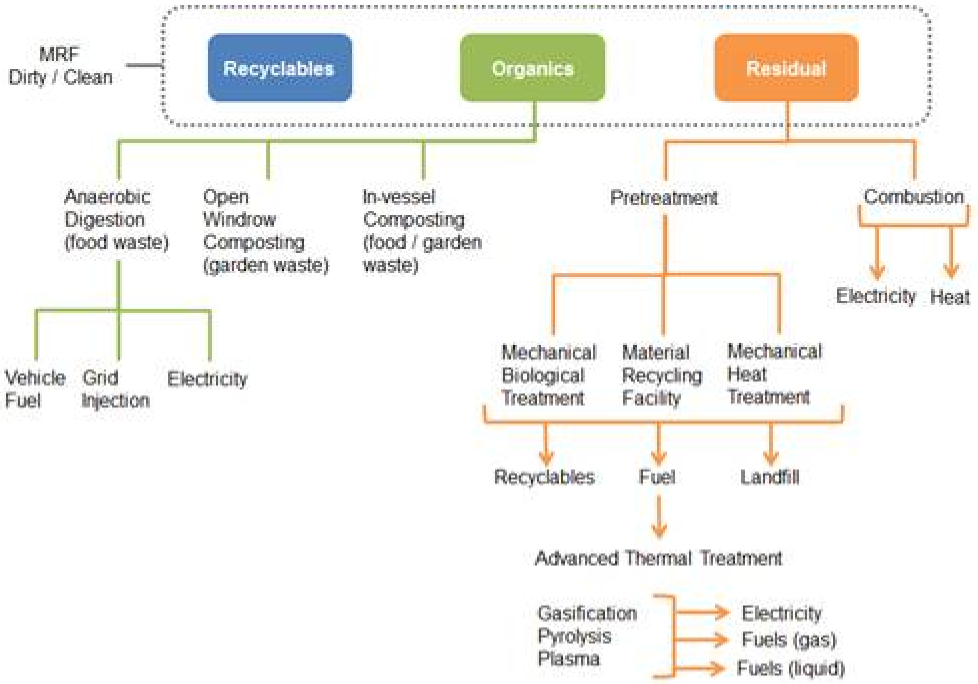
APPENDIX A
Waste Treatment Technology Descriptions
Technical Memo 1a
Oxford County
SLR Project No.: 209.40447.00000

WASTE TREATMENT TECHNOLOGY DESCRIPTIONS

1. OVERVIEW

Waste treatment technologies comprise a wide range of largely mechanical and electrical equipment components configured to undertake particular processes.

The schematic below illustrates the range of technologies used typical in waste treatment processes.



Following is a brief description of the key components and processes involved in the main technologies based on biological and thermal treatment.

2. MATERIALS RECOVERY FACILITY (MRF)

An MRF is a set of primarily mechanical equipment used to separate the different materials in waste collected for recycling. If the waste is not separated at source and contains wet organic wastes the MRF is termed a ‘dirty’ MRF, as distinct from an MRF treating dry wastes that is termed a ‘clean’ MRF. The only difference in the two types of MRF is the separation equipment used and degree of separation of the materials and their degree of contamination.

Process Description

An MRF facility comprises an enclosed building in which the waste is processed and which allows the control of any potential odours when treating food wastes.

The building contains a range of mechanical/electrical equipment so arranged to assist the identification and removal of specified materials for subsequent recycling or to produce refuse derived fuel (RDF) or solid recovered fuel (SRF) for use in an energy production process[1].

The equipment and process configuration will depend on whether the waste is mixed or pre-segregated but typically will comprise a bag opener, ferrous/non-ferrous metal magnets, size reduction/shredder, separation of heavies/lights, separation of paper/card and plastics and optical sorting of the different types of plastic. Most systems will also include a manual element, occasionally for primary sorting of some material types and more frequently as a QA control.

Further refining of the separated materials into specific types/categories may also be applied. The separated materials produced by a 'dirty' MRF will be of lower quality than a 'clean' MRF and command lower market prices, with the residual materials often used to produce RDF/SRF.

Outputs

The output is the different types of separated materials with varying degrees of purity depending on the particular process configuration applied and whether a 'dirty/clean' MRF.

Pros

- produces materials suitable for recycling;
- materials not suitable for recycling can be used to produce RDF/SRF;
- reduces quantity of waste sent to landfill.

Cons

- separated materials may be contaminated and of poor quality;
- recyclate material price subsequently achieved may be lower than expected.

3. MECHANICAL BIOLOGICAL TREATMENT (MBT)

MBT is a hybrid process that uses mechanical treatment processes similar to those in an MRF to separate the organic fraction of the waste from the recyclable material fractions. MBT is used for mixed waste collections that include both food wastes and recyclable materials.

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[1] 'RDF' describes waste that has a relatively high calorific value but where the compositional quality and environmental parameters are not described in a standardized way. 'SRF' is a term used to describe a fuel produced from non-hazardous waste in compliance with European Standard EN 15359, and classifies the calorific value, ash, chlorine, as well as mercury and other heavy metals in the fuel.

The recovered organic fraction can be composted or used in an AD plant to produce biogas. The recovered materials are often of a low quality due to contamination with the organic fraction and often the materials are used to produce RDF/SRF.

Pros

- recovers the organic fraction of mixed wastes for other uses e.g. AD;
- avoids landfilling of the organic content of the mixed waste;
- produces materials that may be suitable for recycling e.g. metals;
- materials not suitable for recycling can be used to produce RDF/SRF;
- reduces the overall quantity of waste sent to landfill.

Cons

- separated materials may be contaminated, of poor quality and command low prices as recyclates;
- digestate produce from non-source separated organics may face regulatory issues regarding suitability for application to agricultural land.

4. BIOLOGICAL TREATMENT

Two types of treatment are commonly used, based on the presence of air, aerobic i.e. composting and the absence of air, anaerobic i.e. anaerobic digestion (AD).

4.1. COMPOSTING

Composting is a biochemical process during which the organic carbon in a material is broken down in the presence of oxygen by various types of microorganisms. Composting is a well proven commercially available technology used to process both green wastes and also food wastes.

The products are carbon dioxide (CO_2) and water vapour. Composting can be undertaken in the open e.g. windrows, or in enclosed vessels. The material is turned on a regular basis (i.e. every 2-3 weeks), to ensure oxygen reaches the interior of the windrow to enable the microorganisms to function and provide the heat that sterilises the solid matter. In enclosed systems air is blown into the pile using underfloor vents.

The output is a compost material that can be used as a soil conditioner and contains nitrogen, potassium and phosphorus, depending on the feedstocks used.

Both green wastes and food wastes can be composted but composting food waste is usually undertaken in an enclosed vessel, to provide conditions to control vermin access, ensure sterilisation of the compost, and provide the ability to control odours.

Process Description

The delivered green wastes are shredded to provide a uniform particle size and mixed to ensure a consistent proportion of green and woody materials, with the latter essential to provide the porosity in the mixture to allow the ingress of oxygen to enable aerobic conditions to be maintained.

The mixture can be either formed into static windrows or placed in an enclosed vessel. Static windrows are turned every few weeks to ensure all of the composting mixture has access to oxygen. During the composting phase the temperature in the pile increases to approximately 60^{0}C and once the active phase is completed the temperature reduces back to ambient over a period of a week or so as the composted organic material is stabilized. Following this stage a period of maturation[2] (or curing) is required in order to ensure that composted material does not damage plant health.

Material can also be placed in an enclosed vessel through which a controlled flow of air is either forced or drawn into the pile via under floor vents. After a number of days treatment the enclosed vessel is opened and the contents transferred to another vessel where the aeration process re-commences for another period of treatment to stabilise the composted organics.

Enclosed composting is used for food wastes to control both potential odour issues and access by vermin. The wet food wastes are mixed with sufficient woody green waste to provide the necessary porosity in the mixture to allow the movement of air through the pile. Forced aeration reduces the composting time significantly. Again, a suitable period of maturation is required.

Output

The output of composting organic wastes is a stabilized material that will not undergo any further degradation. The benefits of compost as an additive to soil are to improve the soil's physical structure, enhance the soil chemistry and soil biology, clean up contaminants and binds heavy metals to prevent them being taken up by plants.

Pros

- simple process that can be used to deal with large quantities of material;
- open windrows used for green wastes and enclosed composting for food wastes;
- variations exist with partly and fully covered windrows;
- subject to the treatment process applied the compost can be made suitable for application to agricultural or domestic land.

Cons

- odour and vermin can be operational issues;
- some pre-processing of the waste is required e.g. shredding woody material and bag opening of food waste etc.;
- overall composting is a net energy user.

[2] CCME PN1340 2005 includes guidelines for determining compost maturity, which will typically involve at least 3 weeks further aeration.

4.2. ANAEROBIC DIGESTION (AD)

Anaerobic digestion (AD) is a biochemical process during which complex organic matter is decomposed in the absence of oxygen by various types of anaerobic microorganisms. AD is a commercially well-proven technology, used widely for treating high moisture content organic wastes. As well as treating agricultural wastes such as animal manure, slurries and energy crops, AD can be utilised to treat waste-water and the organic fraction of municipal solid waste (MSW).

The main products of the process are a) biogas, a mixture of mainly methane (50-65%), carbon dioxide, water vapour and small quantities of other gases, such as hydrogen sulphide and b) digestate, which is the residual decomposed solid substrate which contains many nutrients and can be used as a synthetic fertiliser substitute.

Biogas is a combustible gas and can be used directly in a gas engine generator or turbine to produce heat and electricity. It can also be upgraded to a higher methane content by removal of CO_2, hydrogen sulphide etc. for injection into the natural gas network and used for the same purposes as natural gas, or it can be compressed or liquefied and used as a vehicle fuel.

The energy content of biogas from AD derives from the methane and the composition and properties of biogas vary depending on the feedstock and type of digester, while the quantity of biogas produced depends on the digestion process (i.e. mesophilic [30-40°C] or thermophilic [50-60°C] and the residence time in the digester/fermenter). Biogas with 50% methane content has a heating value of 5kWh/Nm^3 and density similar to air i.e.1.20 kg/Nm^3.

The digested substrate, termed digestate, is a soil fertiliser, with moderate levels of nitrogen, phosphorus, potassium and micronutrients, subject to the feedstocks processed.

Process Description

An AD plant comprises a variety of elements with the layout of a plant dependent on the types and amounts of feedstock to be processed. As many different types of feedstock are suitable for digestion, there are correspondingly different techniques for pre-treating feedstocks and different digester designs and systems of operation. Depending on the type, size and operational conditions of a biogas plant, a range of technologies are used for conditioning, storing and utilizing the biogas.

The main process stages involved in a biogas plant comprise elements of the following list:

- Feedstock
  - delivery
  - storage
- Feedstock preparation
  - crushing
  - maceration

    - sorting
    - pasteurization (can be pre or post digestion)
    - mixing

- Digestion technology
    - wet digestion
    - dry digestion

- Biogas processing
    - desulphurisation
    - drying
    - upgrading to biomethane
    - gas storage

- Gas utilisation
    - power
    - heat
    - CHP (electricity and heat)
    - gas grid injection
    - vehicle fuel

- Digestate
    - dewatering
    - solid/liquid storage
    - land application as fertiliser and soil conditioner.

A wide range of different biomass types can be used as substrates/feedstocks for production of biogas from AD. The most common categories are:

- animal manures and slurries;
- agricultural residues and by-products;
- post production organic wastes from food and agro industries (i.e. vegetable and animal origin);
- organic fraction of municipal waste and from catering (i.e. vegetable and animal origin);
- sewage sludge;
- energy crops (e.g. maize, rye, sorghum, clover etc.).

Outputs

The two outputs from AD plants are biogas and digestate that can be utilized as follows:

- biogas: used to generate electricity and heat in a combined heat and power (CHP) unit;
- biomethane: upgrading biogas to biomethane using various technologies and grid injection;
- compressed/liquefied biomethane: upgraded biogas for use as a vehicle fuel;
- carbon dioxide: recovered from upgrading to biomethane for use in food/manufacturing industry;

- digestate: solid and liquid fractions used as a fertiliser/soil conditioner on agricultural land in lieu of chemical fertilisers.

Pros

- able to treat locally generated food wastes to produce power/heat;
- can treat manures and agricultural residues with added food waste;
- can add energy crops or I,C&I organic wastes to boost biogas output;
- biogas can be utilised in gas engines, gas turbines, fuel cells;
- biogas can be upgraded to a natural gas quality fuel for grid injection;
- overall a net energy producer while still producing a soil conditioner/fertiliser;
- solid digestate fraction is a source of slow release nitrogen and the liquid digestate a source of fast release nitrogen.

Cons

- subject to the feedstock source, pre-preparation of the feedstock may be needed;
- subject to local regulations, pasteurization of food waste derived digestate may be required before application to land.

5. THERMAL TREATMENT TECHNOLOGIES

Thermal treatment encompasses both combustion that is undertaken in the presence of oxygen and Advanced Thermal Treatment (ATT) technologies that are undertaken using limited (i.e. gasification) or no oxygen (i.e. pyrolysis).

These technologies offer the option to treat residual carbon-containing wastes and to recover the intrinsic energy contained in the carbon present in the waste. The technologies differ in how the energy is liberated for recovery. Combustion releases the energy in the waste directly by oxidising the carbon to produce a mixture of mostly ‘hot’ carbon dioxide and nitrogen, whereas both gasification and pyrolysis thermally treat the waste to generate a synthetic gas (syngas) and varying amounts of liquids (tars/oils) and solid (char), from which energy can be generated by combustion.

Thermal plants with energy recovery are known as both wastes to energy (WtE) and energy from waste (EfW) plants.

5.1. COMBUSTION

In a combustion plant the waste is burnt on a grate to produce hot combustion gases that pass to a boiler to capture the heat and convert the heat into steam for use in a steam turbine, or to heat hot oil for use in an organic Rankine cycle (ORC) unit to produce electricity and steam.

The combustion exhaust gases undergo treatment in an air pollution control system to remove particulates and unwanted gaseous compounds to meet regulatory emission limits before release to atmosphere via the exhaust stack.

The waste feedstock can be either raw, untreated MSW, IC&I wastes, residual MSW after recovery/removal of recyclates, or a pre-treated feedstock such as RDF or an SRF. SRF is an RDF fuel produced to specified levels of CV, ash, heavy metals and chlorine content etc.

Raw MSW typically has an energy content or calorific value (CV) of 8-11MJ/kg, whereas RDF and SRF typically are 12-35 MJ/kg. Where raw MSW is processed into RDF the increase in energy content of the RDF is achieved primarily due to drying of the waste (i.e. removal of water) and removal of recyclates (e.g. glass, metals, plastics etc.) and inert materials (stones etc.) that do not contribute to the waste's calorific value CV. The remaining waste going into RDF/SRF comprises wastes with a significant CV (i.e. plastics, dried biodegradable materials, textiles etc.). RDF/SRF produced from source-separated MSW wastes and commercial wastes will have a greater CV than from raw MSW.

To allow complete combustion to take place sufficient oxygen is required to oxidise fully the carbon in the waste. Combustion plant temperatures are typically 850^{o}C and the waste is converted into primarily carbon dioxide, water and ash, together with the inert nitrogen present in the combustion air. Non-combustible materials (e.g. metals, glass, stones etc.), remain on the combustion grate as a solid, known as bottom ash, which contains a small amount of residual carbon, usually <3% by mass. Particulates removed from the exhaust gases are termed air pollution control residues (APCR) and contain the majority of the heavy metal contaminants present in the waste.

Combustion technology is a well-proven, robust technology, able to treat a wide range of solid wastes.

Process Description

The design and configuration of a combustion EfW plants differ between technology providers but any plant will comprise the following key elements:

- waste reception and handling;
- combustion furnace;
- energy recovery plant;
- exhaust gas clean-up;
- emissions monitoring of exhaust combustion gases;
- bottom ash and APCR handling.

Waste reception and Handling

Waste is normally delivered via a waste collection vehicle and tipped into a bunker where it is mixed to blend the incoming wastes to ensure a consistent CV of the waste fed to the combustion chamber and to remove any gross contaminants (i.e. engine blocks, metal beams etc.).

Combustion Chamber

Four main types of combustion technology are employed to burn MSW/RDF/SRF:

1. Moving Grate
    a. roller grate;
    b. stepped inclined grate;
    c. inclined counter rotating grates.
2. Fixed Grate
3. Fluidised Bed (FB)
    a. bubbling FB;
    b. circulating FB.
4. Rotary Kiln.

Energy Recovery

The standard approach to recovery of energy from the combustion of wastes is to use the heat produced and collected by a boiler to produce steam. Of the total available energy in the waste up to 80% can be retrieved in the boiler to produce steam. The steam can then be used for power generation via a steam turbine and/or used for heating. Energy recovery producing both heat and power (i.e. combined heat and power, or CHP), is the most efficient option for utilizing recovered energy from waste via a steam boiler.

Combustion plant producing exclusively heat can have a thermal efficiency c.80% and when used to raise steam for generating electricity the overall gross efficiency of energy conversion in an EfW plant is approximately 17-25%.

Combustion EfW plants will have a similar net electrical and thermal efficiency to most ATT processes generating steam for power generation, due mainly to the energy required to sustain the gasification/pyrolysis process and the scale of the plant.

Emission control for releases to atmosphere

To meet the emissions limits the combustion process must be correctly controlled and the flue gases cleaned prior to release to atmosphere.

A common approach to control emissions involves the following:

- ammonia injection into the hot flue gases for control of NOx emissions;
- lime/sodium bicarbonate injection for control of SO_2 and HCl emissions;
- carbon injection for capture of heavy metals;
- bag filter system for removal of fly ash and other solids (unused lime/bicarbonate reagents).

The control of the concentrations of CO, VOCs and dioxins is achieved primarily through correct combustion conditions being maintained and removal of plastics containing chlorine e.g. PVC.

Clean-up of the flue gases produces APC residues comprising fly ash, lime/bicarbonate reagents and carbon. Typically the weight of APC will be approximately 2 – 6% of the weight of waste entering the combustion plant.

Bottom ash handling

The main residual material from combustion of solid waste is termed “bottom ash”, consisting of the non-combustible constituents of the waste. Bottom ash typically represents approximately 20-30% by weight of the waste feed and 10% by volume. Bottom ash is discharged continually from the bottom of the combustion grate and quenched in a water bath. The amount of ash will depend on the level of any waste pre-treatment prior combustion and will contain some metals that can be recovered for recycling.

Feedstocks

Feedstocks suitable for a combustion process are primarily solid wastes but both semi-solid and liquid wastes can be treated if suitable waste feeding systems are provided.

- raw and residual MSW;
- C&I wastes;
- RDF and SRF.

Outputs

The primary outputs from combustion plants are:

- electricity and/or Heat;
- bottom ash;
- fly ash;
- metals.

Pros

- can handle a wide range of waste types without any pre-processing;
- proven and robust technology;
- uses relatively simple mechanical components;
- can be applied to mid/large scale waste combustion;
- bottom ash can be recycled as a secondary aggregate;
- APCR can be processed for use as a sand replacement material.

Cons

- usually involves a large building and high chimney;
- produces oxidised combustion products suitable only for energy conversion using a steam turbine or hot oil, ORC turbine;
- untreated APCR is a hazardous waste.

5.2. ADVANCED THERMAL TREATMENT

Gasification and pyrolysis are referred to as ATT' (Advanced Thermal Treatment) processes. Gasification and pyrolysis plants thermally treat waste without allowing any or sufficient oxygen for complete combustion.

A brief description of the two processes is presented following.

5.2.1. ADVANCED THERMAL TREATMENT – PYROLYSIS

In contrast to combustion, pyrolysis is a form of thermal treatment that chemically decomposes organic materials by heat in the absence of oxygen. The process requires an external heat source to maintain the temperature required, typically between 300^{0}C - 850^{0}C for materials such as MSW.

There is a degree of misunderstanding concerning the difference between pyrolysis and gasification. True pyrolysis is a low temperature thermal conversion technology that operates in an oxygen-free environment and produces a primary liquid product plus gaseous and solid phase products. If pyrolysis is operated at >800^{o}C the primary product becomes syngas, with the process also producing liquid and solid phase products in lesser amounts.

Raw MSW is not usually appropriate for pyrolysis and typically would require some mechanical preparation and separation of glass, metals and inert materials prior to processing the remaining waste. In general pyrolysis processes tend to prefer consistent feedstocks and have a very limited track record at accepting MSW derived wastes at a commercial scale around the world. The products produced from pyrolysing materials are a solid residue and synthesis gas (syngas). The solid residue (sometimes termed char) is a combination of non-combustible materials and carbon.

Syngas is a mixture of combustible gases including carbon monoxide, hydrogen, methane and a broad range of other VOCs. A proportion of these can be condensed to produce oils, waxes and tars. Syngas typically has a net CV between 10–20 MJ/Nm^3. If required the condensable fraction can be collected by cooling the syngas, potentially for use as a liquid fuel. One key issue for using syngas in energy recovery technologies is the problems related to tarring. The deposition of tars can cause blockages and other operational problems and has been associated with plant failures and inefficiencies at a number of pilot and commercial scale facilities.

Feedstocks

Typical feedstocks suitable for pyrolysis are:

- Commercial & Industrial wastes (C&I);
- RDF/SRF;
- non-waste fuels e.g. wood/other forms of biomass.

Outputs

Primary outputs from pyrolysis are

- electricity and/or Heat – both together if a Combined Heat and Power Plant (CHP);
- syngas that can be purified to produce "biomethane", biofuels, chemicals or hydrogen;
- pyrolysis oils – these can be used to fuel engines, or turned into diesel substitute;
- feedstocks for the chemical industry e.g. allowing biomass to substitute for oil in the production of plastics;
- bottom ash, char, or slag – by products which can be used for beneficial purposes such as aggregates or road bed material.

Pros

- more compact plant than the equivalent capacity combustion plant;
- if syngas can be used as an engine fuel, higher energy conversion efficiencies are achieved.

Cons

- technically more complex than a combustion plant;
- requires an external heating source;
- higher capital cost/t waste than equivalent capacity combustion plant;
- low temperature pyrolysis produces primarily a liquid (carcinogenic) and char;
- high temperature pyrolysis produces syngas but clean-up to an engine grade fuel is complicated and prone to reliability issues;
- char requires burning to recovery the energy content;
- conversion to higher grade products such as methane or bioethanol is costly.

5.2.2. ADVANCED THERMAL TREATMENT - GASIFICATION

Gasification is a partial oxidation process in which the majority of the carbon and hydrogen in the waste is converted into a gaseous form (syngas), leaving a solid residue (ash or char).

There are many different designs of the core gasification reactor such as fluidised bed, rotary kiln, updraft and downdraft reactors, each of which is tailored to give certain benefits when gasifying various types of wastes.

The organic content of the waste is converted mainly to carbon monoxide, hydrogen and lower amounts of methane, although the syngas is generally contaminated by undesired products such as particulate, tar, alkali metals, chloride and sulphide.

Relatively high temperatures are employed, usually 600^{o}C for the most widely used technology using air gasification and 1,000-1,400^{o}C using oxygen. Air gasification is cheaper but results in a relatively low energy syngas, containing up to 60% nitrogen, with a CV of 2-6 MJ/Nm^3. Oxygen gasification gives a higher heating value syngas with a CV of 10-18 MJ/Nm^3 but requires an oxygen supply. High temperature gasification also has the benefit of melting the ash to produce a slag that is inert. The high temperature necessary to melt the ash is produced either by oxygen injection or gas plasma to provide the necessary heat input.

Gasification is a process between pyrolysis and combustion, in that it involves partial oxidation of a substance, by adding oxygen in amounts insufficient to allow the fuel to be oxidised completely or full combustion to occur. The process is largely exothermic but some heat may be required to initialise and sustain the gasification process. Raw MSW is usually not appropriate for gasification and would typically require some mechanical preparation and separation of glass, metals and inert materials prior to processing the remaining waste. The main product is syngas containing carbon monoxide, hydrogen and methane, with typically a net CV of 4-10MJ/Nm^3, together with the nitrogen content of the gasification air used.

With gasification the energy content of the waste is transferred into the gas phase as both chemical and thermal energy, with the chemical energy making it possible to store and utilise the syngas at a later time, or elsewhere, for power generation, or via additional processing for use as a chemical feedstock.

Gasification of a solid waste includes a sequence of successive, endothermic and exothermic steps:

Typical feedstocks suitable for pyrolysis are:

- MSW;
- Commercial & Industrial Waste (C&I);
- RDF/SRF;
- (non-waste fuels, e.g. wood/other forms of biomass).

Outputs

Primary outputs from gasification are:

- electricity and/or heat;
- syngas that can be purified to produce “biomethane”, biofuels, chemicals or hydrogen;
- feedstocks for the chemical industry;
- bottom ash, char, or slag by products that can be used for beneficial purposes e.g. secondary aggregate or land remediation material.

Pros

- more compact plant than the equivalent capacity combustion plant;
- if syngas can be used as an engine fuel a higher energy conversion efficiency is achieved.

Cons

- technically more complex than a combustion plant;
- higher capital cost/te waste than equivalent capacity combustion plant;
- syngas clean-up to engine grade fuel is complicated and prone to reliability issues;
- conversion to higher grade products such as methane or bioethanol is costly.