NORTH LONDON WASTE AUTHORITY

NORTH LONDON HEAT AND POWER PROJECT

ALTERNATIVES ASSESSMENT REPORT

The Planning Act 2008 The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 Regulation 5 (2) (q)

AD05.03

NLWA

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Glossary

See Project Glossary (AD01.05)

Executive summary

i.i.i This report sets out the process by which North London Waste Authority (the Applicant) determined its requirements for future residual waste management, leading to the decision to apply for a Development Consent Order (DCO) for the proposed Energy Recovery Facility (ERF), which forms part of the North London Heat and Power Project (the Project). The report summarises the alternatives that have been considered by the Applicant, in particular the technology and site options, to determine the most appropriate scheme.

i.i.ii The strategic basis for the Applicant's decisions is the Joint Waste Management Strategy which covers the period 2004 to 2020. This strategy contains objectives and targets which set out the need to reduce the amount of waste sent from the north London area to landfill, and targets for increasing recycling in the area to 50 per cent by 2020. The strategy is broadly neutral as to the technological solution to be implemented to achieve these aims and process the residual waste; however, it acknowledges that the use of heat from waste is supported by regional policies.

i.i.iii The report sets out the policy framework applicable to the consideration of alternative technology and site options. Alternative technology and site options are also considered in the following reports which are submitted with the DCO Application:

a. Environmental Statement (AD06.02) which summarises the site selection process and the site layouts considered;

b. Combined Heat and Power Strategy (AD05.06) which sets out potential connections to heat networks and potential future demand, and a heat supply and demand assessment; and

c. Grid Connection Statement (AD05.08) which demonstrates the feasibility and proposed approach to grid connection upgrade works to support the proposed increase in electrical export capacity, while maintaining necessary levels of connection resilience.

i.i.iv The assessments considered in this report were carried out in preparation for a procurement for contracts for future waste management services, including replacement waste management facilities starting in 2008, and were updated in 2013 and 2014. The assessments cover the areas of technology solution and site selection. The applicant considers that the assessments remain valid for the purposes of the DCO Application.

i.i.v The technology solution forming the basis of the Project reflects the technical assessments carried out and the changes in relevant planning policy during the period of assessments. The selection of thermal technology with advanced moving grate is supported by the technological assessments carried out and, following developments in regional and local planning policy during 2013, is consistent with planning policy.

i.i.vi The site selection was based on site availability and suitability. The Edmonton EcoPark meets the criteria for a suitable site for waste management for north London, in particular as it is available to the Applicant for use for waste management purposes, and is of sufficient size to accommodate new facilities while ensuring continuity of waste treatment during the period of construction of new facilities.

1 Introduction

1.1 Introduction

1.1.1 This Alternatives Assessment Report has been prepared to support North London Waste Authority's (the Applicant's) application (the Application) to the Secretary of State for Energy and Climate Change for a Development Consent Order (DCO) made pursuant to the Planning Act 2008 (as amended).

1.1.2 The Application is for the North London Heat and Power Project (the Project) comprising the construction, operation and maintenance of an Energy Recovery Facility (ERF) capable of an electrical output of around 70 megawatts (MWe) at the Edmonton EcoPark in north London with associated development, including a Resource Recovery Facility (RRF). The proposed ERF would replace the existing Energy from Waste (EfW) facility at the Edmonton EcoPark.

1.1.3 The Project is a Nationally Significant Infrastructure Project for the purposes of Section 14(1)(a) and section 15 in Part 3 of the Planning Act 2008 (as amended) because it involves the construction of a generating station that would have a capacity of more than 50MWe.

1.2 Purpose of this Report

1.2.1 This Report has been prepared to summarise the alternatives that have been considered by the Applicant, in particular the technology and site options, to determine the most appropriate scheme.

1.2.2 This Assessment forms part of a suite of documents accompanying the Application submitted in accordance with the requirements set out in section 55 of the Planning Act and Regulations 5, 6 and 7 of the Infrastructure Planning (Applications: Prescribed Forms and Procedures) Regulations 2009 (APFP Regulations 2009), and should be read alongside those documents (see Project Navigation Document AD01.02).

1.3 Structure of this Report

1.3.1 The report is structured as follows:

a. Section 1: Introduction: describes the background to the Project and the Application Site;

b. Section 2: Legislative and policy requirements: summarises applicable national, regional and local polices;

c. Section 3: Strategic development of the Project; summarises the historic and strategic development of technology and site options for delivering a waste disposal solution; and

d. Section 4: Summary and conclusions of assessments: sets out the technology and site options that have been considered by the Applicant for delivering a waste disposal solution.

1.4 The Applicant

1.4.1 Established in 1986, the Applicant is a statutory authority whose principal responsibility is the disposal of waste collected by the seven north London boroughs of Barnet, Camden, Enfield, Hackney, Haringey, Islington and Waltham Forest (the Constituent Boroughs).

1.4.2 The Applicant is the UK's second largest waste disposal authority, handling approximately 3 per cent of the total national Local Authority Collected Waste (LACW) stream. Since 1994 the Applicant has managed its waste arisings predominantly through its waste management contract with LondonWaste Limited (LWL) and the use of the EfW facility at the existing Edmonton EcoPark and landfill outside of London.

1.5 The Application Site

1.5.1 The Application Site, as shown on the Site Location Plans (A_0001 and A_0002 in the Book of Plans (AD02.01)), extends to approximately 22 hectares and is located wholly within the London Borough of Enfield (LB Enfield). The Application Site comprises the existing waste management site known as the Edmonton EcoPark where the permanent facilities would be located, part of Ardra Road, land around the existing water pumping station at Ardra Road, Deephams Farm Road, part of Lee Park Way and land to the west of the River Lee Navigation, and land to the north of Advent Way and east of the River Lee Navigation (part of which would form the Temporary Laydown Area and new Lee Park Way access road). The post code for the Edmonton EcoPark is N18 3AG and the grid reference is TQ 35750 92860.

1.5.2 The Application Site includes all land required to deliver the Project. This includes land that would be required temporarily to facilitate the development.

1.5.3 Both the Application Site and the Edmonton EcoPark (existing and proposed) are shown on Plan A_0003 and A_0004 contained within the Book of Plans (AD02.01). Throughout this report references to the Application Site refer to the proposed extent of the Project works, and Edmonton EcoPark refers to the operational site. Upon completion of the Project the operational site would consist of the Edmonton EcoPark and additional land required to provide new access arrangements and for a water pumping station adjacent to the Deephams Sewage Treatment Works outflow channel.

Edmonton EcoPark

1.5.4 The Edmonton EcoPark is an existing waste management complex of around 16 hectares, with an EfW facility which treats circa 540,000 tonnes per annum (tpa) of residual waste and generates around $40MW_e$ (gross) of electricity; an In-Vessel Composting (IVC) facility; a Bulky Waste Recycling Facility (BWRF) and Fuel Preparation Plant (FPP); an Incinerator Bottom Ash (IBA) Recycling Facility; a fleet management and maintenance facility; associated offices, car parking and plant required to operate the facility; and a former wharf and single storey building utilised by the Edmonton Sea Cadets under a lease.

1.5.5 In order to construct the proposed ERF, the existing BWRF and FPP activities would be relocated within the Application Site; the IVC facility would be decommissioned and the IBA recycling would take place off-site.

Temporary Laydown Area and eastern access

1.5.6 The proposed Temporary Laydown Area is an area of open scrubland located to the east of the River Lee Navigation and north of Advent Way. There is no public access to this area. The Temporary Laydown Area would be reinstated after construction and would not form part of the ongoing operational site.

1.5.7 In addition to the Temporary Laydown Area the Application Site includes land to the east of the existing Edmonton EcoPark which would be used for the new Lee Park Way entrance and landscaping along the eastern boundary.

Northern access

1.5.8 The Application Site also includes Deephams Farm Road and part of Ardra Road with land currently occupied by the EfW facility water pumping station between the junction of A1005 Meridian Way and Deephams Farm Road.

1.6 Surrounding area

1.6.1 The Application Site is located to the north of the A406 North Circular Road in an area that is predominantly industrial. The Lee Valley Regional Park (LVRP) is located to the east of the Edmonton EcoPark.

1.6.2 Land to the north and west of the Application Site is predominantly industrial in nature. Immediately to the north of the Edmonton EcoPark is an existing Materials Recovery Facility (MRF), which is operated by a commercial waste management company, alongside other industrial buildings. Further north is Deephams Sewage Treatment Works. Beyond the industrial area to the north-west is a residential area with Badma Close being the nearest residential street to the Application Site (approximately 60m from the nearest part of the boundary) and Zambezie Drive the nearest to the Edmonton EcoPark at approximately 125m west.

1.6.3 Eley Industrial Estate, located to the west of the Application Site, comprises a mixture of retail, industrial and warehouse units.

1.6.4 Advent Way is located to the south of the Application Site adjacent to the A406 North Circular Road. Beyond the A406 North Circular Road are retail and trading estates; this area is identified for future redevelopment to provide a housing-led mixed use development known as Meridian Water.

1.6.5 The LVRP and River Lee Navigation are immediately adjacent to the eastern boundary of the Edmonton EcoPark, and Lee Park Way, a private road which also forms part of National Cycle Network (NCN) Route 1, runs alongside the River Lee Navigation. To the east of the River Lee Navigation is the William Girling Reservoir along with an area currently occupied by

Camden Plant Ltd. which is used for the crushing, screening and stockpiling of waste concrete, soil and other recyclable materials from construction and demolition. The nearest residential areas to the east of the Application Site and LVRP are located at Lower Hall Lane, approximately 550m from the Edmonton EcoPark and 150m from the eastern edge of the Application Site.

1.7 The Project

1.7.1 The Project would replace the existing EfW facility at Edmonton EcoPark, which is expected to cease operations in around 2025, with a new and more efficient ERF which would produce energy from residual waste, and associated development, including temporary works required to facilitate construction, demolition and commissioning. The proposed ERF would surpass the requirement under the Waste Framework Directive (Directive 2008/98/EC) to achieve an efficiency rating in excess of the prescribed level, and would therefore be classified as a waste recovery operation rather than disposal.

1.7.2 The main features of the Project once the proposed ERF and permanent associated works are constructed and the existing EfW facility is demolished are set out in the Book of Plans (AD02.01) and comprise:

a. a northern area of the Edmonton EcoPark accommodating the proposed ERF;

b. a southern area of the Edmonton EcoPark accommodating the RRF and a visitor, community and education centre with offices and a base for the Edmonton Sea Cadets (‘EcoPark House’);

c. a central space, where the existing EfW facility is currently located, which would be available for future waste-related development;

d. a new landscape area along the edge with the River Lee Navigation; and

e. new northern and eastern Edmonton EcoPark access points.

1.7.3 During construction there is a need to accommodate a Temporary Laydown Area outside of the future operational site because of space constraints. This would be used to provide parking and accommodation for temporary staff (offices, staff welfare facilities), storage and fabrication areas, and associated access and utilities.

1.7.4 Schedule 1 of the draft DCO (AD03.01) sets out the authorised development and the works are shown in the Book of Plans (AD02.01), supplemented by Illustrative Plans (included in the Design Code Principles, AD02.02) that set out the indicative form and location of buildings, structures, plant and equipment, in line with the limits of deviation established by the draft DCO (AD03.01).

1.8 Stages of development

1.8.1 The proposed ERF is intended to be operational before the end of 2025, but with the precise timing of the replacement to be determined. In order to do this, the following key steps are required:

a. obtain a DCO for the new facility and associated developments;

b. obtain relevant environmental permit(s) and other licences, consents and permits needed;

c. identify a suitable technology supplier;

d. agree and arrange source(s) of funding;

e. enter into contract(s) for design, build and operation of new facility and associated development;

f. move to operation of new facility; and

g. decommission and demolish the existing EfW facility.

1.8.2 Site preparation and construction would be undertaken over a number of years and it is expected that the earliest construction would commence is 2019/20, although this may be later. Construction would be implemented in stages to ensure that essential waste management operations remain functioning throughout. This is especially relevant for the existing EfW facility and associated support facilities.

1.8.3 The stages of the Project are as follows:

a. Stage 1a: site preparation and enabling works;

b. Stage 1b: construction of RRF, EcoPark House and commencement of use of Temporary Laydown Area;

c. Stage 1c: operation of RRF, EcoPark House and demolition/clearance of northern area;

d. Stage 1d: construction of ERF;

e. Stage 2: commissioning of ERF alongside operation of EfW facility, i.e. transition period;

f. Stage 3: operation of ERF, RRF and EcoPark House, demolition of EfW facility; and

g. Stage 4: operation of ERF, RRF and EcoPark House, i.e. final operational situation.

2 Legislative and Policy Requirements

2.1 Overarching National Policy Statement for Energy (NPS EN-1)

2.1.1 Section 4.4.1 of NPS EN-1 advises that "*from a policy perspective this NPS does not contain any general requirement to consider alternatives or to establish whether the proposed project represents the best option*" except in relation to legal requirements such as the Habitats Directive[1]. Nevertheless Section 4.4.1 of NPS EN-1 also states that "*it is intended that potential alternatives to a proposed development should, wherever possible, be identified before an application is made to the SoS [Secretary of State] in respect of it so as to allow appropriate consultation and the development of a suitable evidence base in relation to any alternatives which are particularly relevant*".

2.1.2 Section 4.4.3 of NPS EN-1 establishes a number principles of relevance to the Project which the SoS should consider when deciding what weight should be given to alternatives as follows:

a. the consideration of alternatives to comply with policy requirements should be proportionate;

b. whether there is a realistic prospect of the alternative delivering the same infrastructure capacity in the same timescale as the proposed development;

c. where legislation imposes a specific quantitative target for particular technologies the application for development on one site should not be rejected simply because fewer adverse impacts would result from developing similar infrastructure on another suitable site;

d. alternatives not among the main alternatives studied by the applicant should only be considered to the extent that they are both important and relevant to the SoS decision;

e. if a decision to grant consent to a hypothetical alternative proposal would not be in accordance with the policies set out in the relevant NPS, the existence of that alternative is unlikely to be important and relevant;

f. alternative proposals which mean the necessary development could not proceed can be excluded;

g. alternative proposals which are vague or inchoate can be excluded; and

h. where an alternative is first put forward by a third party after an application has been made, the SoS may place the onus on the person proposing the alternative to provide the evidence for its suitability.

2.1.3 NPS EN-1 also imposes a number of specific requirements to consider alternatives, these are:

[1] The European Directive (92/43/EEC) on the Conservation of Natural Habitats and Wild Flora and Fauna

a. Biodiversity and Geological Conservation: in order to avoid ‘significant harm’ to biodiversity and geological conservation interests, the applicant should address any mitigation issues and consider reasonable alternatives;

b. Flood Risk: nationally significant energy infrastructure projects can be located in Flood Zone 3 or Zone C subject to the Exception Test, if there is no reasonably available site in Flood Zones 1 or 2 or Zones A & B. Alternative sites should be considered and choices explained; and

c. Landscape and Visual: the applicant should consider the possibility (and cost) of developing outside the designated area, or meeting the need in some other way.

2.2 National Policy Statement of Renewable Energy Infrastructure (EN-3)

2.2.1 NPS EN-3 includes a number of factors influencing site selection for renewable energy generating stations. Paragraph 2.1.3 states that these are not a statement of Government Policy but are included to provide background information on the criteria that applicants consider when choosing a site. NPS EN-3 recognises that the specific criteria considered by applicants and the weight they give to them will vary from project to project.

2.2.2 Paragraph 2.1.3 states *“it is for energy companies to decide what applications to bring forward and the Government does not seek to direct applicants to particular sites for renewable energy infrastructure other than in the specific circumstances described in this document in relation to offshore wind”*.

2.2.3 At Section 2.5.22 to 2.5.27 NPS EN-3 identifies a number of factors influencing site selection of relevance to the Project as summarised below:

a. Grid connection: the applicant should have assured themselves that a viable connection exists before submitting a DCO application;

b. Transport Infrastructure: applicants should locate new waste combustion generating stations in the vicinity of existing transport routes wherever possible; and

c. Combined Heat and Power (CHP): applications should demonstrate that CHP has been considered.

2.2.4 This Report has been prepared to demonstrate the approach taken in reaching the preferred technology and site as presented in the Application. There are additional requirements to consider alternatives in the EIA regulations[2] and Habitats Directive[3]. This Report does not seek to address these requirements; rather this information is set out in the Environmental Statement and No Significant Effects Report (AD05.17) respectively.

[2] The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999

[3] The European Directive (92/43/EEC) on the Conservation of Natural Habitats and Wild Flora and Fauna

3 Strategic development of the Project

3.1 Relevant history of the Application and Edmonton EcoPark

1970s and 1980s

3.1.1 A summary of the history and timeline of assessments in this section is contained in Appendix A.

3.1.2 The existing EfW facility was commissioned by the Greater London Council (GLC) in 1970/1.

3.1.3 The North London Waste Authority (NLWA) was established in 1986 under the Waste Regulation and Disposal Authorities Order 1985, an Order made by the Secretary of State pursuant to the power under section 10 of the Local Government Act 1985, with responsibility for disposing of the waste collected by the Constituent Boroughs. The freehold interest in the Edmonton EcoPark was transferred from the GLC to the Applicant as part of a wider statutory scheme of transfer of GLC functions and assets to local authorities.

1990s

3.1.4 LWL was established as a joint venture company comprising the Applicant and SITA GB Limited [4] under the now repealed section 32 of the Environmental Protection Act 1990. In 1994, LWL was awarded a contract for waste management services by the Applicant. At the same time, the freehold interest in the Edmonton EcoPark was transferred from the Applicant to LWL.

2006

3.1.5 In 2006, when the existing EfW facility had been in operation for approximately 35 years, the Applicant commenced a process for its replacement, on the basis that a procurement exercise would be undertaken in respect of the waste management services required for the Constituent Boroughs. It was intended to achieve replacement facilities by 2020.

2008-2010

3.1.6 Between 2008 and 2010, the NLWA undertook strategic, technology, planning and site assessments to underpin its procurement strategy. The Applicant's appraisal criteria included sustainability, nuisance, cost, proximity principle, deliverability and risk, technology and performance.

3.1.7 These assessments were reported in an outline business case[5] (OBC), which was presented to the Department for Environment, Food and Rural

[4] In 2009, the Applicant acquired SITA GB Limited's shareholding in LWL and in doing so became the sole shareholder of LWL.
[5] The OBC is in the publication section of the Applicant's website at http://www.nlwa.gov.uk/governance-and-accountability/freedom-of-information-act/publication-scheme

Affairs (DEFRA) in January 2010, as an application for credits under the private finance initiative (PFI).

3.1.8 DEFRA awarded PFI credits to NLWA to support the project set out in the OBC, but they were withdrawn in October 2010 following the Government’s strategic review of funding.

3.1.9 At the start of the procurement process, the Edmonton EcoPark could not be made available to a successful bidder for the waste management contract, because the freeholder, LWL, was not wholly owned by the Applicant, and consideration was given to alternative sites in the north London area. In December 2009, the Applicant became the 100 per cent shareholder in LondonWaste Ltd, the freehold owner of the Edmonton EcoPark, and was then able to incorporate use of the Edmonton EcoPark into its future waste management strategy. The reference project in the OBC required more land than was available at the Edmonton EcoPark, because of the nature of technology proposed. Site searches were carried out, and commercial negotiations with regard to two other sites took place but did not reach a successful conclusion. The site at Pinkham Way was obtained to allow deliverability of the procurement strategy. Sites considered and their assessment, including availability, were covered in the OBC.

2011-2013

3.1.10 The options covered in the OBC were reviewed by the Applicant, and in April 2011, the NLWA concluded that the procurement strategy set out in the OBC should be followed notwithstanding the withdrawal of PFI credits.

3.1.11 In 2013, a further review of alternatives to the procurement strategy was undertaken and a decision was made in September 2013 not to progress the procurement.

3.1.12 The decision not to progress the procurement was taken on the basis of two key assessments. The first assessment related to the planning policy framework for the Edmonton EcoPark, which had altered with the cumulative effect of the Supplementary Planning Document (SPD) for the Edmonton EcoPark by LB Enfield and the Upper Lea Valley (ULV) Opportunity Area Planning Framework (OAPF) by the Mayor of London. These policies represented a shift in attitudes towards future energy recovery on site to replace the existing EfW facility, such that energy recovery at the Edmonton EcoPark was supported. The second assessment was an updated assessment of the cost of delivery of an ERF at the Edmonton EcoPark taking into account the improvement in deliverability of that solution through the changed planning policies. This second assessment confirmed the OBC analysis that a single treatment facility producing energy was more cost effective than other potential treatment options.

3.1.13 The NLWA's decision not to further progress the procurement in September 2013 was taken on the basis that a less expensive solution to waste management could be found, which would involve a short to medium term continued use of the existing EfW facility, and an exploration of a longer term replacement ERF.

3.1.14 In December 2013, the NLWA decided to progress an application for a DCO for the replacement of the existing EfW facility with an ERF at the Edmonton EcoPark. This decision reflected the reviews carried out during 2013, and the consistent outcomes of assessments during the procurement that, if deliverable, EfW technology within north London was less expensive than other residual waste management solutions. Decisions on the procurement route and the funding of the project would be taken during the period of examination and decision by the SoS on the DCO application, to align with the projected timetable for the grant of the DCO.

2014

3.1.15 The technology assessments made during the procurement process were further updated by a review of Thermal Treatment Options in July 2014 (Appendix B), consideration of the plant design and number of lines (Appendix C), review of Flue Gas Treatment Plant Options (Appendix D) and a report on Cooling Plant Technology Options (Appendix E).

3.2 Procurement strategy – further detail

3.2.1 The procurement strategy was for a waste disposal strategy that covered the entirety of the waste received by the Applicant as the waste disposal authority for north London.

3.2.2 Consideration was given both to a strategy which encompassed joint procurement of waste disposal functions and waste collection functions; and to a strategy which covered residual waste only. The Applicant concluded that a procurement strategy for waste and collection services would be too large to attract a good market response, and that benefits could be gained from the waste management contractor having control of all the waste received by the Applicant. Accordingly both residual waste and the management of recyclates received were included in the scope of the contract.

3.2.3 The Applicant assessed a number of options and concluded that the procurement should be for two contracts:

a. a waste services contract covering receipt of waste, creation of a refined fuel from that waste, transport within north London and of the fuel away from the treatment plant, and management of the Household Waste Recycling Centres (now called Recycling and Reuse Centres (RRC)); and

b. a separate fuel use contract, under which the fuel created would be received, and used to generate energy through an ERF, preferably with associated CHP.

3.2.4 The reference project solution set out above was determined to be the most cost effective deliverable solution taking into account the existing policy framework.

4 Summary and conclusions of assessments

4.1 Introduction

4.1.1 This section summarises the assessments carried out relating to the site and technology to be pursued for future waste management in the north London area, and the conclusions reached.

4.2 Approach to technology assessment

4.2.1 The North London Joint Waste Strategy (NLJWS) acknowledges that advanced thermal treatment would be considered in procuring replacement facilities but is neutral as to the precise technology to be used for the treatment of residual waste.

4.2.2 Within the OBC, the Applicant put forward a list of technologies for different waste types, which included landfill, EfW, gasification, pyrolysis, mechanical biological treatment (MBT), anaerobic digestion (AD) and IVC. A long list of the technologies considered is included at Appendix F, together with a table at Table 4.1 providing an update on the considerations applicable.

4.2.3 Scenarios reflecting the three main technologies for treating municipal waste (MBT, EfW and gasification/pyrolysis), and a baseline scenario of continued use of the existing EfW facility to 2014 followed by use of landfill, were assessed by the Applicant with the benefit of advice from technical advisers to rule out approaches that are unsuitable in terms of operating at the required scale, being bankable and meeting the objectives of relevant strategies/policies. The results of this assessment were that the baseline scenario with long-term landfill performed worst. Two methods were used to normalise the results to take account of both qualitative and quantitative assessments. On one, the best performing scenario was EfW with CHP; on the other, the highest scoring technology was a combination of MBT and AD technologies, which, taking account of the other factors considered, and in particular the planning deliverability risk, was used as the basis for the reference project.

4.2.4 The option of building a replacement ERF at the Edmonton EcoPark was considered but discounted initially as being high to very high risk in planning deliverability terms. However once the SPD and ULV OAPF established that future energy recovery on site to replace the existing EfW facility could be welcome, the Applicant commissioned a detailed review of thermal treatment options in 2014. The reports prepared in 2014 on technology options are set out in Appendices B–E.

Table 4.1: Technologies considered

Treatment/disposal technology	Pass/fail in original procurement strategy	Update comments
Landfill	Fail	Position unchanged
EfW (traditional mass burn and fluidized bed)	Pass (limited to current EfW capacity) Since this original assessment was carried out, this planning context has changed significantly due to the change in policy brought about by the OAPF and SPD. There has been a change in Mayoral policy to favour schemes capable of supplying heat through decentralized energy schemes and the GLA have stated that *“the proposed facility will be an asset to London in achieving net self-sufficiency and will allow for energy gains to be achieved”*. In addition, more recently, the prospect of heat off-take through ongoing has been strengthened significantly through ongoing negotiations with LVHN.	Limit to current capacity no longer relevant as result of change in GLA policy regarding EfW use in London
Gasification/pyrolysis (including basic pre-treatment)	Pass (but limited in scale to approx. 250ktpa)	Unchanged – see Review of Thermal Treatment Options (Appendix B)
MBT with no SRF production	Fail	No change to assessment
MBT technologies with SRF production	Pass (with capacity limitations)	Technology option remains as previously. For deliverability, see update on planning policy framework
MBT/autoclave with SRF	Fail	No change to assessment
Gas plasma	Fail	No change to assessment

4.3 Technology options

4.3.1 There are three basic processes for thermal treatment of municipal solid waste, set out below. More detailed information on these processes is set out in the report on thermal treatment options provided at Appendix B.

Combustion

4.3.2 Complete oxidation with surplus oxygen. The combustion process does not require an external energy source (such as gas or electricity) because it releases heat and is self-supporting. The flue gas (primarily comprising water vapour, carbon dioxide (CO2), hydrogen chloride (HCl), mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NOx) and oxygen (O2)) has no calorific value because all the energy is converted into heat;

4.3.3 Combustion type processes can be split into the following two types:

a. advanced moving grate technology; and

b. fluidised bed technology.

Pyrolysis

4.3.4 Thermal breakdown of waste in the absence of oxygen. Waste is heated to high temperatures (>300°C) by an external energy source, without adding steam or oxygen. The products are char, pyrolysis oil and syngas (synthesis or pyrolysis gas). Due to a high level of tar syngas needs extensive cleaning before use.

Gasification

4.3.5 Thermal breakdown/partial oxidation of waste under a controlled oxygen atmosphere where the oxygen content is lower than necessary for combustion. Waste reacts chemically with steam or air at a high temperature (>750 °C). The process requires, as for pyrolysis, an external energy source to heat the process. Syngas from gasification, primarily comprising carbon monoxide (CO) and hydrogen (H2), has a lower calorific value than pyrolysis gas and is dependent upon the gasification process.

4.4 Technology conclusion

4.4.1 The OBC considered the planning delivery of EfW facilities in north London and assessed scenarios with this technology option as having a high to very high planning risk. However the thermal treatment of residual waste scored the most highly in both technical and cost terms, and subsequent assessments have confirmed this position.

4.4.2 The comparative cost of the two technologies, ERF and MBT with SRF production, were reviewed in September 2013 as part of the basis of the assessment as to whether or not to continue with the procurement. A potential differential of £900M was identified as a result of the change in deliverability of ERF technology, and this formed an essential element in the decision to end the procurement.

4.4.3 The 2014 thermal treatment option technology review (Appendix B) concludes that:

a. advanced moving grate is the most well proven, reliable and cost effective means of providing thermal treatment technology for municipal solid waste; and

b. none of the reviewed alternative technologies (gasification or pyrolysis) are able to match advanced moving grate facilities with regard to energy production efficiency or annual availability.

4.5 Approach to site assessment

4.5.1 The Constituent Boroughs have been preparing the North London Waste Plan[6] (NLWP) during the period of the development of the waste disposal strategy. The Applicant has engaged in this process as a stakeholder, and the Applicant's stated waste management requirements have been taken into account.

4.5.2 The Draft NLWP, published for consultation on 30 July 2015, identifies the Edmonton EcoPark as a site safeguarded for waste use in the London Plan, and Pinkham Way (referred to as the Friern Barnet Sewage Works) as a potential new site for waste use. No other sites suitable for the Project have been identified through the NLWP process.

4.5.3 The Project includes land to the east of the Edmonton EcoPark for use as a Temporary Laydown Area during the period of construction and demolition of the Project. The criteria for selection of the Temporary Laydown Area site, and the reasons for selecting this area are set out below.

4.5.4 The Project includes a re-location of the Edmonton Sea Cadets on site as part of its design. The reasons for incorporating accommodation for the Edmonton Sea Cadets are set out below.

4.6 Site criteria for the Project

4.6.1 The following are essential site requirements for the Project, to allow the Applicant to provide its statutory service for waste disposal:

a. a site located in north London, in order to meet policy requirements of management of waste within the sub-region, and to reduce the impact and cost of transport of waste;

b. land ownership or access to the use of the land for the Applicant; this factor is included as there is limited suitable available land in the north London area, and attempts to identify a suitable alternative or additional site in 2008-2010 had led only to the identification of the site at Pinkham Way (see Paragraph 4.7.2 below);

c. sufficient land availability for the required foot print of facilities; this criterion allows for effective management of the residual waste from delivery by the Constituent Boroughs to treatment, minimising the need to transfer untreated waste between sites, or to incur the cost of pre-treatment or bulking activity;

d. established waste use, to manage planning risk associated with the development of new facilities; no other sites of sufficient size with established waste use are available in the north London area;

e. accessible location, with good road transport links for the delivery of waste from Constituent Boroughs; and

f. sufficient site infrastructure, services and utilities for the required facilities and ongoing operations, including availability of grid connection

[6] Information about the NLWP is at www.nlwp.net

for electricity off-take, which is demonstrated (a) through existing connections and (b) through agreement with UKPN as to future connections for the anticipated electricity output from the proposed ERF, as detailed in the Grid Connection Statement (AD05.08) submitted as part of this Application.

4.7 Site conclusions

4.7.1 There are two sites available to the Applicant, and as no other sites are available, they are not considered against the other criteria here. These are both considered by reference to the site criteria, as follows:

4.7.2 The Pinkham Way site does not meet the required criteria, for the following reasons:

a. this site is smaller than the Edmonton EcoPark and is only of a sufficient size to hold a plant appropriate for treatment of half the Applicant's waste;

b. the site does not have an established waste use. It has a dual planning use designation for employment and as a Site of Importance for Nature Conservation (Borough Grade I); and

c. there is no established grid connection.

4.7.3 The Edmonton EcoPark meets the required criteria as follows:

a. it is an existing waste management site of approximately 16 hectares, which is of a sufficient size to accommodate replacement energy recovery facilities and allow for transition from the existing EfW facility to the proposed ERF;

b. the London Plan states that existing waste management sites such as the Edmonton EcoPark should be clearly identified and safeguarded for waste use (Paragraph 5.82), implying that ongoing/future waste uses at such sites should be encouraged;

c. it has been identified as a key existing waste site in the Draft NLWP;

d. the ULV OAPF strongly reinforces the Edmonton EcoPark as the preferred location of the supply hub for the Lee Valley Heat Network;

e. it has an established waste use which provides an appropriate planning policy framework for ongoing use for that purpose;

f. it complies with the Mayor's strategic objective for self-sufficiency within London of waste management;

g. it has good access to the Strategic Road Network;

h. there is an existing connection to the grid, capable of being upgraded in line with the anticipated electricity output from the proposed ERF; and

i. the site is in north London and is available for use by the Applicant.

4.7.4 In addition, in accordance with the requirements of NPS EN-1, consideration has been given to the impact on biodiversity and conservation, flood risk and landscape and visual in selecting the Edmonton EcoPark for the Project. The impact of the Project on biodiversity and conservation, flood risk and landscape is assessed in the Environmental Statement (AD06.02) to be not significant. The Environmental Statement concludes that there would be significant residual adverse visual effects at a number of receptors during construction, but not in the final operational phase.

4.7.5 There are no other sites available and suitable for the Project. The Applicant has therefore based the Project on use of the Edmonton EcoPark.

4.8 The Temporary Laydown Area

4.8.1 A temporary dedicated space is needed to support construction and decommissioning/demolition activities for plant, storage, fabrication, parking and construction site offices. This space is referred to as the Temporary Laydown Area and the proposed location is an area of open scrubland located directly to the east of the River Lee Navigation and north of Advent Way.

4.8.2 A Temporary Laydown Area outside of the Application Site is needed as the Edmonton EcoPark would not have sufficient space to support the construction activities of the scale required; site offices; storage areas; parking; and the ongoing site waste operations. During the peak construction phase around 550 construction-related workers are expected on the Edmonton EcoPark site. This would be in addition to the workforce involved in the on-site waste management operations.

4.8.3 A number of key considerations were taken into account when selecting an appropriate Temporary Laydown Area. These included, ease of access, distance from the Edmonton EcoPark, layout and size, ability to connect to utilities, site security and availability. Other off-site locations were considered such as the land within Deephams Sewage Treatments Works (to the north), Eley Industrial Estate (to the west) and IKEA car park (to the south). These locations were not considered suitable as they did not satisfy the key considerations needed to ensure the proposed Temporary Laydown Area would be feasible for the purposes of the Project.

4.8.4 The Temporary Laydown Area is owned by Thames Water Utilities Ltd. This is currently an area of open space with no public access. The Temporary Laydown Area is required between Stage 1a (site preparation) and Stage 3 (demolition).

4.8.5 The size of the proposed Temporary Laydown Area is approximately 3.3 hectares and is sufficient to support construction activities. Separate areas within the Temporary Laydown Area are proposed for parking (223 car park spaces and 42 parking spaces for larger vehicles), offices, storage and fabrication.

4.8.6 Access to the proposed Temporary Laydown Area is suitable, subject to installation of a new access point. The Temporary Laydown Area has an existing access point at Walthamstow Avenue which would be used predominantly by construction vehicles and deliveries. A new access point is proposed off Lee Park Way for access to the designated parking area.

4.8.7 The location of the proposed Temporary Laydown Area relative to the Edmonton EcoPark is suitable and would support ease of transport between the two sites. Construction traffic from the Temporary Laydown Area is assumed to travel to the Application Site via Walthamstow Avenue/Advent Way. Some light vehicles including construction shuttle buses (for employees and/or visitors) may travel to the Application Site via the new Lee Park Way access. Construction employees would travel to the Temporary Laydown Area at the start of work shifts and then onwards to the main construction site via Lee Park Way (in shuttle buses). The majority of vehicles associated with the construction of the proposed ERF would travel via the A406 North Circular Road and A1055 Meridian Way to the Ardra Road/Deephams Farm Road access.

4.8.8 For the reasons outlined above the proposed Temporary Laydown Area was selected as a suitable location for the purposes of the Project. The Applicant has therefore included the proposed Temporary Laydown Area within the Application Site.

4.9 Edmonton Sea Cadets

4.9.1 The Edmonton Sea Cadets have a lease of a small property within the Edmonton EcoPark which expires in 2017, and was granted for a term of 28 years with the benefit of the protection of the Landlord and Tenant Act. In designing the Project, the Applicant considered options of the Edmonton Sea Cadets remaining on site or of providing a suitable alternative location.

4.9.2 The essential requirements for a replacement facility specified by the Edmonton Sea Cadets were:

a. drill hall/main deck (10 metres x 10 metres);
b. five classrooms (for eight to 10 cadets each) (classrooms are specialised and split into five disciplines);
c. kitchen/galley;
d. two offices (one person each);
e. wardroom (staff room);
f. male and female cadet showers, changing rooms and WCs;
g. yard storage for canoes, toppers and dinghies (secure);
h. boat shed;
i. radio room;
j. seamanship room (for rope work etc);
k. navigation room (maps and charts);
l. expedition room (maps and charts);
m. juniors' room;
n. mast;
o. secure storage for radios and valuables;

p. uniform storage space;

q. a parking area for a minibus;

r. rollers on the slipway to assist with getting boats out of the water;

s. mooring points and safety rails at the waterside; and

t. CCTV.

4.9.3 The following additional items were considered desirable:

a. drill square;

b. dock for a powerboat with boat shed above;

c. winch and slipway to help remove boats from the water;

d. BBQ area;

e. the large decommissioned gun currently on site; and

f. fold-up bunks for overnight stays.

4.9.4 The options considered were:

a. a replacement facility on the Edmonton EcoPark with access to the River Lee;

b. an alternative facility located at Stonebridge Lock south of the existing facility on the River Lee; and

c. an alternative facility located at the nearby Banbury Reservoir.

4.9.5 In all cases a new purpose built facility was proposed, which would meet the requirements of the Edmonton Sea Cadets as set out above.

4.9.6 Although both alternative facilities would have allowed access to the water, because of other activities along the river, and the location of other Sea Cadet groups, neither were considered as satisfactory locations for a replacement of the facility at the Edmonton EcoPark.

4.9.7 The facility at Stonebridge Lock would have been located on land owned by the Canal and River Trust. Discussions identified that it would be possible to construct a building with facilities that allowed for the Edmonton Sea Cadets requirements and shared community use. It was, however, preferable for the Edmonton Sea Cadets to remain in their current location to prevent any overlap of the waterway territory with other similar groups. Commercial terms were therefore not progressed.

4.9.8 The facility at Banbury Reservoir would have been located on land owned by Thames Water. Although there were initial discussions which indicated that this site might be suitable, as a result of discussions it became clear that the use would not be compatible with land management requirements.

4.9.9 The conclusion was that the most suitable option was to construct a replacement facility in the existing location at the Edmonton EcoPark. It is proposed that the new facility for the Edmonton Sea Cadets is incorporated into the design of the new EcoPark House building. The Edmonton Sea Cadets would occupy a secure area within the new building with access to the outside area and the River Lee Navigation.

4.10 The Project

4.10.1 The application for a DCO for an ERF at the Edmonton EcoPark is the culmination of the Applicant's strategic approach to future waste management. The Project has developed from the various assessments the Applicant has undertaken in establishing the procurement strategy and considering alternatives to that strategy in order to meet the objectives of the NLJWS.

4.10.2 The Project focuses on the core responsibility for treatment of residual waste delivered by the Constituent Boroughs, giving rise to an application for an energy generating facility using that waste as fuel.

4.10.3 In addition, as the Edmonton EcoPark is available to the Applicant and has an existing waste management use, associated activities and those needed for the operation of the proposed ERF are included. These uses include the RRF, which covers bulking and pre-treatment of waste received prior to onward transfer (organic waste) or treatment in the proposed ERF. This activity is essential for the operation of the proposed ERF, and is a replacement facility for existing activities, currently carried on in the area to the north of the EcoPark where the proposed ERF would be located. The RRF also would include a RRC, for use for residents in disposing of recyclates, and for small business use for recyclates and deposit of commercial and industrial waste. This is co-located within the RRF for the bulking and waste pre-treatment such as sorting and shredding of wastes unsuitable for reuse and recycling.

Appendix A: Chronology of assessments

Date	Activity	Assessment	Key points
1970	EfW use started		
1986	North London Waste Authority Established		
1994	LondonWaste Ltd took contract for waste management from joint venture NLWA and SITA GB Ltd. EcoPark site transferred from GLC to LWL		
2009 (February)	NLJWS	Waste modelling and composition studies; Strategic Environmental Assessment	Reduction in waste to landfill, waste reduction, increased recycling with target 50% by 2020, technology to support energy use
2008-2010	Preparation of OBC as application for PFI credits, submitted to DEFRA January 2010	Strategic, Technology, planning and sites assessments carried out and reported in OBC. Options appraisal criteria were: sustainability, nuisance, cost, proximity principle, deliverability/risk, proven technology and performance.	Technology outcomes supported EfW with CHP or MBT/AD with separate EfW; Reference project required additional land in north London – sites strategy led to acquisition of Pinkham Way; Planning assessment showed EfW as high to very high risk, and reference project as medium risk Target for household recycling 50% by 2020; Target for landfill avoidance 75%.
2009 (December)	NLWA acquisition of SITA's shares in LWL – now owns 100%		

Date	Activity	Assessment	Key points
2010	Withdrawal of PFI credits as part of Government comprehensive spending review		
2011		Assessments relating to technology options and planning refreshed	Outcome confirmed OBC reference project as most deliverable. Planning deliverability risk unchanged.
2013	Options considered as plan B in the event that the procurement did not reach successful conclusion	Assessments relating to planning and cost refreshed	Cost of EfW provided within area significantly lower than reference project; planning policy change led to reduced planning risk such that EfW at same risk level as MBT/AD with separate EfW – medium deliverability risk.
2013 (September and December)	Decisions taken (a) not to proceed with procurement outcome and (b) to progress planning for an ERF at EcoPark		
2014		Waste modelling and waste composition studies carried out.	Volume of waste requiring treatment established
2014	Assessments carried out to inform decisions on the Project	Review of Thermal Treatment Options	Conclusion: Advance Moving Grate Technology most appropriate for the requirements
2014 June		Design and number of plant lines	Conclusion: 2 lines appropriate for the requirements
2014 (August)		Factual Geotechnical Ground Investigation Report	Provided assessment of ground conditions at EcoPark

Date	Activity	Assessment	Key points
2014 (September)		Flue Gas Treatment Technology Options	Considered wet, dry and combined systems. Authority decision in September 2014 to adopt either a wet or combined system but not a dry system.
2014		Waste data report and waste forecast model	Methodology and results of waste forecasting modelling to identify future residual requirements.
2015		Cooling Plant Technology Options	Reviewed cooling plant technology options and relative merits

Appendix B: Review of thermal treatment options

Intended for
North London Waste Authority

Document type
Report

Date
November 2014

NORTH LONDON HEAT AND POWER PROJECT - A REVIEW OF THERMAL TREATMENT OPTIONS

RAMBØLL

CONTENTS

1 EXECUTIVE SUMMARY

Introduction

When developing an energy recovery facility (ERF) for municipal waste treatment (MSW) one of the fundamental technical decisions is the selection of the most suitable technology. Today there appears to be a choice between well proven advanced moving grate systems and the less proven alternative technologies.

Alternative technology suppliers have made significant marketing efforts and lobbied government to provide assistance with the launch of their schemes on claims of higher efficiencies, smaller footprints and other less technical points.

To make the right technology choice it is important to look at the key criteria as the facility will be operated for many years, needing to provide a reliable and robust service.

Background

The ERF will provide a vital part of the waste management infrastructure for the North London Waste Authority (NLWA). The existing Edmonton facility has provided a much needed service since the early 1970s, exhibiting very good reliability. This has resulted in not only a cost effective and efficient solution, but also the diversion of millions of tonnes of waste from landfill disposal. As a local service it has meant that waste can be collected and treated in a short cycle avoiding waste build up and the consequent hygiene and other risks associated with storage of untreated putrescible waste.

In the current climate a number of other criteria must be addressed. These include:

- Energy efficiency and recovery;
- Environment – emissions, health and safety;
- Flexibility to handle variations in waste composition;
- Fit within the local infrastructure and plans for the future; and
- Ability to operate at the "capital city" scale.

Technical Options

The technical options that are considered include:

- Advanced moving grate technology;
- Pyrolysis;
- Gasification; and
- Two stage combustion.

Advanced moving grate technology has evolved over many years. Research and even further development of this technology continues today. Its performance has made significant steps over the last 10 years to achieve very high levels of reliability and high efficiency, especially when combined with a district heating scheme. The technology can meet and exceed strict regulatory limits on emissions and yet it offers the flexibility to accept waste of varying composition and calorific value. To this end it is considered as a bankable solution. Examples of this technology can be found across the globe and many new advanced moving grate plants are under construction and at the design stage today. Technology suppliers continue to expend a considerable research and development (R & D) budget to keep this technology at the cutting edge of efficiency, performance and reliability.

The gasification and pyrolysis technologies are commonly referred to as 'advanced' thermal treatment technologies. The reason being that thermal gasification processes produce syngas, which can potentially be used to produce electricity with higher efficiency or for producing liquid fuels or chemicals. Syngas has about half the energy density of natural gas. Syngas is used in a boiler or other device for power production. Therefore, the main question is whether the additional technical complexity and increased energy consumption of the gasification processes can be justified by the potential increase in efficiency and/or attractiveness of the by-products when compared to conventional combustion.

Thermal gasification of municipal solid waste (MSW) has experienced around 25 years of often challenging development. These alternative technologies generally require MSW to undergo extensive pre-processing. In addition, operational experience is sparse, availability has been shown to be significantly lower than that of modern advanced moving grate plants, and operational costs are higher. Furthermore, the operational data from reference facilities shows that the overall energy efficiency of thermal gasification processes are less efficient than direct combustion plants.

Two stage combustion technologies have a number of reference plants. Some facilities have been in operation for circa 10 years. Most of the facilities are designed with relatively low steam parameters, thus achieving lower energy efficiency. Furthermore, pre-treatment of waste is required and plants may experience lower availability when compared to modern advanced moving grate fired plants.

Whilst a number of alternative technologies are actively promoted by development companies, there is little evidence to suggest they have achieved sufficient track records and performance levels required to meet the aims of NLWA for (i) safe and secure residual waste treatment (ii) combined with ability to deliver high service availability and (iii) high levels of consistent energy production into a local energy network. The commercial and stakeholder relationship consequences of service failure or short comings at a municipal scale are significant for any waste management authority. On this basis, Ramboll recommends the use of well proven advanced moving grate combustion.

Table 1 provides a general comparison of the different thermal treatment technologies.

Table 1 – Comparison of technologies

Parameter	**Adavanced Moving Grate**	**Thermal Gasification / Pyrolysis**	**Two Stage Combustion**
Waste requirements • Pre sorting • Size reduction	Not required Only items > 1000 mm	Removal of metals Shredding required	Removal of metals Shredding required
Energy* • Gross electricty • Net electricity • CHP mode ** of lower calorific value*	25 – 33% 22 - 30% Up to 100%	Limited data 0 – 10% Up to 100%	Limited data * Limited data ** Up to 97% *in theory close to avanced grate technology , if material and design are adjusted/changed to handle higher steam parameters. ** loss of additional 2-3% points compared to advanced moving grate due to pretreatment.
Environment • Bottom ash (depends on ash in waste) • Health and safety Compliance with EU regulation	≈ 16-20% by weight Minimal contact with waste Yes	≈ 16-20%* by weight Contact with waste during cleaning of pre-treatment plant Yes * Pyrolysis results in the production of a char. A Defra report classifies municipal solid waste pyrolysis char as *"Hazardous waste, but could be used as coal replacement in certain combustion applications or as a gasifier feedstock."*	≈ 16-20% by weight Contact with waste during cleaning of pre-treatment plant Yes
Operation experience Information level Handling changes in waste composition Annual availability Net electricity production at 10 MJ/kg	Well documented Higher flexibility ≥8,000 hrs 0.6 - 0.65 MWh/t	Limited data available Lower flexibility <5,500 hrs 0 – 0.25 MWh/t	Limited data available Medium flexibility <7,000 hrs 0.4 - 0.45 MWh/t

Parameter	Adavanced Moving Grate	Thermal Gasification / Pyrolysis	Two Stage Combustion
Technical risks			
Overall assessment	Low	High	Medium
Proven treating MSW or MSW derived waste	Well proven	Well proven in Japan. (with very limited net electricity production)	Further demonstration of track record still required from independently owned plants.
Number of plants	>1,500	Unclear, around 50 to 80 facilties	Less than 10 facilities (with lower steam parameters and mainly 'heat only' plants.)
Advantages	- Well proven - High availability - High efficiency	- Facilities could apply for renewables benefits (previously double ROCs) - Better public perception in the UK	- Facilities could apply for renewables benefits (previously double ROCs - Potentially better public perception in the UK
Disadvantages	- Limited access to renewables benefits from government - Less positive public perception in the UK	- Low net efficiency - Availability uncertain - Unproven technology to produce syngas for use in gas turbine or upgrade to fuel	No reference plants achieve steam parameters or/and availability similar to facilities based on advanced moving grate technology.
Number of modules for a large scale thermal waste treatment facility e.g. 700,000 tpa	2 lines of 44 t/h	Circa 90+ modules of 1 t/h, could base design on around 8 to 10 larger capacity units.	Circa 18 to 20 lines of 5 t/h

2 INTRODUCTION

Over the last decade there has been a considerable push towards improved ERF efficiency. Advanced moving grate has made considerable progress in terms of efficiency and reliability. Efficiency figures for electricity only plants have improved from 20% to 25% or more. The inclusion of district heating supplies can increase the efficiency much further and Scandinavian plants using advanced grate technology combined with district heating are now achieving above 80% efficiency.

There has been considerable interest in new technologies to see if even greater efficiencies and performance levels can be achieved. Of particular interest are the gasification and pyrolysis options as an alternative to advanced moving grate based systems. The technical and financial factors are set out below:

The three main technical motivations for gasification/pyrolysis are:

- Syngas can potentially be used to produce high-value energy carriers or materials. This includes possible syngas use as a feedstock for gas-engines, which have high energy efficiency, as a liquid fuel in the transport sector in the form of hydrogen, or converted to ethanol or methanol which can be used in the chemical industry;

- Reduced production of mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NOx), hydrogen chloride (HCl) and sulfur dioxide (SO_2). However, the cleaned emissions from conventional facilities are likely to be similar due the strict emission requirements in the Industrial Emission Directive, (IED); and

- Gasification technologies most often melt ash residues to form a vitrified bottom ash, which effectively immobilizes heavy metals. This has been a key driver in Japan, where it is a regulatory requirement to vitrify bottom ash.

The main financial motivation for gasification/pyrolysis has been:

- Ability to apply for double ROCs (Renewables Obligation Certificate) in the UK. This subsidy will not be available after March 2017 when it is to be replaced by new arrangements.

ROCs have now been replaced by an alternative electricity sale mechanism called Contract for Difference (CfD) and the level of support or subsidy is no longer certain.

3 TECHNOLOGY DESCRIPTION

This section provides a general description of the main types of thermal treatment processes and provides general performance data.

There are three basic processes for thermal treatment of MSW:

- **Combustion (more commonly referred to as incineration when waste is the feedstock)** is complete oxidation with surplus oxygen. The combustion process does not require an external energy source because it releases heat and is self-supporting. The temperature in the combustion chamber is typically >1,000 °C. The flue gas (primarily comprising water vapour, carbon dioxide (CO_2), hydrogen chloride (H_2O), mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) and oxygen (O_2)) has no calorific value because all the energy is converted into heat.

- **Pyrolysis** is the thermal breakdown of waste in the absence of oxygen. Waste is heated to high temperatures (>300°C) by an external energy source, without adding steam or oxygen. The products are char, pyrolysis oil and syngas (pyrolysis gas). The pyrolysis gas has a high calorific value. Due to a high level of tar syngas needs extensive cleaning before use.

- **Gasification** is the thermal breakdown/partial oxidation of waste under a controlled oxygen atmosphere where the oxygen content is lower than necessary for combustion. Waste reacts chemically with steam or air at a high temperature (>750 °C). The process requires, as for pyrolysis, an external energy source to heat the process. Syngas from gasification, primarily comprising carbon monoxide (CO) and hydrogen (H_2), has a lower calorific value than pyrolysis gas and is dependent upon the gasification process. The tar levels in the syngas are lower than for pyrolysis gas and the amount depends on the actual gasification technology.

The above processes are illustrated in **Figure 1**.

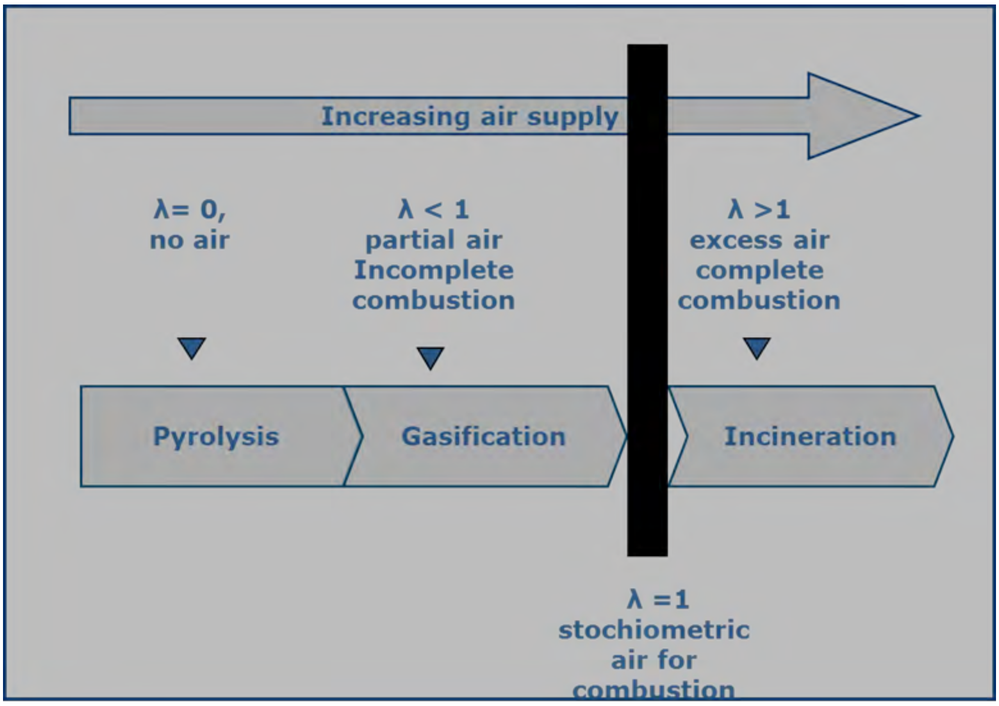


Figure 1: Air supply for thermal treatment technologies

Complete combustion of waste in an ERF facility consists of a sequence of pyrolysis, gasification and combustion steps. With a conventional ERF combustion system these three steps are integrated. Alternative conversion systems generate an intermediate product and the combustion process is carried out later. **Figure 2** presents an overview of the process. If limited heat and air is added then gasification occurs. If excess air is supplied then complete combustion takes place. The left side of the figure illustrates the three steps in the combustion process whereas the right side shows different forms of energy use.

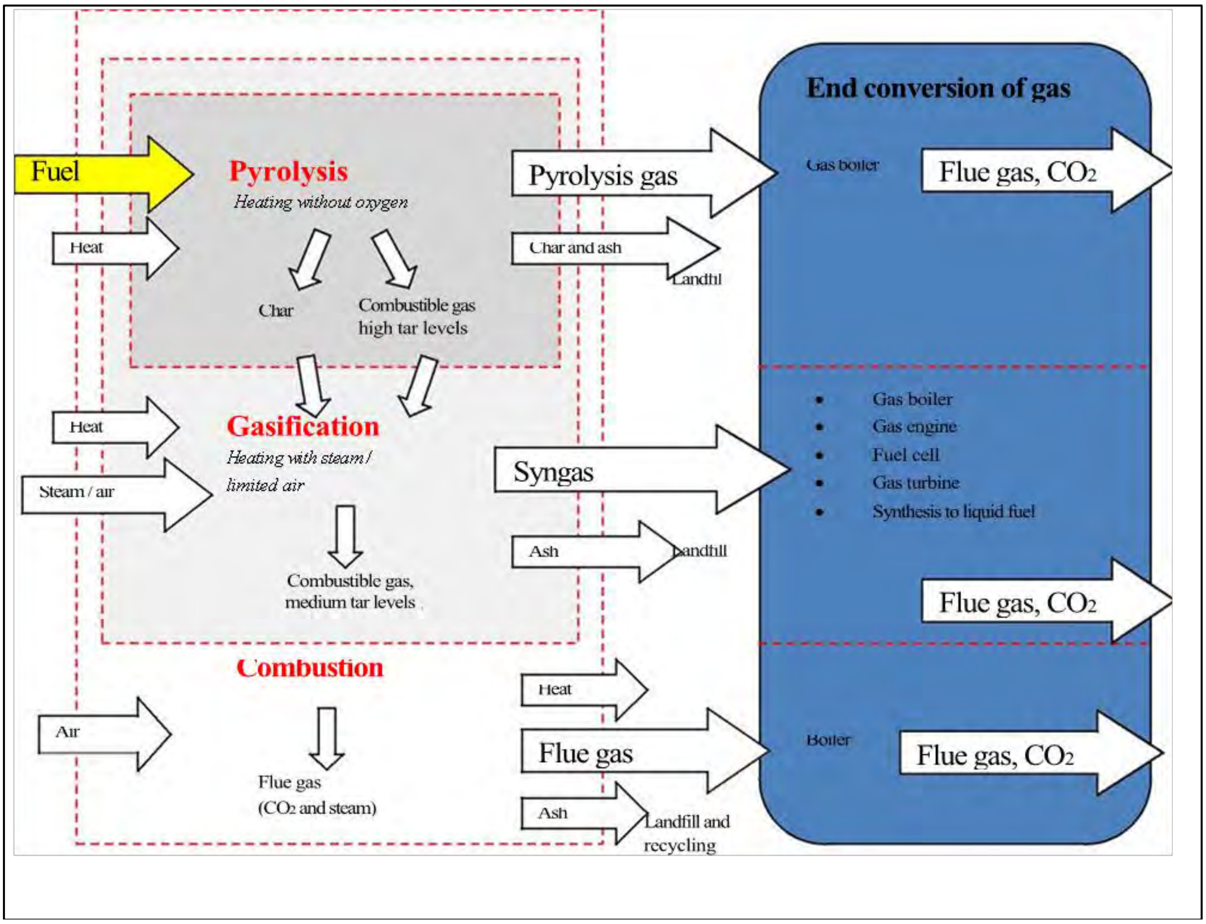


Figure 2: Overview of thermal processes

Some technology providers offer a two-stage combustion process. The first stage of the combustion is operated with limited amount of oxygen, resulting in gasification. However, these processes do not generate a syngas output, as the gas is immediately burnt in a combustion chamber with excess air injection. The gasification chamber and the combustion chamber are fully integrated. Energy recovery takes place in a conventional boiler followed by flue gas cleaning using systems that are no different from those at a modern ERF. The technology is more correctly characterized as a two-stage combustion technology. However, in the UK these technologies have been classed as gasification processes for the purposes of the ROC scheme.

Combustion type processes can be split into the following two types:

- Advanced moving grate technology
- Fluidised bed technology

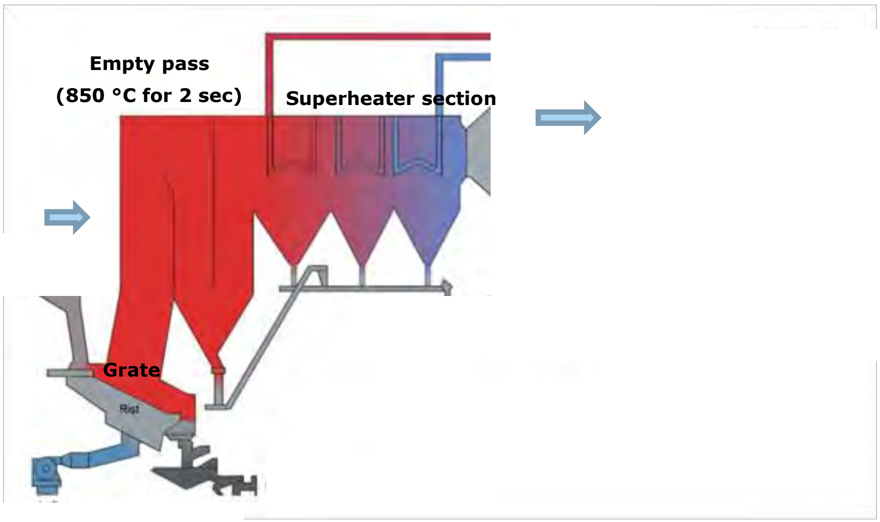
Advanced moving grate technology is the most popular and successful thermal treatment technology worldwide. There are examples of fluidised bed facilities installed to treat residual waste, both in Europe and the UK.

3.1 Advanced Moving Grate Technology

Key information about advanced moving grate technology is summarised in **Table 2** below.

Table 2 – Assessment of Advanced Moving Grate Technology

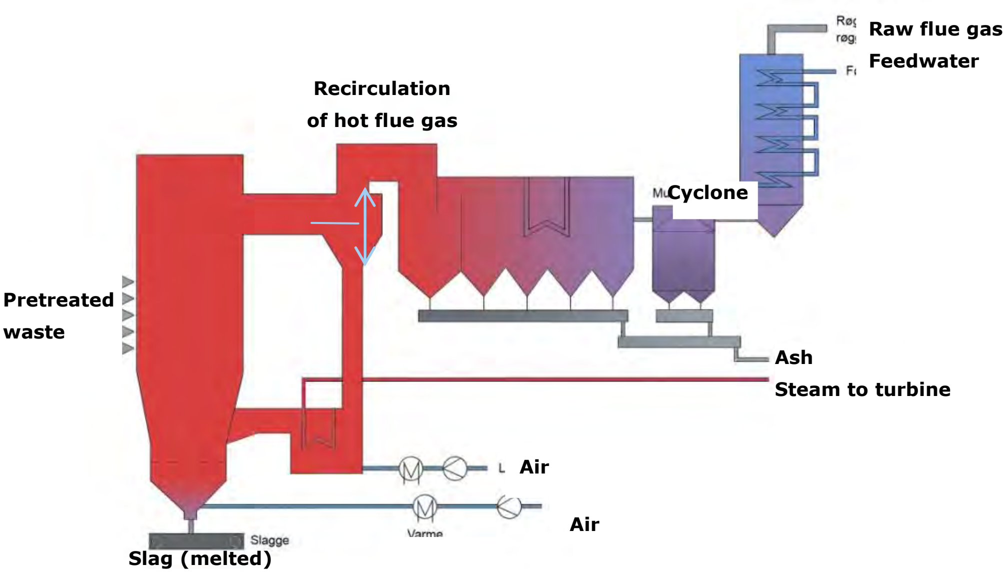
Technology Assessment – Advanced Moving Grate Technology	
Historical Background:	Moving grate technology was first employed in the 1930's.
Technology Development:	Many hundreds of grate fired lines have been installed in Europe and other parts of the world. The technology has undergone continuous development to achieve very high levels of efficiency, reliability and performance. It is the preferred technology worldwide to recover energy from residual waste. Technical developments include: - Modern advanced moving grate plants incorporating combined heat and power can achieve efficiencies of more than 80%. - Increase in steam parameters from the well proven 400 °C/40 bara to around 425 °C/60 bara. Some facilities have increased steam parameters further but it is always a trade-off between corrosion issues and the additional income from electricity sale. - The use of high quality metal alloys (e.g. Inconel) to reduce corrosion issues. - Lower boiler outlet temperature to increase amount of heat used for steam generation. - High temperature steam may be drawn from the turbine and used for district heating system improving overall energy efficiency. - Condensation step to recover energy from the clean flue gas prior to entering the stack (chimney). The additional heat can be transferred to district heating networks and further increase plant efficiencies. New plants in Scandinavia incorporating flue gas condensation units coupled with district heating schemes achieve near 100% energy efficiency. Flue gas condensation for heat recovery requires a low temperature district heating scheme. - Automatic combustion control to ensure a very efficient burn-out rate, typically around 99%. - Automatic deNOx control system to ensure efficient mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NOx) removal and low consumption of ammonia water. - Automatic flue gas control system that use raw gas measurement to adjust dosing of chemicals and secure low emission values.
Technical Description:	Waste is taken from a storage bunker by a crane and dropped into a chute. At the bottom of the chute waste is fed onto the combustion grate. The waste on the grate is combusted at a temperature of 850 °C or more with combustion air injected from below the grate. Waste is moved forward on the grate and the residue (bottom ash) drops into a water bath at the end of the grate. Complete gas phase combustion is reached by injection of secondary air above the grate. The system ensures that a temperature of at least 850 °C for a minimum of 2 seconds is reached (EU requirement). Auxiliary fuel is only used for start-up and shutdown to achieve regulatory temperature conditions for waste feed. Energy released from waste combustion is transferred to the boiler system. This typically has as an energy efficiency of around 85% for steam production. A conservative design for steam parameters is typically 40 bara and 400°C for electricity production. Many new advanced moving grate combustion facilities use higher steam parameters (i.e. 60 bara and 425 °C). The selection of steam parameters is a trade-off between efficiency of the turbine and acceptable boiler corrosion rates that affect plant availability and maintenance costs. Flue gas from combustion is often treated in a dry/semi-dry gas clean-up system, where hydrated lime or in a few cases sodium bicarbonate is injected upstream of a large filter to neutralise the acidic gases (hydrogen chloride (HCl), sulfur dioxide (SO_2) and hydrogen fluoride (HF)). Activated carbon is added to

	adsorb heavy metals (mainly mercury) and dioxins. Other heavy metals are bound to the surface of the fly ash particles and removed in the filter. The residue from the filter requires treatment and disposal as a hazardous waste. More complex wet systems are often installed in Germany, Switzerland and Scandinavia where there are outlets for effluent from the treatment process. Wet systems make it possible to recover additional heat from the flue gas through condensation of the water vapour in the flue gas and thus increase overall efficiency.
Illustration:	
Input Requirements:	Residual waste - No pre-treatment required. Bulky waste - requires shredding. Flexibility to accept changes to inputs e.g. calorific value, composition, moisture content. Can also process refuse derived fuels and solid recovered fuels.
Inputs:	Fuel to auxiliary burners during normal operation - minimal. Ammonia water (25 %) for deNOx: ≈ 4 kg/t (of waste treated) Lime for flue gas treatment: ≈ 14 kg/t Activated carbon: ≈ 0.5 kg/t Internal electricity consumption: ≈ 100 kWh/t (around 3% of the energy content in waste)
Outputs:	Steam from boiler system ≈ 85% of the energy in the waste will be recovered. Electricity for internal use and export Heat for district heating and/or industrial process use Incinerator bottom ash: ≈ 20% by weight FGT residue (incl. fly ash): ≈ 30 kg/t (of waste treated)
Commercial:	Commercial availability: Numerous recognised suppliers.
	Typical capacity range per line: 2.5 - 44 t/h per line Annual processing of up to 350,000 tonnes for each process line.
	Operational data availability: Information on availability, energy recovery efficiencies, level of clean gas emissions and a wealth of other data is available for a large number of plants.

3.2 Fluidised Bed Technology

Key information about fluidised bed combustion is summarised in **Table 3** below.

Table 3 – Assessment of Fluidised Bed Technology

Technology assessment - Fluidised Bed Technology	
Historical Background:	The fluidised bed reactor was developed in the 1920's for coal combustion. It has been successfully developed for the combustion of wood chips and sewerage sludge.
Technology Development:	Around 40 waste fired plant lines have been established in Europe. Fluidised bed lines are mostly fuelled by refuse derived fuel (RDF), produced from municipal waste through sorting/recovery of metals and organic matter, and processed wood waste. The technology performs best with a relatively uniform feedstock. Thus very few facilities treat a feedstock comprising residual waste, which is highly variable. Reference plants have a history of poor and challenging performance. It is believed that very few waste management companies would select fluidised bed technology for waste combustion when given the option of advanced moving grate combustion.
Technical Description:	Waste undergoes a process of metal removal and shredding for size reduction. It is transferred to the reactor chamber. The reactor chamber contains very hot sand, which is fluidised by an air stream from the wind box below. The combustion process is very fast and the primary typically takes less than 30 seconds. The EU requirement of minimum 2 seconds at 850 °C is achieved in the secondary combustion zone. Energy is recovered as heat in a boiler system similar to a grate fired facility. Fluidised bed technology inherently produces low mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NOx) emissions and it is often able to meet EU requirements without the use of a deNOx system. The remaining FGT system is similar to the system required for moving grate technology. 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 combustion gas. This has a significant adverse financial impact because fly ash is typically classified as hazardous waste, whereas bottom ash is considered non-hazardous waste.
Illustration:	

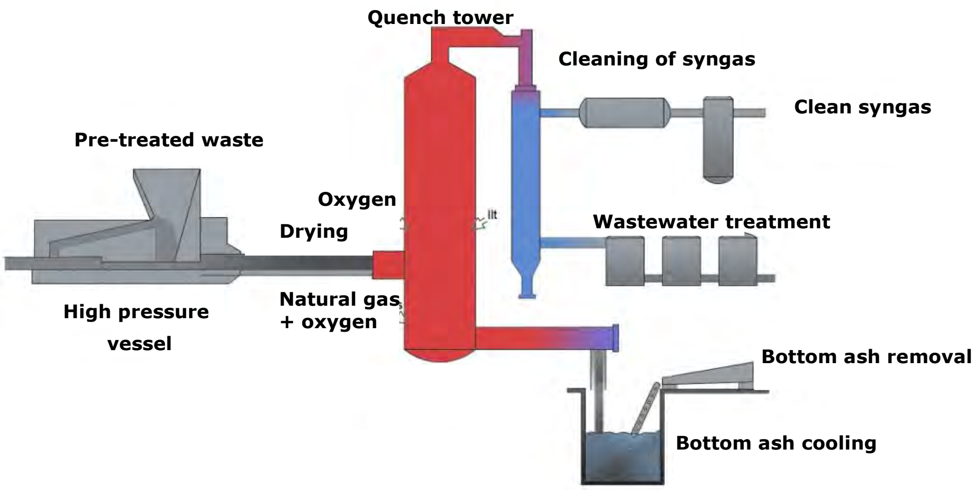
Input Requirements:	Residual waste – Shredding required, typically to a particle size of 5 - 15 cm, and removal of metals. Restrictions on input changes e.g. heating value, ash content and moisture content because the combustion process is sensitive to sudden changes of the waste composition.
Input:	Fuel to auxiliary burners during normal operation - minimal. Ammonia water (25 %) for deNOx: ≈ 0 to 2 kg/t (of waste treated) Lime for flue gas treatment ≈ 10 kg/t Activated carbon ≈ 0.5 kg/t Electricity consumption ≈ 100 kWh/t (around 3% of the energy content in waste) + minimum 50 kWh/t and up to several hundred kWh/t for the pre-treatment step.
Output:	Steam from boiler system ≈ 85% of the energy in the waste will be recovered. Electricity for own use and grid supply Heat for district heating and/or industrial process use Incinerator bottom ash ≈ Depends on inert content. 50% of inert to IBA Boiler ash ≈ 50% inert to fly ash plus carry-over of sand. FGT residue ≈ 30 kg/t (of waste treated) * High velocity of the fluidized air results in a relative high fraction of fly ash compared to IBA.
Commercial:	Commercial availability: Limited recognised suppliers
	Typical range: 5- 20 t/h per line
	Operational data availability: Some plants have published the efficiency of energy recovery and clean gas emissions. Information on electricity requirement for the pre-treatment step is difficult to obtain.

3.3 Thermal Gasification Technology

Key information for thermal gasification is summarised in **Table 4** below. The 'Two-Stage Combustion' technology, also considered as gasification, review is set out below in **Section 3.5**.

Table 4 – Assessment of Thermal Gasification

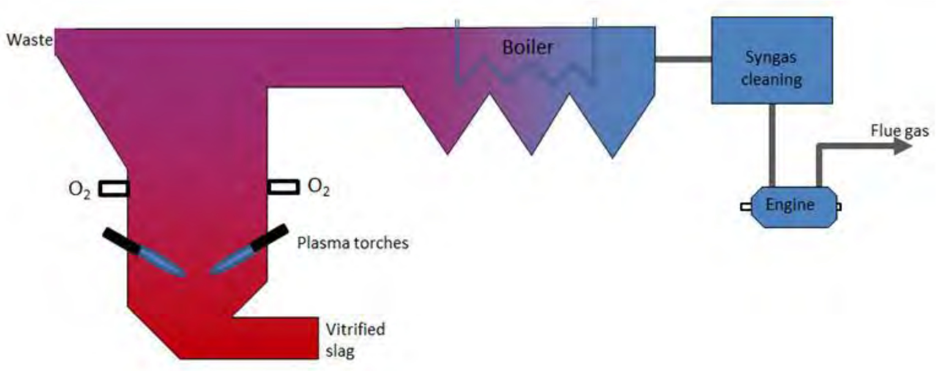
Technical Assessment - Thermal Gasification	
Historical Background:	Thermal gasification was invented in the 1800's to produce city-gas from coal. The technology is now commonly used in areas with large coal deposits to convert coal into a gas and subsequently produce diesel and oil.
Technology Development:	Most gasification plants treating residual waste are located in Japan. The high operational temperature (up to 1,600 -2,000 °C) makes it possible to melt bottom ash and fly ash into a clinker. This was a common requirement in a Japanese environmental permit. There appears to be no clear conclusion regarding the environmental benefits of clinker compared to bottom ash. Relatively fewer gasification facilities are presently built in Japan, as the production of clinker appears to be a less common requirement today. A few large gasification plants were built in the 1990's in Europe for municipal solid waste treatment. These plants experienced operational problems and ceased to operate. According to a 2008 survey by Juniper, up to 80 waste processing gasification lines were in operation with only a handful located outside of Japan. Limited information is available about the types of waste processed and capacities of the plants. Only a few facilities appear to use syngas from gasification in a gas turbine to produce electricity. This would theoretically achieve a higher electrical efficiency than plants using steam turbine technology.
Technical Description:	Waste is indirectly exposed to a high temperature which causes the organic matter to crack and volatilise. Only limited oxygen is added to ensure that limited combustion takes place at this stage. There are a number of suppliers, primarily Japanese companies. 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 intent was to use the gas in reciprocating engines with a net electricity efficiency of circa 40% - compared with a steam turbine with an efficiency of circa 30%. However, at most plants the energy is recovered through a boiler system with similar steam parameters as a grate combustion facility. This is due to operational problems with alternative approaches offering higher theoretical efficiencies. Flue gas is treated in a similar system as for advanced moving grate fired facilities.

Illustration:	Concept Example 
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: Unknown, but significant amount Ammonia water (25%) for deNOx: <0-2 kg/t (of waste treated) Lime for flue gas treatment: <10 kg/t Activated carbon <0.5 kg/t Electricity own consumption: Unknown Enriched air (high oxygen) Unknown
Output:	All residues are normally melted into a relatively inert clinker, rock-like material. Net electricity is very limited and may even be negative for some plants – based on information collected during Ramboll's site visits in Japan. Better energy efficiency is achieved by processes that do not melt the inert fraction.
Commercial status:	Commercial availability: A number of suppliers, but none with a proven track record relevant to the scale of the North London Heat and Power Project
	Typical capacity range: 1 - 10 t/h per line
	Operational data availability: Difficult to obtain on public domain.

3.4 Plasma Gasification Technology

Key information for plasma gasification technology is summarised in **Table 5** below. Plasma gasification is a variant of gasification as syngas is produced, but it varies from other gasification processes as a plasma torch (electric arc) is used the destruct waste at extremely high temperatures.

Table 5 – Assessment of Plasma (Thermal Gasification)

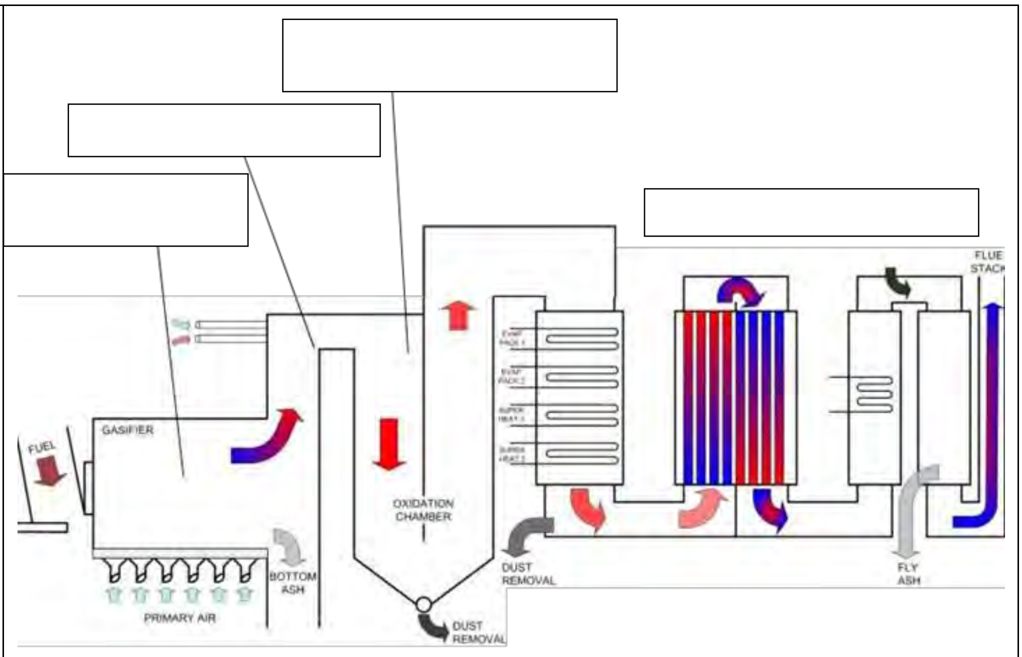
Technical assessment – Plasma (Thermal Gasification)	
Historical Background:	Plasma gasification is a variant of thermal gasification. The energy source for cracking of organic matter is an ionized gas produced by emitting gas through an electrical arc where the gas reaches a temperature up to 3,500 °C. The high temperature vitrifies bottom ash into a glassy clinker.
Technology Development:	Plasma gasification is commercially available and at least three companies are promoting plasma gasification for treatment of residual waste.
Technical Description:	Similar to thermal gasification – except that a plasma torch (electric arc) is used to reach the high temperatures required.
Illustration:	Pre-sorted and shredded waste is introduced at the top of the reactor. Waste is destructed during the downward fall through the extremely hot plasma produced from the electrically powered plasma torches. Inert material melts near the plasma torches. The glass melt is removed from the bottom of the reactor. The syngas exits at top of the reactor, is cooled down in a boiler and requires cleaning prior to further use. 
Input Requirement:	Similar to thermal gasification
Input:	Similar to thermal gasification, but additional high power consumption of the plasma torch.
Output:	Similar to thermal gasification
Commercial status:	Commercial availability: Limited suppliers and none with a proven track record relevant to the scale of the North London Heat and Power Project`
	Typical capacity range: 1 - 10 t/h per line
	Operational data availability: No operational data appears to be publicly available for recognised reference plants.

3.5 Two-Stage Combustion Technology

Key information on 'Two-stage Combustion' is summarised in **Table 6** below.

Table 6 – Assessment of Two Stage Combustion

Technology assessment – 'Two-Stage Combustion'	
Historical Background:	The 'Two-Stage Combustion' process consists of an upstream stage with drying and gasification of waste and a downstream stage for the combustion of the syngas produced. The purpose of the technology was to develop a small scale energy-from-waste plant with minimal emissions to atmosphere and high flexibility in handling different waste types with regard to calorific value, composition and moisture content.
Technology Development:	A number of lines have been established in Europe since 1997 with typical line capacities of 40,000 tpa.
Technical Description:	Residual waste is prepared by removal of metals and shredding for particle size reduction and transferred to a feeder. The primary chamber is operated with limited oxygen to produce a syngas consisting of hydrogen (H_2), methane (CH4) and carbon monoxide (CO). Secondary air is injected into the transfer channel to increase excess oxygen (O_2) content to 7%. This is similar to traditional waste combustion. To our knowledge, there is no experience of syngas extraction for alternative uses i.e. 1) use in gas turbine or 2) upgrade to a liquid fuel. The lower temperature of the waste on the grate is reported to reduce the overall production of hydrogen chloride (HCl) and sulphur dioxide (SO_2). It is reported that raw gas level of mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NOx) from the process is significantly lower than conventional combustion. Overall, clean gas emissions appear to be comparable with grate combustion. We understand that manual cleaning of the boiler is required up to 4 times per year. Moving grate combustion normally only requires one annual manual boiler clean. Existing plants predominately only produce heat and are operated with lower steam parameters than moving grate combustion plants.

Illustration:	
Input Requirements:	Residual waste: requires shredding and the removal of metals. Bulky waste: requires shredding
Input:	Fuel to auxiliary burners during normal operation - minimal. Lime for flue gas treatment: ≈ 5 to 10 kg/t (of waste treated) Activated carbon: ≈ 0.5 kg/t Electricity consumption: estimated as being about 100 kWh/t (around 3% of the energy content in waste) + around 25 to 50 kWh/t for the pre-treatment.
Output:	Steam from boiler system ≈ 85% of the energy in the waste will be recovered. Electricity for own use and grid supply Heat for district heating and/or industrial process use Incinerator bottom ash: Similar to conventional waste combustion (excluding. any metals removed in fuel pre-treatment) FGT residue: ≈ 25 – 30 kg/t (lower than traditional waste combustion as less lime is required)
Commercial:	Commercial availability: Limited of suppliers and none with a proven track record relevant to the scale of the North London Heat and Power Project`
	Typical range: Typically installed in modules of 5 t/h, corresponding to circa 40,000 tpa.
	Operational data availability: Data regarding energy efficiency and clean gas emissions is available.

4 OPERATIONAL EXPERIENCE

Thermal gasification is, as stated above, not a new technology. Gasification is a commercially-proven manufacturing process that converts feedstock such as coal and biomass into syngas that can be further processed into fuels or used for electricity generation.

During World War II, where oil supplies were limited, thermal gasification reactors were mounted on cars to enable operations on gas engines using syngas from the gasification of biomass. In countries with significant coal resources like South Africa large scale thermal gasification of coal is used to produce syngas. This is subsequently converted to synthetic diesel by catalytic processes.

Gasification of coal and biomass has been used commercially around the world for several decades by the chemical, refining and fertilizer industries and for more than 35 years by the power industry. At least 420 gasifiers, primarily processing coal and, to a limited extent, biomass, were in operation in 2011.

Due to the heterogeneous nature of MSW, thermal gasification of it is more complex. The commercial experience gained from gasification of coal cannot be directly applied to the treatment of MSW. Gasification of MSW has been studied since the 1980s, but there are very few MSW gasification facilities in operation. These are mainly small scale or pilot plants. Numerous large scale MSW gasification facilities have been closed down due to malfunction or high costs.

Most gasification facilities are located in Japan. These plants typically treat industrial process waste e.g. plastic waste and auto shredder fluff. Very few facilities, if any, process MSW.

There are no full-scale commercially operated MSW gasification facilities in operation in Europe or in North America that can provide three years of efficient and well documented operational track record. The UK is the main market for new gasification projects due to financial incentives. A limited number of commercially operated gasification facilities are due to commence operations over the coming years. These facilities will provide a basis for further testing the likely success of using gasification technology to treat MSW.

The number of gasification/pyrolysis installations reported to be in operation varies in different literature studies. The available information carries a high degree of uncertainly with respect to the feedstock types, plant availability, and operational data. The table below presents the figures, which appear to be most valid and are drawn from various independent literature sources.

Table 7 – Operational Experience Summary of Thermal MSW Treatment Technologies

	Pyrolysis	Gasification	Combustion
Years of operation	~30	~10	~125
Numbers of plants	<10	<50	~1,500
Total amount of waste (mill tonnes)	<0.5	<1*)	>100

*) we have tried to omit biomass, coal and other feedstock. However, this figure has a degree of uncertainty and may include separately collected industrial waste or other supporting fuel.

5 PRE-TREATMENT AND END PRODUCTS

5.1 Pre-treatment of Waste Feedstocks

Modern advanced moving grate based combustion plants generally accept waste feedstock with average heating values ranging between 7 - 15 MJ/kg and, from a size perspective, up to 1 m in length. In contrast most gasification processes require preparation of the feedstock and have limitations on the type of feedstock that can be processed. Recovery of metals can take place in a front end material recovery facility (MRF) or extracted from bottom ash.

Waste pre-treatment may be required for a number of reasons:

- To increase the calorific value as the acceptable heating value range is typically narrower than for grate combustion. Gasification processes are generally able to accept and prefer a high calorific value feedstock to produce syngas with higher heat content. The performance figures stated by technology developers often assume very high heating values of the incoming waste and intensive front-end sorting to ensure a caloric value between 11 - 15 MJ/kg. MSW typically has a calorific value in the range of 9 to 10 MJ/kg.

- To dry waste because some processes are not designed to process wet/high moisture content waste.

- To remove fractions not suitable for the gasifier. Most gasification technologies have strict requirements to remove inert materials such as glass, concrete, metals and chlorine rich fractions (PVC plastics) from feedstock.

- To reduce the size of particles entering the gasification process. Most gasification technologies are based on fluidized bed or entrained flow reactors. These require homogenous shredded waste. Particle sizes should typically not exceed 5 to 15 cm.

While some of the recovered materials have a market value, e.g. metals, other rejected materials such as glass, porcelain and organic waste with low heating values must be disposed of at a cost.

The equipment necessary for pre-treatment of MSW for gasification requires significant investment and energy input, leading to significant operating costs. It is important to consider the complete process and include all pre-treatment processes when comparing different gasification technologies or comparing combustion with gasification technologies using MSW. A schematic overview is illustrated in **Figure 3**.

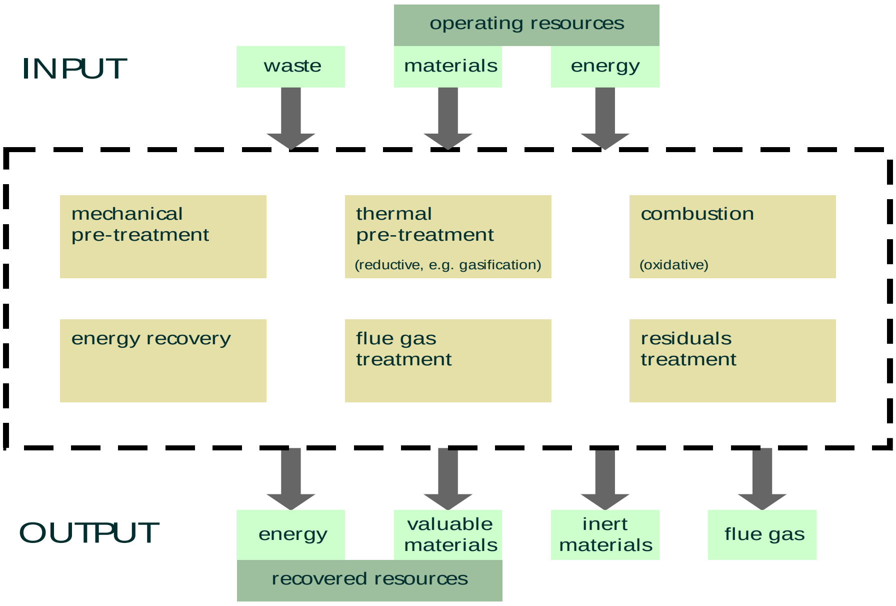


Figure 3: Energy and mass balance concept for thermal treatment processes

5.2 End Products From Thermal Waste Treatment

The environmental impacts and value/costs of different end products from thermal waste treatment technologies are a key discussion point. General guidance on this area is provided below:

Combustion technologies (incl. two-stage combustion):

Three residues are produced:

- Bottom ash: After the recovery of metals, bottom ash may be used as a construction aggregate. Most of the metals from the waste feedstock can be recovered from bottom ash and recycled. Bottom ash typically amounts to about 20 % of the waste processed by weight;

- Boiler ash/fly ash: Heavy metals from the waste are concentrated in fly ash. Fly ash amount is approximately 2 % of the input mass;

- Residues from the flue gas cleaning: Depending on cleaning technology, the residues amount to 1-2 % of the input mass.

Fly ash and residues from flue gas cleaning are typically disposed of at controlled landfill facilities.

Gasification technologies:

Waste products from thermal gasification plants vary with the specific technology used, but normally include:

- Ash, often not separated into fly ash and bottom ash. Therefore, the entire ash amount must be stored in a controlled landfill.

- In some gasification processes ash is vitrified at a high temperature e.g. by use of plasma technology. The leaching of the rock-like material will be lower than for non-melted ash due to the lower surface area. A disadvantage of this is very high electricity consumption to reduce the leaching properties to a very low level.

6 ALTERNATIVE TECHNOLOGIES – RESULTS SO FAR

The main technical and financial drivers for gasification/pyrolysis are to increase the energy/resource recovery from thermal treatment of waste.

The potential applications for syngas are illustrated in **Figure 4**. This technical review shows that, to date, the only long-term application for syngas from MSW has been through direct combustion with heat recovery in a boiler for heat and power production. Other solutions - mainly combustion in a gas turbine or internal combustion engine – appear to have ceased due to technical and financial challenges.

Gasification/pyrolysis plants have generally not been able to provide the benefits promoted by the suppliers.

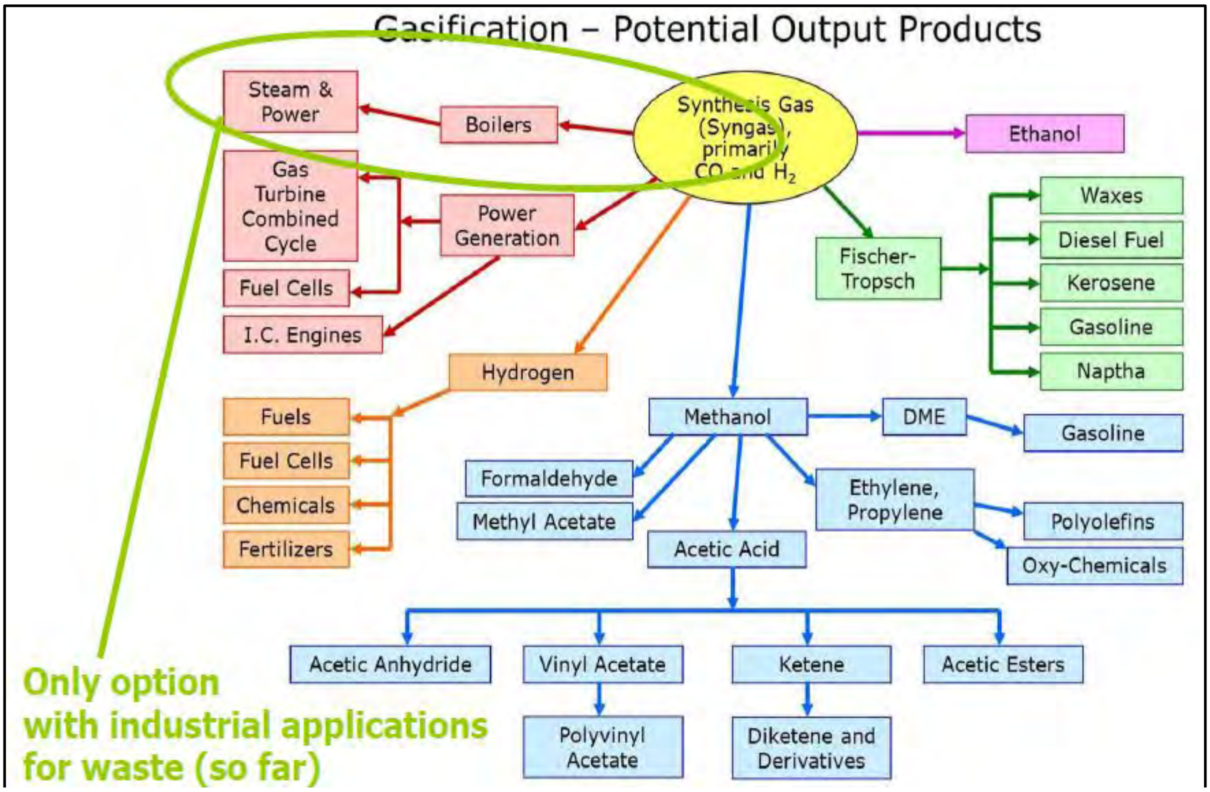


Figure 4: Gasification and the potential products

7 CHALLENGES FOR THERMAL GASIFICATION

This section describes the challenges for gasification technologies processing MSW compared to advanced moving grate-fired combustion.

7.1 Operational Challenges

Limited validated operational data is available for gasification facilities even though the gasification of MSW is much debated and heavily promoted. This is due to the limited number of plants that are in commercial operation as well as technology suppliers withholding information.

One of the challenges of operating a waste fired gasification facility is the production of syngas. Syngas is highly toxic, explosive and contaminated with pollutants and therefore needs significant cleaning before use. The cleaning process has been found to be challenging and costly. In many cases facilities have modified processes to include syngas combustion in a steam boiler followed by a flue gas cleaning module. To reduce the risk of explosion, the process equipment is often placed outdoors.

MSW is a heterogeneous material with inconsistent composition, moisture content, inerts and particle size. This is in sharp contrast to the strict feedstock requirements for gasification technologies.

Gasifiers often run on a partial mix of MSW with industrial and other waste supplies. Therefore, operational data from these facilities is not directly comparable to operating on MSW.

The production of ethanol or methanol from MSW-derived syngas involves the addition of chemical processing equipment to the back-end of an MSW gasification facility. For this reason, all of the consideration presented above for the MSW gasification applies to any MSW gasification-to-ethanol or MSW gasification–to-methanol facility. Once syngas is produced and cleaned sufficiently, the production of ethanol or methanol is a straightforward process that has been proven on a commercial basis. The main challenge is to produce syngas with sufficiently high purity.

Gasification facilities have the appearance of small utility power plants or industrial manufacturing plants. The plants are primarily found to be demonstration facilities or smaller scale facilities with a capacity of 25 - 250 tpd. Attempts to establish full-scale facilities have foundered, and those that tried to date have experienced functional and financial challenges before finally being closed down.

7.2 Energy Production

MSW gasification facilities report theoretical higher electricity generation rates than traditional waste combustion facilities. One of the reasons for this is the higher thermal efficiency of gas-fired power plants when compared to solid-fuel power plants. However, gasification facilities use a significant part of the power generated as process energy for initiating the gasification process and for pre-processing waste (shredding, drying, etc.). Thus, the total net energy production and export has been found to be lower than for advanced moving grate combustion facilities and, in some cases, gasification plants are net importers of electricity.

Very limited information is found in literature about the overall energy performance of existing gasification installations, and it is impossible to find complete dataset for a full mass and energy balance for the complete system because figures are often presented without sufficient detail.

The theoretical energy efficiency should be higher in a gas engine than grate combustion with recovery of energy using a steam boiler and turbine/generator-set. However, some of the more reliable data sources state that the calculated electric efficiencies of a number of thermal gasification technologies with gas engines range between 13 - 24%, even when ignoring the loss of energy during pre-treatment. Pre-treatment can often further reduce this efficiency by half. This ends up significantly lower than the output from modern advanced moving grate combustion plants which achieve an electrical efficiency of 25 - 30%.

In Japan, where most of the operational gasification installations are located, the focus is on minimizing residual products rather than optimizing the energy production. In mainland Europe and elsewhere where energy efficiency is one of the drivers, gasification processes are not prevalent. However, the UK is an exception due to the financial incentives which favour gasification/pyrolysis.

7.3 Costs

Financial information publicly available for gasification technologies is often provided by the technology suppliers and not presented on the basis of any contractual commitments to the parties involved. As a result, it is not clear whether the reported capital costs address all capital and construction cost elements, nor is it clear that reported operating costs address all real costs.

There are no commercial MSW gasification facilities with a long operating track record in North America or in Europe. Japanese facilities represent the best source of actual cost data. Maintenance at Japanese plants is reported by the plant operators to be an on-going and significant process. As a result, scheduled maintenance outages and costs for this technology are significantly higher than for a modern advanced moving grate plant.

The heavy maintenance and the technical challenges reduce the availability of the gasification facilities to 5,000 - 6,000 hours per year or lower. This compares poorly with the availability of advanced moving grate plants that achieve performance figures in the order of 8,000 hours per year. This equates to above 80% annual advanced moving grate plant availability.

Based on information collected through Ramboll' assignments, study tours, and prices published by SWANA (the Solid Waste Association of North American) typical gate fees for gasification are in the area of £180 per tonne, and up to £350 per tonne if all associated waste processes are included. This can be compared to a typical gate fee for advanced moving grate combustion of around £50 to £100 per tonne in Europe.

8 CONCLUSION

This thermal treatment option technology review shows that advanced moving grate is the most well proven, reliable and cost effective means of providing thermal treatment technology for MSW. The robustness, availability and energy efficiency has led to its historic dominance for MSW treatment. Continuous technical development of the advanced moving technology has secured this position today. None of the reviewed alternative technologies (gasification, pyrolysis and plasma technology) are able to match advanced moving grate facilities with regard to energy production efficiency or annual availability.

The appetite for gasification in the UK is mainly driven by energy sales incentives. Elsewhere in Europe there is very little activity with regard to alternative technologies to process MSW due to the lack of financial incentives and due to the last 25 years of problematic thermal gasification projects.

A number of gasification plants and two-stage combustion facilities are now at an advanced project stage in UK. Some gasification plants are entering commercial operation in 2014 or soon after. The next 5 to 10 years will show the performance of gasification in terms of energy production efficiency, emissions, availability and cost of operation.

Ramboll shares the opinion concluded in the report prepared by SWANA (the Solid Waste Association of North American), in December 2011:

- Gasification is unproven on a commercial scale for MSW;

- Gasification of MSW to produce electricity is technologically viable. However, MSW gasification is not a mature technology, and therefore, some risk mitigation strategies would need to be developed to limit risk; and

- Process and equipment scale-up is needed to demonstrate reliable systems and define economics. Commercial applications on MSW will be very challenging and involves high costs.

Future technology advances may or may not change the situation. Until this has been proven by long term operation, it is Ramboll's view that any project involving thermal gasification of MSW should be considered as a high risk project.

Appendix C: Design of plant: number of plant lines

Intended for
North London Waste Authority

Document type
Report

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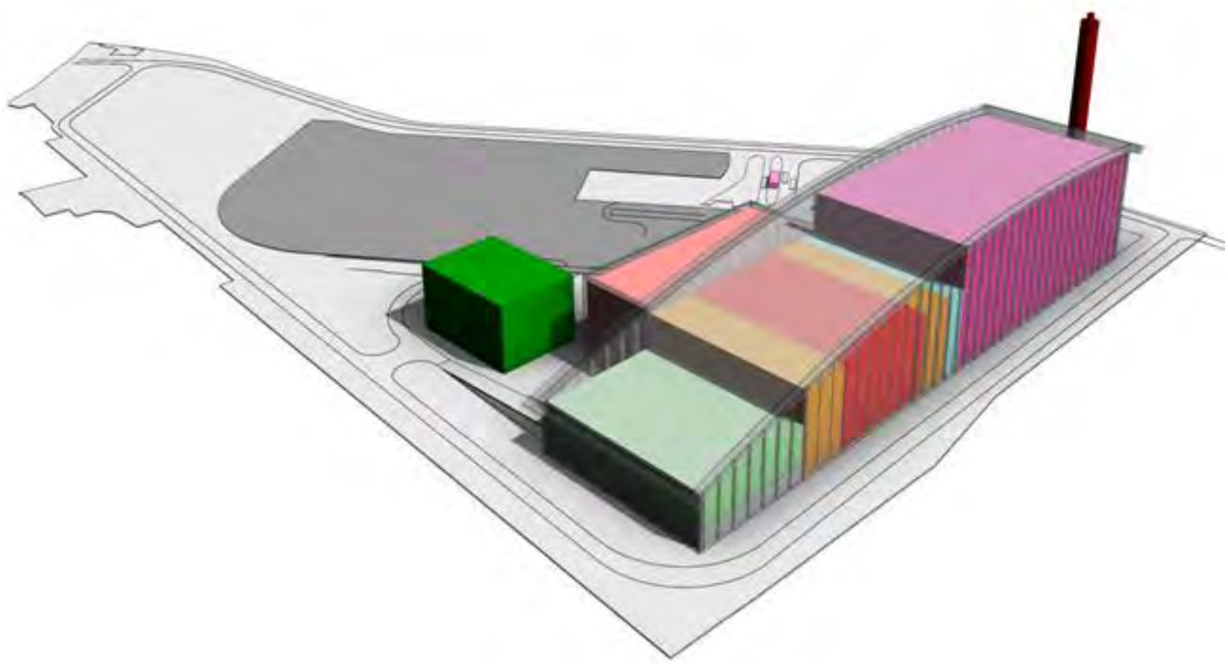
NORTH LONDON HEAT AND POWER PROJECT – DESIGN OF PLANT, NUMBER OF PLANT LINES



CONTENTS

1. EXECUTIVE SUMMARY

The existing Edmonton Energy from Waste (EfW) facility consists of five combustion lines. It was designed to accommodate planned and unplanned shutdowns with minimal disruption to waste processing such that with one line down for maintenance the other lines could continue to function. This is the design concept adopted for many older EfW facilities.

Advances in Energy Recovery Facility (ERF) technology have led to the following improvements evident in recent plants:

- Materials technology – use of better quality steels and alloys, developments in refractory linings, anti-corrosion systems, use of composites.
- Automation – advances in computerised control systems for combustion, steam generation, emissions control, power generation and heat supply.
- Plant design – better understanding of logistics, waste handling, waste processing, combustion gas flow, heat transfer, treatment and removal of pollutants, energy recovery, residue management.
- Manufacturing – higher levels of accuracy and precision with machines and devices leading to higher efficiencies and greater reliability.

The above improvements have increased ERF reliability, availability and performance. This has reduced the need for duplication and redundancy, in particular the number of plant lines, to achieve high availability and reliability. Technology suppliers are now able to provide a single plant line that can process 40 tonnes per hour or more waste. This means that a 600,000 tonnes per annum capacity requirement can be met with two lines that achieve the availability and reliability levels seen by a plant comprising more smaller processing capacity lines.

A two line plant processing 600,000 tonnes per annum of waste offers savings of capital cost and a reduced land take over a five line plant designed to process the same amount of waste. There are some operational advantages for a five line plant in terms of flexibility, but this in turn requires greater maintenance, spares and such with more than twice the number of equipment items to maintain.

Design Change to a 700,000 tpa Facility

NLWA’s waste flow modelling showed that a 600,000 tpa facility would not have offered sufficient capacity for future long term needs. Ramboll were requested to assess the feasibility of an increase in mechanical throughput for a two line facility. It is feasible to increase the plant processing capacity to 700,000 tpa. This can be achieved through two 350,000 tpa process lines. This approach will be more cost effective and will have a smaller footprint than a three smaller process line alternative providing the same capacity.

A throughput of 350,000 tpa per processing line requires the combustion of 44 t/h over 8,000 hours per year. Ramboll is of the view that there will be supplier interest and competition to provide a plant based on 350,000 tpa line capacity.

The increase in capacity moves the plant mechanical design point from 38 t/h to 44 t/h. This shifts NLWA’s design point to the limitation of a capacity diagram from a mechanical throughput perspective. This implies that NLWA will not be able to process waste at a higher rate than 44 t/h. Therefore, the ERF thermal/power generation capacity cannot be maintained with lower calorific value (CV) waste.

The smaller 38 t/h (300.000 tpa per processing line) plant would provide NLWA with flexibility to maintain maximum thermal/power generation when processing lower calorific value fuels by increasing waste throughput rate.

The waste storage bunker is an important area of any ERF and serves a number of important purposes. These include the ability to receive waste and mix it to create a homogeneous fuel. A homogeneous fuel facilitates (i) optimising and achieving stabilised combustion, (ii) keeping raw flue gas pollutants to levels suitable for stable flue gas treatment plant operations and (iii) better managing other plant operations such as energy production.

Ramboll recommends a bunker capacity equating to a storage capacity of circa two weeks with one line in operation. This is equivalent to one week with both lines in operation. This will provide NLWA with buffer/capacity to manage both waste delivery and plant revision (planned maintenance/servicing) periods.

Ramboll will undertake a study setting out bunker storage options and bunker management scenarios. This will be provided to NLWA to support a decision on bunker storage capacity and aid stake holder discussions.

Grate fired waste technology offers the flexibility to process waste with a wide range of CVs and provides a robust solution for future variations. The current design CV assumption is 10 MJ/kg. CVs lower than this will preclude full use of the thermal capacity, thus less power generation than possible in the nominal design point. Ramboll recommends:

- London Waste Limited (LWL) continue monitoring the CV of incoming waste to establish the current waste CV; and
- A detailed waste compositional study should be conducted prior to detailed design to confirm ERF design CV.

The above will facilitate the design and delivery of a plant better fitting NLWA's needs and establishing a more robust new ERF at Edmonton.

2. INTRODUCTION

The existing Energy from Waste (EfW) plant at Edmonton consists of five combustion lines. It was designed to accommodate planned and unplanned shutdowns with minimal disruption to waste processing such that with one line down for maintenance the other lines could continue to function. The plant employs vertical boiler design with super heaters exposed to high temperature corrosive gases. This requires a higher repair and maintenance budget than more recent plant designs using a horizontal type boiler with super heaters less exposed to high temperatures.

The purpose of this report is to discuss design concepts and options for the replacement Energy Recovery Facility (ERF) that will give the best overall capital and operating cost package whilst achieving high efficiencies, market leading availability and competitive gate fees.

The value of energy sales is a significant factor and as important as the need to minimise diversion of waste during shutdown periods.

3. ADVANCES IN TECHNOLOGY

Today with the advantage of the experience gained over the past 20 years with increasingly higher quality standards for design and performance ERF technology suppliers can offer designs that are robust and highly efficient. Nonetheless, with any plant it is important to keep capital and Operations and Maintenance (O&M) costs in check. The latest generation of plants benefit from technological advances in the following areas:

- Materials technology – use of better quality steels and alloys, developments in refractory linings, anti-corrosion systems, use of composites.
- Automation – advances in computerised control systems for combustion, steam generation, emissions control, power generation and heat supply.
- Plant design – better understanding of logistics, waste handling, bunker design, waste processing, combustion gas flow, heat transfer, abatement of pollutants, energy recovery, residue management.
- Manufacturing – higher levels of accuracy and precision with machines and devices leading to higher efficiencies and greater reliability.

4. PERFORMANCE

The increase in reliability and availability of processing equipment has resulted in performance levels requiring less duplication and redundancy. Therefore, a reduction in the number of process lines no longer results in lower availability or reliability, provided engineering and design work is done correctly.

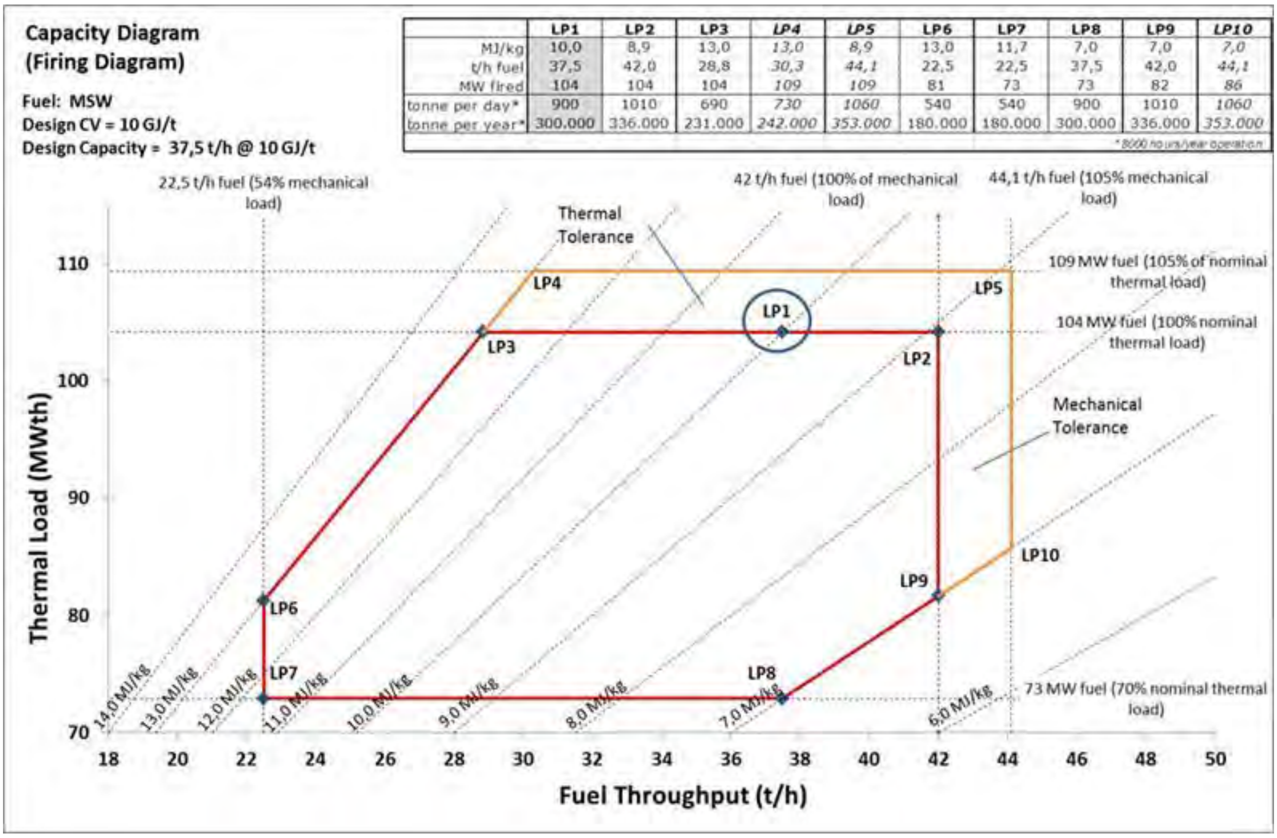
A modern ERF is still highly dependent upon certain critical systems and these are duplicated to allow operations to continue during maintenance, for example:

- Dual waste feed cranes, ensuring 100% redundancy, and spare grabs. These are fundamental to continued operation and subject to heavy wear from arduous operation. It is vital to thoroughly mix waste placed in the feed hoppers for each process line, which should hold sufficient waste for a short period of operation. Therefore, feed cranes are in operation all the time and this is assured by a two crane design.
- Boiler water feed pumps are vital for boiler operation and protection. Three pumps are required in order to mitigate the effect of a failure or outage.

5. PLANT DESIGN LAYOUT

Today, following many years of experience and development, the processing capacity of a single line can be 40 tonnes per hour or more waste. This means that a processing capacity of more than 300,000 tonnes per annum per line is possible and several such lines are under construction. Furthermore, informal discussions with a number of technology suppliers have confirmed the market's interest in and readiness to bid and supply plants with single line processing capacities of 300,000 tonnes per annum. Therefore, a capacity of more than 600,000 tonnes can be met with two processing lines and there are a number of reference plants that can demonstrate high efficiency and good reliability at this scale. NLWA's design of 350,000 tonne per annum plant lines is discussed below (**Section 9**).

A likely firing diagram for a 300,000 tonnes per annum plant is provided below (**Figure 1**).



	LP1	LP2	LP3	LP4	LP5	LP6	LP7	LP8	LP9	LP10
MJ/kg	10,0	8,9	13,0	13,0	8,9	13,0	11,7	7,0	7,0	7,0
t/h fuel	37,5	42,0	28,8	30,3	44,1	22,5	22,5	37,5	42,0	44,1
MW fired	104	104	104	109	109	81	73	73	82	86
tonne per day*	900	1010	690	730	1060	540	540	900	1010	1060
tonne per year*	300.000	336.000	231.000	242.000	353.000	180.000	180.000	300.000	336.000	353.000

* 8000 hours/year operation

Figure 1: Plant capacity diagram with a design CV of 10 MJ/kg (300 ktpa line)[1]

6. ADVANTAGES OF HIGHER PROCESSING CAPACITY PER LINE

The impact of reliable large capacity processing lines is primarily one of lower capital cost (construction and commissioning). There is also a knock on effect for operations and maintenance with less of a need for critical spares. The higher level of automation in a modern plant also results in lower manpower requirements.

[1] Plant thermal input is the product of the waste amounts processed and the calorific value of waste. The plant will have a fixed thermal capacity determined at the design stage. This is 104 MWth for the design illustrated above. This capacity is met by processing 37.5 t/h of fuel at the design point (a design calorific value of 10 GJ/t). When waste has a lower calorific value than 10 GJ/t more waste needs to be processed to match the thermal capacity of 104 MWth. Similarly less waste is needed when waste calorific value if greater than 10 GJ/t. The volumes of waste need to remain within the defined plant capacities set out above. Electrical output from the plant will depend on the thermal input into the boiler, thus less power will be produced when the thermal load is lower than the design capacity of 104 MWth.

As with any advanced processing facility, there needs to be an effective repair and maintenance strategy. Its effectiveness is heavily influenced by the plant layout and engineering so that planned shutdowns can be kept short and repair works can be carried out safely. This requires good arrangements for access at all levels within the plant and good cranes, hoists and other devices for the maintenance works. Adequate workshops and stores also need to be configured into the design.

A further advantage of using fewer process lines is land use. A five line plant of 600,000 tpa throughput will have a significantly larger footprint than a two line plant with the same processing capacity. In terms of building height a two line plant will not be higher than a five line plant.

The reason for this is related to the combustion characteristics and the need to maintain 850 °C for two seconds – the retention time. The combustion chamber and boiler first pass is usually designed to achieve a particular steady gas velocity. This delivers a stabilised flow running parallel to the heating surfaces allowing even heat transfer and distribution. It is important to avoid hot spots, areas prone to erosion and stalled flow conditions where deposits can build up. As a consequence the height of the boiler first pass is not directly proportional to the plant throughput i.e. a 20 tph is almost the same as the height of a 40 tph boiler.

7. ADVANTAGES OF A FIVE LINE PLANT

The key advantage of a five line plant is the flexibility to adapt to changing volumes and characteristics of waste and the ability to continue processing 80% of the intended throughput if one line goes down.

A twin line plant needs both lines operating for a single steam turbine to operate in its optimal point. However, if one line stops the turbine will be able to continue operating albeit slightly below its maximum efficiency. On a five line plant the loss of one line will have less impact on power efficiency. The impact of this aspect will be small.

8. CONCLUSIONS: 600,000 TPA FACILITY

A two line plant offers savings of capital cost and a reduced land take. There are some operational advantages for a five line plant in terms of flexibility but this in turn requires greater maintenance, spares and such with more than twice the number of equipment items to maintain.

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9. DESIGN CHANGE TO A 700,000 TPA FACILITY

NLWA's waste flow modelling showed that a 600,000 tpa facility would not offer sufficient capacity for its long term needs. Ramboll were requested to assess the feasibility of an increase in mechanical throughput for a two line facility. Accordingly, this addition to Ramboll's report is provided to consider issues related to plant capacity change from two 300,000 tpa process lines to two 350,000 tpa process lines.

The points addressed are as follows:

- The market for a 350,000 tpa plant
- An expected capacity/firing diagram
- Operational implications of 2 lines at higher capacity
    - Availability, flexibility, maintenance
    - Bunker size consideration
    - Maintenance requirements
    - Time required to bring a line/plant back into operations
    - Approach to plant redundancy and strategic spares storage
- 3 smaller lines at 233,000 tpa v 2 lines at 350,000 tpa
- Higher recycling trend impacts on waste CV

9.1 The Market for 350,000 tpa Plant Lines

The NLWA is seeking to implement a two line facility, each with a processing capacity of 350,000 tpa with a design CV of 10 GJ/t, thus thermal rating of 122 MWth. The total processing capacity of the plant at the design CV will be 700,000 tpa, with 8,000 hours per annum operations.

A number of plants are already under construction or in procurement with line capacities close to 350,000 tpa. These have been tendered by recognised suppliers offering competitive proposals for these projects. The Amager facility in Copenhagen, Denmark, which is in construction, is one such example. This plant will comprise two process lines, each with a processing capacity of 42 tph (with a CV of 9.6 GJ/t) corresponding to a thermal capacity of 112 MWth. Furthermore, a single line facility in the UK with planning consent for 300,000 tpa has applied to increase its capacity to a single 350,000 tpa facility.

Given the competition experienced for current similar capacity process line plants, Ramboll believes that NLWA will be able to obtain competitive tenders from recognised suppliers for a two 350,000 tpa process line facility.

9.2 Capacity Diagram

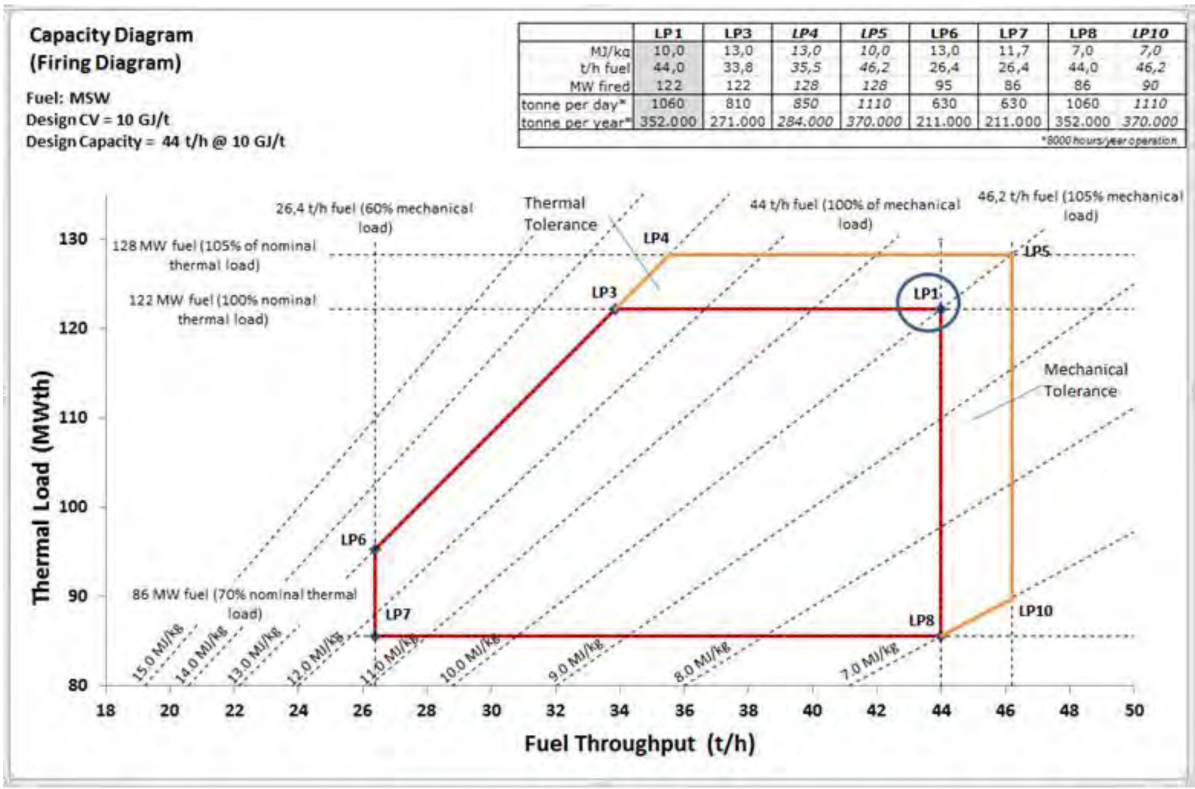
The capacity diagram of an ERF sets out the operational range of the plant with respect to mechanical processing and thermal throughput. The diagram forms the basis of guarantees from supplier with respect to acceptable caloric values and expected energy yields. The ideal diagram from an operational perspective provides flexibility for processing fuels with both increases and decreases in waste CV relative to the design point. The rate of throughput would need to be increased or decreased accordingly to match plant thermal capacity. Grate fired technology provides thermal and mechanical tolerances offering additional capacity to operate within for short periods.

One of the key drivers of a capacity diagram, and thus plant design, is waste design CV. NLWA has advised Ramboll to assume a design CV of 10 MJ/kg. It is recommended that this CV is confirmed through a test programme or information readily available at the existing LondonWaste Limited plant.

Figure 2 shows the capacity diagram Ramboll foresees for a 350,000 tpa processing line with a design CV of 10 MJ/kg. Key observations from the capacity diagram are as follows:

- The design point mechanical capacity of the plant is at the upper limit of the operational range.
- The thermal capacity of the plant is at the upper end of the boiler capacities for ERF plants.
- The full thermal capacity of the ERF can be utilised with a higher waste CV than 10 MJ/kg. The mechanical throughput capacity will reduce in line with increasing waste CV – as on any other ERF plant.
- Waste with a CV of less than 10 MJ/kg will preclude utilising the full thermal capacity of the ERF due to limitations on how much waste can be supplied to the grate/furnace. This is with the exception of mechanical tolerances that are acceptable for limited and short periods.
- Ramboll has undertaken modelling to estimate plant outputs on the basis of firing 44 t/h (thus 88 t/h for two lines) of waste with a calorific value of 10 GJ/t. This analysis shows that the plant will yield circa 70 MWe (gross) with both lines in operation. If 44 t/h (thus 88 t/h for two lines) of waste with a CV of 9 GJ/t is processed, the power output will reduce to circa 62 MWe (gross).

Ramboll expects the design for a 300,000 tpa line plant to offer more flexibility with lower CVs than that offered by the 350,000 tpa plant line. This is due to increased mechanical capacity relative to the design point at 10 MJ/kg offering the ability to feed more waste to match ERF thermal capacity. However, such an approach is only relevant and of benefit as long as the ERF does not process more than it is allowed to under its operational permit.



	LP1	LP3	LP4	LP5	LP6	LP7	LP8	LP10
MJ/kg	10,0	13,0	13,0	10,0	13,0	11,7	7,0	7,0
t/h fuel	44,0	33,8	35,5	46,2	26,4	26,4	44,0	46,2
MW fired	122	122	128	128	95	86	86	90
tonne per day*	1060	810	850	1110	630	630	1060	1110
tonne per year*	352.000	271.000	284.000	370.000	211.000	211.000	352.000	370.000

*8000 hours/year operation

Figure 2: Plant capacity diagram with a design CV of 10 MJ/kg (350 ktpa line)

9.3 Operational Implications

The key implications of increasing ERF line capacity from 300,000 tpa to 350,000 tpa, indicated in the above firing diagram, are outlined below.

Overall we would expect the difference between the two plants to be limited to the following:

- Same availability (hours per year)
- Same maintenance requirements
- Same performance guarantees
- Same approach to plant redundancy and strategic spares storage
- Time required to bring line back to operation will largely be the same
- Bunker size will increase pro-rata with the capacity upgrade (i.e. by 17%). In both cases the bunker has to be typically designed for a two week capacity with one line in operation. This facilitates continued services with time for maintenance on one line. This is further discussed in **Section 9.4**.

Plant flexibility with respect to waste CV is discussed above in **Section 9.2**. An overview of waste CV impacts on the operations of 300,000 and 350,000 tpa plant lines is summarised below.

Consequence Scenario	Line size	
	300,000 tpa	350,000
Higher CV than the design point	Throughput (tph) will be reduced to maintain max thermal input	Throughput (tph) will be reduced to maintain max thermal input
Lower CV than design value	Throughput (tph) may be increased to maintain same thermal max. (Strategy subject to permit limitations on max. tonnage) The estimated gross power output, when firing waste with a CV of 10 GJ/t (37.5 t/h (thus 75 t/h for two lines)), is 60 MWe. If waste with a CV of 9 GJ/t is processed, the power output will be maintained at 60 MWe (gross) by increasing waste processing capacity to 41.7 t/h (thus 84.4 t/h for two lines).	Throughput (tph) will be maintained at max (44 tph). Thermal input/output will be reduced correspondingly. As illustrated above, if waste with a CV of 9 GJ/t is processed (44 t/h (thus 88 t/h for two lines)), the power output will reduce from 70 MWe (gross) (with 10 GJ/t CV waste) to circa 62 MWe (gross).
Variations around design value	Reduced throughput (tph) during periods with high CV may be made up from a tonnage throughput perspective during periods with low CV	Reduced throughput (tph) during periods with high CV cannot be made up from a tonnage throughput perspective during periods with low CV

9.4 Bunker Sizing

The waste storage bunker is an important area of any ERF plant and serves a number of purposes. These include the ability to receive and mix waste to create a homogeneous fuel. A homogeneous fuel facilitates (i) optimising and achieving stabilised combustion, (ii) keeping raw flue gas pollutants to levels suitable for stable flue gas treatment plant operations and (iii) better managing other plant operations such as energy production etc.

Bunker sizing and management has two further goals. These are:

(i) Maintain sufficient fuel in the bunker for continuous plant operations in the event of waste supply disruptions. This avoids plant shutdowns and restarts, which can be costly occurrences. Shutdowns and restarts could each typically be in the order to 8 to 12 hours. Therefore each occurrence can result in disrupting operations of a day or so.

(ii) Enable continued waste reception in the event of plant shutdown, both planned and unplanned. This will help to maintain the Boroughs' ability to continue their waste collection services when the plant is not able to process waste. This could be through processing a limited capacity if one process line is shut or total processing capacity loss if both lines are not operating. Planned maintenance can be arranged such that one line is in operation whilst work is performed on the other lines. Maintenance will also require periods where both lines are down at the same time, typically for work on common systems i.e. piping, cabling, electrical systems etc. The total downtime for each process line, both planned and unplanned, would typically be in the order of 5 weeks i.e. typical of a modern well designed and operated ERF. Maintenance works may typically require both lines to be shut for up to 2 weeks, perhaps on an annual basis. The balance of the time will be required for works on the individual lines.

Bunker management and plant maintenance needs to balance the above operational goals through maintaining sufficient fuel levels to cope with waste delivery disruptions and making capacity available for waste reception in the event of planned/unplanned shut downs. Therefore, bunker sizing needs to be such that both goals can be met.

ERF plants in the UK have typically been designed with storage capacities equivalent to 3 to 5 days of storage equivalent to the plant throughput capacity. The approach to bunker sizing for European plants is typically a storage capacity equivalent to two weeks of operations with one line in operation. This lends itself to a storage volume equivalent to 7 days of processing with two lines in operation. The difference in approach is mainly accounted for (i) the competitive financial environment ERF plants in the UK are delivered under i.e. smaller bunkers lead to cost savings (ii) desire to limit "long term" waste storage, thus a preference for smaller bunkers. Thereby, the resulting bunker capacities for ERF plants in the UK mean a more limited buffer time and the need to divert waste to other facilities, if capacity is available, or landfill when plants are undergoing maintenance lasting more than a few days, planned or unplanned.

Ramboll recommends a bunker capacity in line with ERF plants in Europe. This would provide NLWA with a greater buffer/capacity to manage both waste deliveries and plant shutdown related disruptions. **Appendix 1** presents bunker storage and dimension information for a 5 day and 7 days storage capacity bunker (equivalent to both process lines operating). If required, the plant will be able to store additional waste by stacking against the boiler hall side wall of the bunker and provide capacity for continued waste reception on the opposite wall with tipping bay openings. These measures are proven in many similar scale projects and should be specified and implemented on the NLWA plant.

9.5 Three Smaller Capacity Lines at v Two Larger Capacity Lines

An alternative approach for NLWA to provide a processing capacity of 700,000 tpa (still at 10 MJ/kg) is the implementation of three 233,000 tpa capacity process lines. One nominal advantage of this approach is that more references are available than for this size of process lines. However, as mentioned above, Ramboll is of the view and has the experience that the market is ready and able to offer the larger lines.

Furthermore, as mentioned above for the 300,000 tpa capacity process lines, the smaller processing lines will offer some extra flexibility in terms of how lower CVs may be accommodated. However, if the plant has permit restrictions on throughput, then this flexibility may not be any significant benefit.

A configuration based on three smaller lines will yield an increase in capital cost requirements.

Other notable adverse differences will include a much greater plant footprint for a three line facility. This is despite the smaller capacity per line. The additional footprint will primarily be in the facility width, which will increase from 70 m for two 350,000 tpa lines to circa 90 m for three 233,000 tpa lines.

It should also be noted that three smaller capacity lines will result in higher operational cost. This will be as a result of factors including the need for more operational staff, spare parts as well as other maintenance/service costs.

Overall Ramboll is of the view that it is feasible for NLWA to provide a processing capacity of 700,000 tpa with two process lines, each with a capacity of 350,000 tpa (design CV of 10 MJ/kg) and that this will be more advantageous from a footprint as well as a financial perspective.

9.6 Higher Recycling Trend Impacts on Waste CV

Municipal solid waste (MSW) comprises various fractions/waste types with differing properties. **Table 1** sets out the caloric value of the expected waste types. These values have been determined by extensive laboratory testing (Warren Springs) and are widely used as the basis for estimating the theoretical calorific vale of waste.

The information presented in **Table 1** shows that the caloric value of waste fractions varies widely from glass (LHV ~0.55 GJ/t) to plastics (~25 to 30 GJ/t LHV).

	Warren Springs (1986)	
	HHV (GJ/t)	LHV (GJ/t)
Paper and Card	12	10.5
Plastics	27	25
Textiles	15	13.5
Misc. Combustibles	13.5	12
Misc. Non-Combustibles	1.48	1.43
Glass	0.56	0.55
Putrescibles (organic waste)	5.6	3.7
Cans / Metals	0	0
<10mm	3.6	2.3
dense plastic	30	28

Table 1: Waste types and their calorific value

Table 2 details waste composition from a confidential UK based Ramboll project. The information details waste composition findings from recent years and the expected composition in the short and medium term. The general trend/aim in this case is recycling increases for paper and card, plastics and glass. There is also a notable difference in the reduction of putrescible materials. Therefore, these materials are expected to make up a smaller fraction of MSW, thus a noticeable proportional increases in "misc combustibles". These trends would be typical of increasing the separation of recyclables at households and a general trend towards less production or separate collection of organic waste.

	2009/2010	2012/2013	2015/2016	2019/2020	2024/2025
Paper and Card	19.20%	20.10%	18.70%	17.50%	17.50%
Plastics	13.80%	13.50%	11.90%	8.40%	8.30%
Textiles	3.90%	3.50%	3.60%	3.30%	3.30%
Misc comb	16.50%	21.80%	24.00%	27.80%	27.80%
Misc non-comb	3.40%	4.10%	4.40%	5.10%	5.10%
Glass	4.10%	4.30%	4.30%	3.30%	3.20%
Putrescibles	32.90%	25.70%	25.90%	26.80%	26.90%
Cans / Metals	3.80%	3.90%	3.70%	3.90%	3.90%
<10mm	2.40%	3.30%	3.40%	4.00%	3.90%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Table 2: A waste composition example for the UK and expected composition variations

Table 3 sets out Ramboll's estimate of the MSW calorific value with the waste fractions for the composition given for the different periods. Results show a drop in calorific value from the current levels of circa 10 MJ/kg to 9.1 MJ/kg.

	2009/2010	2012/2013	2015/2016	2019/2020	2024/2025
Average LHV (MJ/kg)	9.9	10.0	9.8	9.1	9.1

Table 3: Expected waste LHV variation with the above composition variations

The above example illustrates the dependency of calorific value on waste composition. The removal of some materials for recycling, i.e. plastics, will yield reductions in the average waste CV. However, the removal/reduction of other materials, i.e. putrescible, will yield an increase in the average waste calorific value. Therefore, there is a tendency for variations in waste composition to provide a balance with respect to the average calorific value. Whilst a change in CV is inevitable with waste composition variations, this balancing act somewhat limits a large difference with respect to the base CV. Ramboll's UK project findings and the general view/experience in the future planning of European plants supports this view.

As discussed above, grate fired waste technology offers the flexibility to process waste with a wide range of CV and provides a robust solution for future variations. The process lines that can be sourced for NLWA's two 350,000 tpa lines offer a greater flexibility and the ability to use thermal plant capacity with increase in CV. The current design CV assumption is 10 MJ/kg. CVs lower than this will preclude full use of the thermal capacity, thus less power generation than the current design case. Hence, Ramboll recommends:

- LondonWaste Limited continue monitoring the CV of incoming waste to establish the current waste CV; and

- A detailed waste compositional study should be conducted prior to detailed design to confirm the ERF design CV.

The above will facilitate the design and delivery of a plant better fitting NLWA's needs and establishing a more robust new ERF at Edmonton.

As illustrated above, if waste with a CV of 9 GJ/t is processed (44 t/h (thus 88 t/h for two lines)), the power output will reduce from 70 MWe (gross) with 10 GJ/t CV waste to circa 62 MWe (gross).

10. APPENDIX 1: WASTE BUNKER SIZING

Preliminary Waste Bunker Information – 5 day capacity Consideration and ~7 day Capacity Option

The following cases are presented below:

- Initial 5 day capacity design in line with UK plants
- ~7 day capacity design in line with European plants

Hydraulic Storage Capacity (Processing Capacity Equivalent)		5 Days (Initial Consideration)	6.8 Days (Adjustment with Tipping Floor Level Rise & Bunker Width)
Key Plant Parameters			
Plant Processing Capacity	t/h	87.5 (Two lines, 43.75 t/h per line)	
Annual Availability	h	8,000	
Annual Throughput	t/y	700,000	
Design CV	MJ/kg	10	
Thermal Input	MWth	244 (122MWth/line)	
Bunker Storage Parameters (Approximate)			
Hydraulic Volume Storage Amount	t	10,500	14,300
Waste Density in the Bunker	kg/m^3	350	350
Hydraulic Volume Required		30,000	40,800
Hydraulic Bunker Depth (fixed by geology and tipping floor height)	m	16	20
Bunker Length (fixed by plant width)	m	68	68
Bunker Width (Variable for capacity needs, but need to consider crane span)	m	28	30

Hydraulic Storage Capacity (Processing Capacity Equivalent)		5 Days (Initial Consideration)	6.8 Days (Adjustment with Tipping Floor Level Rise & Bunker Width)
Bunker Outer Parameters (Allowing 1m wall and base thickness)			
Hydraulic Bunker Depth (fixed by geology and tipping floor height)	m	17	21
Bunker Length (fixed by plant width)	m	70	70
Bunker With (Variable for capacity needs, but need to consider crane span)	m	30	32
Material Excavation (Approximate)			
Ground Level at Bunker Area	mAOD	12.5	12.5
Below Ground Excavation (outer parameters – current design)	m	11.5	11.5
Excavation Volume (Excluding Foundations)	m^3	24,200 Thus ~26,000 With Margin for Sheet Piling of Walls	25,800 Thus ~28,000 With Margin for Sheet Piling of Walls
Indication of Material Excavated - Materials to 2 mAOD (BH 306)	• Made Ground: Variable historic demolition rubble, including ash and clinker • Alluvium: Silty clay • Kempton Park Gravel (River Terrace Deposits): Variably sandy, silty and clay gravels • London Clay: Grey, occasionally sandy or silty clay From Amec Draft Factual Ground Investigation Report, 14 August 2014, (Section 2.3 Geology)		

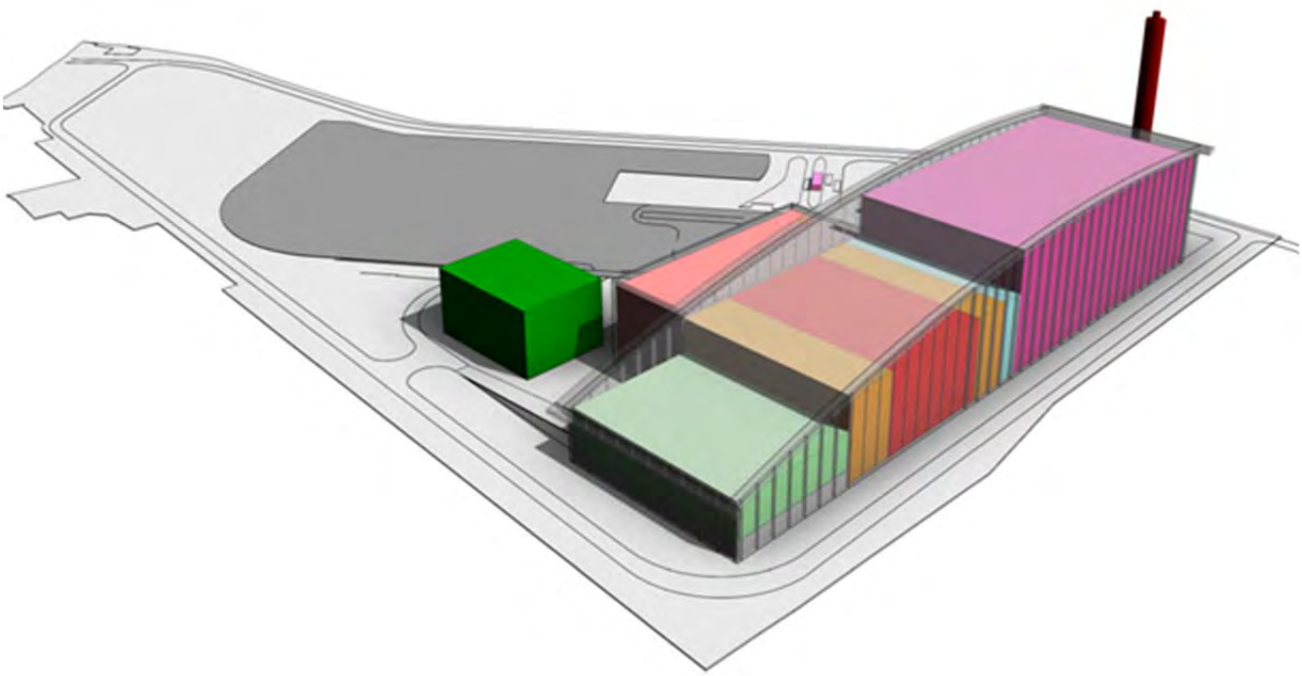
Appendix D: Flue Gas Treatment plant options

Intended for
North London Waste Authority

Document type
Report

Date
November 2014

NORTH LONDON HEAT AND POWER PROJECT – FLUE GAS TREATMENT PLANT OPTIONS



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ENERGY

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1. EXECUTIVE SUMMARY

Introduction

The combustion of solid fuels, including waste and waste derived fuels results in the production of gases consisting water vapour, carbon dioxide and excess air. This mixture of combustion gases is termed "flue gas" and carries components including acid gases, organic substances, heavy metals and fly ash particles that can have adverse health and environmental impacts. Although these components represent a much smaller part than water, carbon dioxide or excess air, thermal process/power plants, including Energy Recovery Facilities (ERFs), treat flue gases to mitigate the impact of pollutants.

Water vapour is harmless but contributes to a visible plume at the stack outlet. Depending on waste properties, water vapour concentration typically lies in a range between 10% and 24% of the flue gas flow.

Carbon dioxide is the universal end product of combustion, but also the product of biological aerobic metabolisms. Carbon dioxide concentration of combustion gases is approximately 10% of the total volume, as an order of magnitude.

The major part, approximately 75%, of the flue gas is excess air, consisting of unburned oxygen and atmospheric nitrogen as well as argon (Ar) and other atmospheric components. This is harmless and does not require treatment.

This document provides an overview of flue gas treatment (FGT) technologies together with key criteria for technology selection and the drivers that impact technology choice. The document concludes with recommendations for NLWA's proposed new ERF at Edmonton, London.

Waste processing volumes and waste composition are key drivers for FGT plant technology selection and design. Waste to be processed is assumed to comprise municipal solid waste (MSW) derived from household waste, some commercial and industrial (C&I) waste, and residual waste from Household Waste Recovery Centres (HWRC´s). Any other waste, such as solid recovered fuel (SRF), is assumed to be the product of sorted MSW that will, when combusted, give rise to similar flue gas.

FGT system selection and operation requirements need particular attention due to the content of sulfur and chlorine in waste fractions. These are the sources of sulfur dioxide (SO_2) and hydrogen chloride (HCl) in the raw gas resulting from the combustion process and they have a key influence over the design of a FGT system.

Site Factors

Site specific factors that influence FGT choice include restriction to nitrogen oxide (NOx) emissions if a local area is regarded as a "high NOx" region. Furthermore, restriction on the discharge of wastewater containing chlorine will preclude the ability to select a wet scrubbing system.

Environmental Factors

Environmental permits set limits on the allowable concentration of pollutants in gaseous emissions from ERFs. Similarly there are specific requirements on the condition of wastewater discharged to a water course. Discharge condition limit values for air emissions and discharge of wastewater from ERF plants in the UK are determined on the basis of the parameters set in the European Union Directive 2010/75/EU on Industrial Emissions (IED). However, in some cases the permitted emission limits are more stringent than IED limits with reference to the principles of using Best Available Techniques (BAT) as defined in the Best Available Technology Reference Documents (BREF) documents and specific local conditions such as air quality.

BREF documents do not provide specific guidelines on the choice of technology, and both wet and dry systems can be considered as BAT. There are guidelines in the documents on the choice of reagent for pollutant abatement.

Residues

Flue gas treatment using a reagent such as lime results in the production of solid residues. This is regardless of the FGT plant system in place. Residues are classified as hazardous waste and are disposed of at suitably licenced facilities. These can be hazardous landfill or underground storage. Some treatment techniques stabilise residues and reduce the potential for leaching. Residue production per tonne of waste combusted is a reflection of the pollutant removal efficiency of the FGT system. Residue amounts and composition will depend on the choice of FGT process, raw gas pollutant content, untreated flue gas and other process conditions.

Flue gas treatment technologies

Basic FGT systems treat raw combustion gas after it has passed through the boiler to limit the emissions to air of dust, acidic gases (hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur dioxide (SO_2)), heavy metals, nitric oxide/nitrogen dioxide (NOx) and dioxins.

NOx is treated in a separate system, within the combustion chamber or thereafter. Carbon monoxide (CO) and total organic carbon (TOC) content limits are addressed by control of the combustion in the furnace.

FGT plants are categorized into distinct systems: dry, semi-dry, and wet systems.

‘Dry’ systems use a dry reagent and reaction process, residues leave the facility as a dry product, and no wastewater is produced. This system is commonly employed in the UK.

‘Wet’ scrubbing systems have several processing stages. These include a wet scrubber producing a solution containing the majority of the chloride released from the combusted waste, thereby limiting the generation of solid residues.

Dry systems (bicarbonate or lime)

Traditionally dry FGT systems have been the most commonly employed system worldwide and still widely used today. Dry bicarbonate and lime based systems are technically very similar. The dry system is relatively simple to install and operate. Space requirements are low. Therefore, the associated capital investment and maintenance costs are relatively low.

The dry process has limited capability when treating elevated levels of pollutants and the process is not suited for reaching very stringent emission values unless a large excess of hydrated lime is used. Significant quantities of residue generation increase disposal costs and make the process expensive from an operating perspective.

Ramboll’s FGT system comparison below assumes a bicarbonate system.

Semi dry systems

Semi-dry systems were introduced to optimise the chemical reaction between acidic combustion gases and lime added to the flue gas stream. This is achieved by introducing water to control flue gas temperature and humidity. Water may be injected directly into the flue gas stream or hydrated lime may be added as slurry.

Semi dry systems are relatively simple to install and operate. Furthermore, space requirements are moderate. The systems are more efficient than dry process. The process produces significant quantities of flue gas treatment residues, although somewhat less than dry, lime based treatment systems.

Wet scrubbing systems

Wet scrubbing systems have not been installed at ERFs in the UK. This is believed to be due to higher capital cost requirements than alternative technologies and no readily available effluent outlets. However, the system is common in Europe e.g. Germany and Switzerland. Although the system is not common in UK, the concept is included in this report as a valid alternative representing an option to assess the most beneficial FGT solution.

In the wet FGT system hydrogen chloride (HCl) is separated simultaneously with hydrogen fluoride (HF) and mercury (Hg) in an acidic scrubber. Sulfur dioxide (SO_2) and the remaining hydrogen fluoride (HF) contents are removed in a caustic or neutral scrubber. Wet FGT systems produce wastewater that requires treatment before discharge.

Wet FGT plants can achieve efficient flue gas cleaning, are robust with respect to changes in raw gas composition and have the flexibility to meet more stringent emission limits than currently in place. Low consumption of consumables results in low volumes of residue generation.

A wet scrubbing system includes many process steps, hence requiring high capital investment, is more complex to operate, and requires specialist staff. The treatment of wastewater is an additional process. The cost of liquid effluent disposal can be significant. There is significant plume visibility unless the flue gas is reheated prior stack exit.

A wet system can be combined with a semi dry system to avoid effluent discharge needs. Such a combined system archives high pollutant removal efficiency and reduces residue generation.

FGT Technology Costs

The operational costs for FGT plants include consumables, the management of the resulting residue, staffing and maintenance. The following is Ramboll's cost rankings for the FGT systems detailed. The wet process yields much smaller amounts of residues, but requires more specialised staff and resources to operate. This is due to the high complexity of the plant. The advantages and disadvantages of the plant are balanced and consequently operating costs of the system are favourable over other systems.

The operating cost estimates below take account of wastewater treatment costs for the wet system.

Note: 1 equates to lowest cost and 4 equates to highest cost

Cost	Dry Bicarbonate	Semi-dry	Combined	Wet
Capital Cost Ranking	1	2	3	4
Operating Cost Ranking	4	2	3	1
Overall Lifetime Cost Ranking	4	1	3	2

Table 1: FGT Plant Capital, Operational and Lifecycle Cost Rankings

De-NOx systems

Waste combustion in grate fired systems results in the production of nitrogen oxides (NOx) with typical flue gas contents of around 350 mg/Nm^3 with a reference condition of 11 % O_2, dry. The current permitted NOx emission level from ERFs is 200 mg/Nm^3 (dry flue gas at 11% O_2). A dedicated deNOx process is required to meet this requirement. The process options are:

- Selective Non-Catalytic Reduction (SNCR)
- Selective Catalytic Reduction (SCR).

The SNCR process entails ammonia water injection in the upper part of the combustion chamber. Suppliers of SNCR systems are usually willing to provide nitrogen oxides (NOx) emission guarantees in the range 100 – 150 mg/Nm^3.

The SCR process entails ammonia injection upstream of a catalyst. SCR can achieve nitrogen oxides (NOx) emission levels lower than 25 mg/Nm^3 and limit ammonia consumption to a greater extent than the SNCR system.

The costs of deNOx by SCR are much higher than SNCR systems due to higher capital requirements. SCR systems can also have higher operating costs if there are heating requirements. Therefore, SNCR is usually the preferred deNOx technology in the UK due to its cost benefit advantages and the fact that the system enables compliance with current IED emission limit requirements. However, more stringent NOx emission limits i.e. 100 mg/Nm^3 or lower requirements may be set in the coming years. Modern plant designs using SNCR systems often make space allowance for the future retrofit of an SCR system to meet possible more stringent NOx emission requirements.

DeNOx System Costs

Operational costs for deNOx technologies include consumables, staffing and maintenance. The following are Ramboll's cost rankings for deNOx systems. The cost estimates, considering both operational and capital cost estimates, conclude the SNCR 150 option as the most beneficial from a cost perspective. In general the SNCR process is much more attractive than the SCR perspective from a total cost perspective.

Note: 1 equates to lowest cost and 4 equates to highest cost

Cost	SNCR 150	SNCR 120	SNCR 100	SCR after semi-dry	Front-end SCR
Capital Cost Ranking	1	2	3	4	5
Operating Cost Ranking	2	3	5	4	1
Overall Lifetime Cost Ranking	1	2	3	5	4

Table 2: deNOx System Capital and Operational Cost Rankings

The SCR process captures much more NOx than the SNCR process. Therefore, the SCR process is more cost efficient if evaluated from a perspective of cost per kg of NOx captured. The SCR process is likely to compare favourably from a financial perspective where NOx taxes are in place i.e. Scandinavia.

Energy recovery options

Process design of the plant looks at energy efficiency across all components. The design of the FGT system and the adjoining equipment offers opportunity for energy recovery and improvements in overall plant efficiency. These include:

- Economiser design

The use of economisers in connection with flue gas treatment plants is frequently an opportunity to increase the overall energy efficiency of the plant. This is achieved through greater heat recovery from the flue gases emitted by the plant. An impact of this is increased possibility of plume visibility.

- Flue gas condensation

Flue gas condensation is primarily aimed at the recovery of latent energy contained in wet flue gases. When cooling flue gas to temperatures below water dew point, a part of the water vapour content condenses, releasing heat. The recovered heat can then be transferred by heat exchanger to a consumer such as district heating. A disadvantage of cooled saturated flue gases is increased plume visibility above the stack and the need to avoid droplet precipitation.

Assessment of FGT technology options

The table below presents a high level comparison of the different FGT systems with a range of evaluation criteria. No single flue gas treatment concept is advantageous under all the evaluation criteria. The importance of each criterion needs to be weighed up for the specific project in hand.

Evaluation criteria:	Dry	Bi-carbonate	Semi-dry	Combined (Wet and Dry)	Wet
Operational availability					
- **Performance history of reliable operation**	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
Capability					
- **Ability to handle changes in raw gas composition**	✓	✓✓	✓✓	✓✓✓	✓✓✓
Flexibility					
- **Ability to meet more stringent future emission limit**	✓	✓	✓✓	✓✓✓	✓✓✓
Health and safety					
- **Reduced contact with hazardous material**	✓✓	✓✓✓	✓✓	✓✓	✓✓
Sensitivity to local conditions					
- **Limited plume visibility**	✓✓✓	✓✓✓	✓✓✓	✓	✓
- **Discharge of treated wastewater**	N/A	N/A	N/A	N/A	✓
Other environmental issues					
- **Low chemical consumption**	✓	✓✓✓	✓✓	✓✓✓	✓✓✓
- **Low electricity consumption**	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
- **Low residue production**	✓	✓✓✓	✓✓	✓✓✓	✓✓✓

'✓✓✓'= attractive feature, '✓✓'= neutral feature, '✓'= existing but less attractive feature

Conclusion

The semi-dry FGT system is the most attractive option for NLWA for the following reasons:

- The system is optimal for ERFs processing MSW where waste pollutant content will not vary notably in future years;
- There is no production of wastewater requiring specialist treatment and discharge;
- Flue gas condensation is not envisaged to be beneficial for NLWA due to the absence of adequately low cold water return temperatures from a potential district heating network;[1]
- There are relatively simple operational requirements; and
- There is a relatively low capital investment requirement.

A wet flue gas treatment system can reduce some emission limits to lower levels. However, this system produces effluent requiring treatment at the plant and its discharge as wastewater. If an outlet can be secured for wastewater, a wet flue gas treatment plant could be used to reduce emissions to lower levels than can be achieved by a semi dry system. Wet flue gas treatment systems are attractive for the following reasons:

- System flexibility to meet potentially more stringent future emission requirements;
- Capability to accept changes in waste composition, thus raw gas composition; and
- The amount of reagents used and resulting by products can be optimized to a higher degree.

'Advanced' SNCR systems can achieve NOx emission guarantees of around 100 mg /Nm^3. This corresponds to 50% of the current daily average emission limit set in the IED. It is noted that the Edmonton region is recognised as a high NOx area. SCR systems can reduce NOx emissions to 25 mg NOx/Nm^3 or lower. NLWA's air quality modelling should consider the emission limits that can be achieved with SNCR 100 and SCR systems to facilitate an informed consultation and decision on the deNOX system choice. Furthermore, financial considerations should also form part of the decision making process. This may include a consideration of a tax on NOx emissions. ERF plants in Scandinavia are taxed on NOx emissions and this may also be introduced in the UK in the coming years or over the plant life.

[1] It is believed, that the main option for heat supply (outside the FGT system) is the use of medium or low pressure steam extraction from a suitable turbine.

2. INTRODUCTION

This document provides an overview of the health and environmental risks posed by Energy Recovery Facility (ERF) emission to air, flue gas treatment (FGT) technologies available to mitigate risks, key criteria for technology selection and the drivers that impact technology choice. The document concludes with recommendations for NLWA's ERF at Edmonton.

Ramboll's evaluation criteria for flue gas treatment technology selection is presented and discussed in **Figure 1** below:

Operational availability

- The concept shall use proven technology with a performance history demonstrating reliable operations.

Capability

- The concept shall be readily capable of accommodating changes in the composition of the raw flue gas (i.e. derived from the composition of waste).

Flexibility

- The concept shall have the flexibility to meet more stringent future emission limits through no or minor adjustment of main processes and their operation. To that end, consideration shall be given to the emission limits achieved at commissioning and margins for further emission level reductions.

Health and safety

- The concept shall ensure a safe working environment and limit the risk of contact with hazardous materials and impact by dust or odours.

Sensitivity towards site specific conditions

- Visible plume from the stack may be unacceptable. Concepts entailing wet scrubbers result in wastewater/effluent production and bring about the need for extensive effluent treatment and discharge options.

Other environmental issues

- Excessive solid residue generation, excessive amounts and power consumption of consumables should be evaluated.

Figure 1: FGT Plant Evaluation Criteria

3. HEALTH AND ENVIRONMENTAL RISKS OF ERF EMISSIONS TO AIR

3.1 Introduction

The combustion of solid fuels, including waste and waste derived fuels results in the production of gases consisting of water vapour, carbon dioxide and excess air. This mixture of combustion gases is termed “flue gas” and carries components including acid gases, organic substances, heavy metals and fly ash particles that can have adverse health and environmental impacts. Although these components represent a much smaller part than water vapour, carbon dioxide or excess air, thermal process/power plants including ERFs treat flue gases to mitigate impact of pollutants.

Water vapour is harmless but contributes to a visible plume at stack outlet. Depending on waste composition, water vapour concentration typically lies in a range between 10% and 24% of the flue gas flow.

Carbon dioxide is the universal end product of combustion, but also the product of biological aerobic metabolisms. Carbon dioxide concentration of combustion gasses is approximately 10% of the total volume, as an order of magnitude.

The major part (approximately 75%) of the flue gas is excess air comprising unburned oxygen and atmospheric nitrogen as well as the noble gas argon (Ar) and other atmospheric components that are harmless and do not require treatment.

The flue gas components that require treating and their potential impacts, if untreated, are discussed below.

3.2 Acid Gases

3.2.1 General

Sulfur doxide (SO_2), hydrogen chloride (HCl), hydrogen Fluoride (HF) and nitrogen oxides (NO_x) are acid gases. Solutions of acid gases and water have a low pH-value, thus acidic, and can have negative impacts on vegetation. Acidic gases released into atmosphere are converted into sulfuric acid, hydrochloric acid and nitric acid as they dissolve in water droplets and precipitate onto soil and into water basins.

Emission of acidic gases can result in acid rain impacting vast amounts of vegetation and areas of the natural habitat by acidification. The deposition of acid gases can also have corrosive effects on buildings.

3.2.2 Sulfur Dioxide (SO_2)

Sulfur dioxide (SO_2) health concerns include effects on the respiratory system. People with asthma or bronchitis are most vulnerable to these adverse health effects. Combustion processes that lead to high concentrations of sulfur dioxide (SO_2) generally also lead to the formation of sulfur trioxide (SO_3). This in turn leads to the formation of fine sulphate aerosol particles in the atmosphere, imposing health risks, as they penetrate into the lungs and over time causing potential respiratory disease.

3.2.3 Hydrogen Chloride (HCl)

Hydrogen chloride (HCl) is gaseous and forms hydrochloric acid when in contact with humidity or water droplets and deposit on to the ground. Flue gas treatment measures to reduce sulfur dioxide (SO_2) emissions also lead to a significant reduction in hydrogen chloride (HCl) emissions.

Exposure to highly concentrated hydrogen chloride (HCl) may affect human health; causing throat irritation and in extreme cases severe swelling of the throat. Inhalation of hydrogen chloride (HCl) can also lead to asthma. However, hydrogen chloride (HCl) at normal background levels is unlikely to have any adverse impacts on human wellbeing.

3.2.4 Nitrogen Oxides (NO_x)

The components nitric oxide (NO) and nitrogen dioxide (NO_2) are together termed nitrogen oxides (NO_x), because over time nitric oxide (NO) is transformed into nitrogen dioxide (NO_2).

Nitrogen dioxide (NO_2) can contribute significantly to the formation of ozone near ground level and contribute to the formation of photochemical smog. Excess ozone (O_3) concentrations are believed to cause increased respiratory symptoms and asthma. Nitrogen dioxide (NO_2) is in itself toxic and reacts with ammonia, moisture, and other compounds to form small particles. The health effects of nitrogen dioxide (NO_2) are similar to that of sulfur oxides.

3.3 Nitrous Oxide (N_2O)

Other oxides of nitrogen include nitrous oxide (N_2O). Nitrous oxide (N_2O) is not a direct hazard to health, but a greenhouse gas with a significant global warming potential.

3.4 Ammonia (NH_3)

Ammonia (NH_3) is a volatile gaseous component originating as excess from the injection of ammonia water or urea in the nitrogen oxide (NO_x) cleaning processes.

Ammonia (NH_3) deposition to ground has effects on biological conditions through nitrification.

3.5 Heavy Metals

3.5.1 General

Heavy metals are metallic elements with a greater density than iron and are generally of environmental concern. These metals, with the exception of mercury (Hg), are released in their oxidized form during combustion. They are discharged from the plant with either incinerator bottom ash, fly ash or the residual FGT products. Heavy metals from fly ash can leach into a watery phase and thereby enter the environment. Therefore, fly ash is sent to safe/hazardous landfills.

3.5.2 Mercury (Hg)

Mercury (Hg) is the most prominent heavy metal and a naturally occurring element that is found in air, water and soil. The tendency of mercury to stick to fly ash particles is low.

Mercury (Hg) may have toxic effects on the nervous system and organs. Even at low concentrations mercury (Hg) can cause serious health problems and is a threat to the child development. Human activity is the main cause of mercury release. Once in the environment mercury (Hg) can be accumulated in the food chain.

Mercury must be specially taken care of in the flue gas treatment plant, either by application of activated lignite coke as an adsorbent or by absorption in an acidic reactor.

3.6 Dioxins and Other Organic Compounds

3.6.1 General

Organic compounds, as a rule, are only generated when there is incomplete combustion e.g. lack of combustion air or insufficient combustion temperatures. Organic compounds are molecules that contain carbon (C) and typically hydrogen (H), oxygen (O) and other elements. Simple molecules like carbon dioxide (CO_2) are regarded as inorganic, whereas methane (CH_4) is classified as organic. Organic molecules can form long molecule chains, rings, and combinations hereof. A well-known class of such molecules are polycyclic aromatic hydrocarbons (PAH´s) which can be toxic and can influence hormonal balance. Organic compounds and PAH´s are unlikely to form or survive under normal combustion conditions.

3.6.2 Dioxins

Dioxins are highly toxic and relatively stable organic compounds with a polycyclic structure. The presence of chloride (Cl) is a precondition for the formulation of dioxins. During typical waste combustion processes dioxins are generated in the boiler in trace amounts and mostly segregated and conveyed away with fly ash. In the FGT dioxins are further reduced by injection of activated carbon or lignite coke or alternatively by catalytic reduction.

Dioxins entering the environment are persistent pollutants and can accumulate in the food chain, mainly in the fatty tissue of animals. Dioxins can cause reproductive and development problems, damage to the immune system, interfere with hormones and also cause cancer. Human exposure is mainly through food consumption, thus food supply is monitored by relevant agencies/organisations to detect concentrations and prevent human consumption.

People have background exposure to dioxin levels that does not impact health. However, efforts are undertaken to reduce current background dioxin exposure levels through limiting emissions from sources. ERFs are often claimed as being a significant source of dioxins. This is not the case when the dioxin emission levels are limited with flue gas treatment.

3.7 Particles

Particulate matter and dust mainly originates as fly ash from the combustion process. The introduction of powdery reagents and reaction products in FGT plants also adds to particulate matter presence in the flue gas. Particulate filters limit particulate matter and dust emissions from ERFs. The absence of a particle filter at an ERF would result in a dark exhaust plume from the stack.

3.8 Development Conclusions

The historical development of emissions from ERFs has been assessed in the separate study “Health Impact Literature Review”. Emissions from ERFs have significantly reduced over the last 40 years. Substantial reductions have been achieved since the 1990s. Emissions of main pollutants under the current regulation (IED and BREF) have reduced by a factor of around 10 compared to the mid-1990s and by a factor of around 100 compared to previous decades before any regulations were implemented. This applies to key pollutants such as particulate matter, hydrogen chloride (HCl), dioxins and most trace heavy metals. Other pollutants such as sulphur dioxide (SO_2) and mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) have also reduced significantly. Technical developments now offer the potential to reduce NOx emissions even further.

4. CONSIDERATION FOR FLUE GAS TREATMENT DESIGN

4.1 Plant Capacity and Waste Input

Waste processing volumes and waste composition are key drivers for FGT technology selection and design. This document outlines FGT systems for concept selection. The types of flue gas treatment systems discussed are applicable to the industrial scale ERF plant NLWA is considering.

4.2 Waste Composition

The waste to be processed is Local Authority Collected Waste (LACW) assumed as primarily comprising municipal solid waste (MSW) derived from household waste with some (minor) contribution from commercial and industrial (C&I) waste. Similarly any/possible waste derived fuels i.e. solid recovered fuel (SRF) that may be processed is assumed to be the product of treating MSW waste streams, thus resulting in similar composition flue gas.

MSW typically has an approximate net heating value of 9 to 10 MJ/kg. The heating value and pollutant content of waste streams such as C&I are generally higher than that of household waste. C&I waste typically has an approximate calorific value of 11 to 12 MJ/kg.

FGT system selection and operations at ERFs requires particular attention due to sulfur and chlorine in waste fractions. These are the respective sources of sulfur dioxide (SO_2) and hydrogen chloride (HCl) in the raw gas resulting from the combustion process and they have a key influence over the design of a FGT system. Usually almost all chlorine is converted to hydrogen chloride (HCl) whilst only a proportion of sulfur is converted to sulfur dioxide (SO_2), i.e. some 30-70%.

Chlorine in household waste occurs at moderate levels (typically 0.1 - 0.3%, excluding the effect of PVC), predominantly from normal household salt. PVC with a chlorine content of circa 50% is a key source of chlorine in waste treated at an ERF plant. Even small amounts of PVC in waste would generate high hydrogen chloride (HCl) levels in raw flue gas. Thus, the indicative waste specification reflects a certain amount of PVC or similar waste fractions. The nature of waste types delivered to EfW plants has a significant influence when selecting a FGT concept due to the need to meet specified hydrogen chloride (HCl) emission limits.

The indicative waste amount and composition for the ERF is assumed to be as stated in **Table 3**:

Parameter	Unit	Nominal waste	Proposed range [2]
Waste flow	ton/h	43.75	
Annual hours of operation	hrs/yr	8,000	
Annual waste throughput per line	ton/yr	350,000	
Annual waste throughput by a 2 line plant	ton/yr	700,000	
Lower heating value	GJ/t	10	7-12
Thermal energy input per line	MW	122	
Ash content in waste	%	20	
Moisture content in waste	%	31	
Sulfur in waste, S	%	0.13	0-0.5
Chlorine in waste, Cl	%	0.64	0-1.5

Table 3: Waste specification for FGT-technology selection

[2] The range maybe exceeded for individual waste loads/samples, but it shall be possible to mix the waste fed to the furnace to fit within the range, e.g. by efficient mixing of waste in the bunker. The nominal values are derived from the waste analysis and recommendations. The nominal point is the design point for the plant. A range is stated for Lower Heating Value, sulfur and chlorine contents to reflect the possible values with waste compositions variations.

Ramboll reviewed the “Waste Composition Analysis for NLWA” report prepared by Entec, dated September 2010. The study supports the assumption of an average lower heating value of 9.5 GJ/t. However, sulfur content (around 0.1%) seems to be lower than usually assumed for MSW, but chlorine content (0.8%) is higher than that usually assumed for MSW.

It is believed that supplementary waste fractions such as bulky waste will contribute to the waste volumes to be processed, thus a typical blended (mixed) waste is assumed. In our experience typical sulfur concentrations for such mixed waste would be 0.2% and chlorine would be 0.5%. Thus the nominal sulfur content has been elevated to 0.13 % and the chlorine has been lowered to 0.6% in order to take the uncertainties into account.

Ramboll’s analysis assumes that there will be no pre-treatment of MSW received at the ERF.

Based upon current operations at the existing Edmonton plant, NLWA have advised a calorific value of 10 GJ/t for preliminary ERF design and sizing.

Ramboll recommends that further waste sampling is undertaken as part of the detail design process to better inform the waste composition the ERF will be designed to process. Information such as raw gas properties at the existing Edmonton could also be monitored to provide information to support new ERF design.

4.3 Flue Gas Flow and Composition

The MSW sulfur and chlorine contents discussed above are considered appropriate to evaluate the FGT concept options for NLWA.

The flue gas flow rate and composition for a 350,000 tpa line is provided below in **Table 4**.

Parameter	Unit[4)]	Nominal value	Min - max. (½-hr mean values) [5)]
O_2 content in flue gas, dry basis	% O_2, dry	8.5*	6-10
Flue gas flow, actual O_2 and H_2O	Nm^3/h	235,000*	160,000 – 260,000
Flue gas flow (dry, 11 % O_2)	Nm^3/h	244,000	170,000-270,000
Flue gas temperature @ boiler exit	°C	170	160-200[1)]
Flue gas moisture content	%	17	10-24
Emission components at 11 % O_2, dry (reference state)			
CO	mg/Nm^3	10	0-40
TOC	mg/Nm^3	1	0-30
Dust	mg/Nm^3	2,100	500-5000
HCl	mg/Nm^3	1000	50-2500
SO_2 and SO_3 (as SO_2)	mg/Nm^3	200	0-1200
HF	mg/Nm^3	20	0-50
NO_x (as NO_2) without SNCR	mg/Nm^3	350	250-500
NO_x (as NO_2) with SNCR [2)]	mg/Nm^3	120	100-300
NH_3 [2)]	mg/Nm^3	10	0-20
Σ 9 metals [3)]	mg/Nm^3	10	50
Hg	mg/Nm^3	0,2	0,5
Cd+Tl	mg/Nm^3	1	2
Dioxins and furans, TEQ	ng/Nm^3	2	5

Table 4: An example of raw, untreated flue gas flow rate and composition (1 x 350 ktpa line)

*): Dependent on furnace/boiler guaranteed performance.
1): Dependent on boiler optimisation and choice of FGT-concept
2): Assuming SNCR for deNOx
3): Σ 9 metals is the sum of concentrations for: Sb, As, Pb, Cr, Co, Cu, Mn, Ni and V
4): Nm^3 are cubic meters at standard conditions at 0 °, 101,325 Pa.
5): Range applies for normal operation under which all guarantees shall be fulfilled. The range may be exceeded on occasions i.e. for a short term basis or during abnormal operations, e.g. during water spraying for removal of ash deposits.

4.4 Site Specific Factors

Site specific conditions at Edmonton as well as the priorities of NLWA may have a strong impact on the choice of FGT system. For instance, plant location may mean it is not possible or permitted to discharge wastewater with elevated content of salt in solution (non-hazardous calcium chloride) to a recipient or sewage system, e.g. foul drain. In such cases FGT plants comprising wet scrubbing systems as a rule are not suitable. A typical wastewater specification at a water treatment plant outlet is presented in **Table 8**.

5. ENVIRONMENTAL REQUIREMENTS

5.1 General

Environmental permits set limits on allowable concentration of pollutants in gaseous emissions from ERF plants. Similarly there are specific requirements on the condition of wastewater discharged to a water course. Discharge condition limit values for air emissions and discharge of wastewater from ERF plants in the UK are determined on the basis of the parameters set in the EU Directive 2010/75/EU on Industrial Emissions (IED). However, in some cases the resulting emission limits for the permit are more stringent than IED limits with reference to the principles of using Best Available Techniques (BAT) as defined in the BREF documents. These aspects are discussed below.

5.2 IED Directive

The air emission limit values set out in the IED are listed in **Table 5** below.

Parameter	Unit, ref. dry flue gas at 11% O_2	Air emission limit values, cf. IED-directive Daily average	½-hour average 97 % / 100 %
Dust	mg/Nm^3	10	10 / 30
HCl	mg/Nm^3	10	10 / 60
HF	mg/Nm^3	1	2 / 4
SO_2 + SO_3	mg/Nm^3	50	50 / 200
NO_x as NO_2	mg/Nm^3	200	200 / 400
		Result of spot sampling	
Cd + Tl	mg/Nm^3	0.05	
Σ 9 metals [1)]	mg/Nm^3	0.5	
Hg	mg/Nm^3	0.05	
Dioxin, TEQ	ng/Nm^3	0.1	

Table 5: Emission limit values within the EU

1) Σ 9 metals include the metals and their compounds: Sb, As, Pb, Cr, Co, Cu, Mn, Ni and V

Emission limit values for carbon monoxide (CO) and total organic carbon (TOC) are not included in **Table 5**. These parameters are not notably affected by the flue gas treatment processes. However, they are controlled by waste combustion conditions and there are specific regulatory requirements for these.

5.3 BAT Requirements and BREF-Document

Best Available Techniques (BAT) has been introduced in the Integrated Pollution Prevention and Control (IPPC) directive and subsequently into the Industrial Emissions Directive (IED). This requires the EU commission to issue BAT reference documents (BREF).

The preamble of the IED reads (item 13),

'In order to determine best available techniques and to limit imbalances in the Union as regards the level of emissions from industrial activities, reference documents for best available techniques (hereinafter "BAT reference documents") should be drawn up, reviewed and, where necessary, updated through an exchange of information with stakeholders and the key elements of BAT reference documents (hereinafter "BAT conclusions") adopted through committee procedure. In this respect, the Commission should, through committee procedure, establish guidance on the collection of data, on the elaboration of BAT reference documents and on their quality assurance. BAT conclusions should be the reference for setting permit conditions. They can be supplemented by other sources. The Commission should aim to update BAT reference documents not later than eight years after the publication of the previous version.'

The BREFs are supplemented by the research institute of the EU Commission in Seville, Spain. Thirty different BREFs are issued, all with a standard table of contents of which chapter 5 is on BAT. The BREF on waste incineration has 5 subsections. Section 5.1 of these is on “Generic BAT” for all waste incineration and 5.2 is “Specific BAT for municipal waste incineration” that contains 63 recommendations of particular interest in this context.

The IED-directive includes a clause (Article 15, 3) stating:

‘The competent authority shall set emission limit values that ensure that, under normal operating conditions, emissions do not exceed the emission levels associated with the best available techniques as laid down in the decisions on BAT conclusions…’

It remains to be seen how this clause will be implemented in practice and we await a new edition of the BREF that will detail conclusions.

The latest update of the BREF on waste incineration was issued in 2006, and a new edition including “BAT conclusions” is due “no later than 2016” according to the wording of the preamble:

The latest BREF BAT 35 is the closest one that gets to the BAT conclusions. BAT 35 reads; ‘the use of an overall flue-gas treatment (FGT) system that, when combined with the installation as a whole, generally provides for the operational emission levels listed in ***Table 6*** *for releases to air associated with the use of BAT.*

Parameter	Unit	BATOEL daily average	BATOEL ½-hour average 100 %
Dust	mg/Nm^3	1-5	1-20
HCl	mg/Nm^3	1-8	1-50
HF	mg/Nm^3	<1	<2
SO_2 + SO_3	mg/Nm^3	1-40	1-150
NO_x as NO_2	mg/Nm^3	120-180$^{1)}$ 40-100$^{2)}$	3-350$^{1)}$ 40-300$^{2)}$
		Result of spot sampling	
NH_3	mg/Nm^3	<10	
Cd + Tl	mg/Nm^3	0.005-0.05	
Σ 9 metals	mg/Nm^3	0.005-0.5	
Hg	mg/Nm^3	<0.05	
Dioxins, TEQ	ng/Nm^3	0.01-0.1	

Table 6: BAT intervals (BAT Operational Emission Levels)

$^{1)}$ With SNCR. $^{2)}$ With SCR

BREF-documents do not provide specific guidelines on the choice of technology, hence both wet and dry systems can be considered as BAT. There is no guideline in the documents with respect to the choice of consumables for pollutant abatement, e.g. use of quick lime, hydrated lime or sodium hydroxide (NaOH) for sulfur dioxide (SO_2) absorption.

5.4 Expected Future Air Emissions Limit Values

This document considers FGT system options with respect to their flexibility towards meeting future emission limit values. This is somewhat helped by providing margins over the existing emission limits set out in **Table 6**. Therefore, the actual emission limits achieved by plants should not exceed the current daily average value requirements set in detail in **Table 7**.

Future limit values and the BAT conclusions are not known, thus any attempt to suggest future limit values shall be considered as Ramboll’s best estimate based upon currently available information. Ramboll cannot be held liable for actual future requirements different from our professional opinion at this time.

Our estimate considers the following, amongst other, factors:

- The above cited clause of Article 15, 3 of the IED-directive.
- The actual implementation of the IED-wording into permits remains to be seen when the revised BREF note is published with new BAT Conclusions.
- The conflicting basis of limit values that should not be exceeded anytime, and “operational emission levels” achieved under “normal” operation”.
- The limit values for waste incineration are already low for most pollutants, compared to other combustion sources i.e. coal and biomass.
- Extensive tightening of limit values may necessitate relatively costly additional equipment, and the socio-economic benefit of reduced emissions may not be a reasonable proportion to the additional cost.
- Emissions of particulate matter, sulphur dioxide (SO_2), hydrogen chloride (HCl), hydrogen fluoride (HF) and dioxins are already reduced to environmentally less significant levels by current limit values.
- BAT Operational Emission Levels (BATOEL) for hydrogen fluoride (HF) is close to detection levels, further reducing the Emission Limit is difficult. The neutralization of hydrogen fluoride (HF) follows the same mechanisms as hydrogen chloride (HCl), thus effective hydrogen chloride (HCl) removal yields effective hydrogen fluoride (HF) removal. Therefore, in some cases continuous hydrogen fluoride (HF) measurements are substituted by continuous hydrogen chloride (HCl) measurement and supplementary periodic hydrogen fluoride (HF) spot measurements.
- The current emission limit value for mercury (Hg) is less stringent when compared with other pollutants, considering the severe environmental consequences of its emission. This is particularly the case for human toxicity and some European countries, e.g. Germany, have already tightened the mercury (Hg) limit value and require continuous monitoring.
- The current emission limit value for mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) allows a significant environmental impact considering the range of impacts of their emissions (e.g. SMOG-formation, acidification, eutrophication and human toxicity) and associated socio-economic cost.
- The local air quality objectives may necessitate lower emissions at specific locations, particularly for mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x), as many cities have challenges in meeting the EU air quality requirements, particularly for nitrogen dioxide (NO_2). Indications are that the Edmonton site falls into this category.
- Ammonia has no limit value in the IED-directive, but its frequent use in SNCR-systems makes a limit value obvious.
- Nitrous oxide (N_2O) may be introduced in the revised BREF because it is a common by-product from the use of urea in the SNCR process.

Parameter	Unit	daily average	½-hour average 100 %
Dust	mg/Nm^3	5	20
HCl	mg/Nm^3	8	40
HF	mg/Nm^3	<1	<2
$SO_2 + SO_3$	mg/Nm^3	30	100
NO_x as NO_2	mg/Nm^3	40 - 150	100 - 200
NH_3	mg/Nm^3	5	20
N_2O	mg/Nm^3	5	30
		Result of spot sampling	
Cd + Tl	mg/Nm^3	<0.02	
Σ 9 metals	mg/Nm^3	<0.1	
Hg	mg/Nm^3	<0.02	
Dioxins, TEQ	ng/Nm^3	<0.05	

Table 7: Possible Minimum Future Emission Value Requirements

5.5 Wastewater Discharge

Flue gas treatment processes entailing wet scrubbers generate wastewater that requires treatment and discharge. For further explanation refer to **Section 6.6 - Wet Scrubbing Systems**.

Wastewater discharged from the plant should, as a minimum, fulfil the requirements of the IED directive, ref **Table 8**. The relevant authorities may choose to tighten these requirements as a result of local conditions with a view to the BAT emission levels as guided by BREF documents.

5.6 Solid FGT Plant Residues

Flue gas treatment using reagents such as lime result in the production of solid residues. This is regardless of the FGT plant in place. Some of the residues produced are classified as hazardous waste. Such residues are treated at approved facilities. Management practices of these in the UK are usually either underground storage at licensed facilities or blending in a concrete mixture to stabilise hazardous substances and landfilling the resulting non-hazardous mixture. The amount of residue production is a reflection of the pollutant removal efficiency of the FGT system and how much additional reagent is required to treat the hazardous component.

For UK based ERFs, fly ash from the boiler is usually diverted into the bottom ash collection stream. However, a change in legislation may require its management as hazardous waste. In this event fly ash can be diverted into the FGT residue stream and managed accordingly. The treatment costs for hazardous waste is many times that of non-hazardous waste.

Parameter	Unit	IED	Chloride wastewater (wet FGT only)	Condensate (flue gas condensation only)
Flow	m^3/tonne waste	-	0.1-0.2	0-0.5
Chloride	mg/l	-	30 000	200
Sulphate S	mg/l	-	1,500	800
Suspended matter (95 %)	mg/l	30	10	5
Ammonium-N	mg/l	-	10	5
Cyanide, CN	µg/l	-		
Mercury, Hg	µg/l	30	3	0.2
Cadmium, Cd	µg/l	50	5	1
Thallium, Tl	µg/l	50	3	2
Arsenic, As	µg/l	150	20	5
Lead, Pb	µg/l	200	50	5
Chromium, Cr	µg/l	500	50	5
Copper, Cu	µg/l	500	50	5
Nickel, Ni	µg/l	500	50	5
Zinc, Zn	µg/l	1500	300	50
Antimony, Sb	µg/l	-	100	10
Cobalt, Co	µg/l	-	30	10
Manganese, Mn	µg/l	-	-	-
Vanadium, V	µg/l	-	50	15
Tin, Sn	µg/l	-	50	10
Silver, Ag	µg/l	-	10	3
Molybdenum, Mo	µg/l	-	100	30
Selenium, Se	µg/l	-	-	-
Dioxins and furans, TEQ	ng/l	0.3	0.05	0.02

Table 8: Expected flow rate and concentrations of wastewater from an optimised WWT facility

6. FLUE GAS TREATMENT TECHNOLOGIES

6.1 General

FGT refers to a ranges of processes imposed on raw (untreated) combustion gas to limit harmful pollutants such as emissions of dust, acidic gases, heavy metals, and dioxins to levels well below legal emission limits.

Mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) are treated in a separate system within the ERF. The options for this are described in detail in **Section 7**.

Carbon monoxide (CO) and total organic carbon (TOC) content requirements are addressed by controlling the combustion conditions in the furnace.

FGT plants are categorized into distinct systems: dry, semi-dry, wet systems and combinations hereof.

- ‘dry’ systems are where the chlorine and sulfur content of the waste leaves the facility as a dry product, and no wastewater is produced. This system is commonly employed by UK based ERFs.
- ‘wet’ scrubbing systems have several processing stages. These include a wet scrubber that produces a solution containing the majority of the chloride released from the combusted waste, thereby limiting the generation of solid residues.

It is possible to combine the above concepts as a ‘dry-wet’ process. The concept of the combined system is to remove the majority of the pollutants in an upstream dry system and include a downstream polishing scrubber to improve the overall efficiency of the flue gas treatment. Effluent from the scrubber is withdrawn as a bleed to control the salt level in the scrubber and is evaporated in the upstream ‘dry’ process step. Therefore, the combined dry-wet system is wastewater free.

Below are examples of typical FGT technologies. There are many specific variations for each of the systems presented.

6.2 Principles of Dry and Semi-dry FGT Systems

Dry and semi-dry flue gas cleaning concepts are characterized by the reaction of the acid flue gas components (hydrogen chloride (HCl), sulphur dioxide (SO_2), and hydrogen fluoride (HF)) with the reagents forming dry cleaning products or FGT residues.

Residues are typically collected with the dioxin / furan loaded activated carbon (AC) or lignite coke, usually added to flue gas alongside with dry basic reagents. Heavy metal contents are simultaneously removed from flue gas.

Dry and semi-dry systems are less complicated compared to equivalent wet systems, because the cleaning process is performed in one common step.

Dry and the semi-dry flue gas cleaning processes usually function through the injection of hydrated lime into the flue gas stream. This leads to the neutralization of the acid flue gas components.

The process is called dry if hydrated lime is used as a dry pulverized reagent without adding water. It is called semi-dry if lime is moistened with water before injection into the system. In both cases the reaction product and a surplus of unreacted reagent is collected in a dry powdery form by bag house filters. There are numerous commercially available dry FGT systems. Similarly, there are some alternatives to hydrated lime as a reagent e.g. sodium bicarbonate.

6.3 Dry Lime Based Systems

Introduction

Dry lime based systems have traditionally been the most common FGT system and are still widely used.

The key components of the dry lime based system, flue gas and material flows together with conditions such as typical flue gas temperatures at various stages of the plant are shown in **Figure 2**.

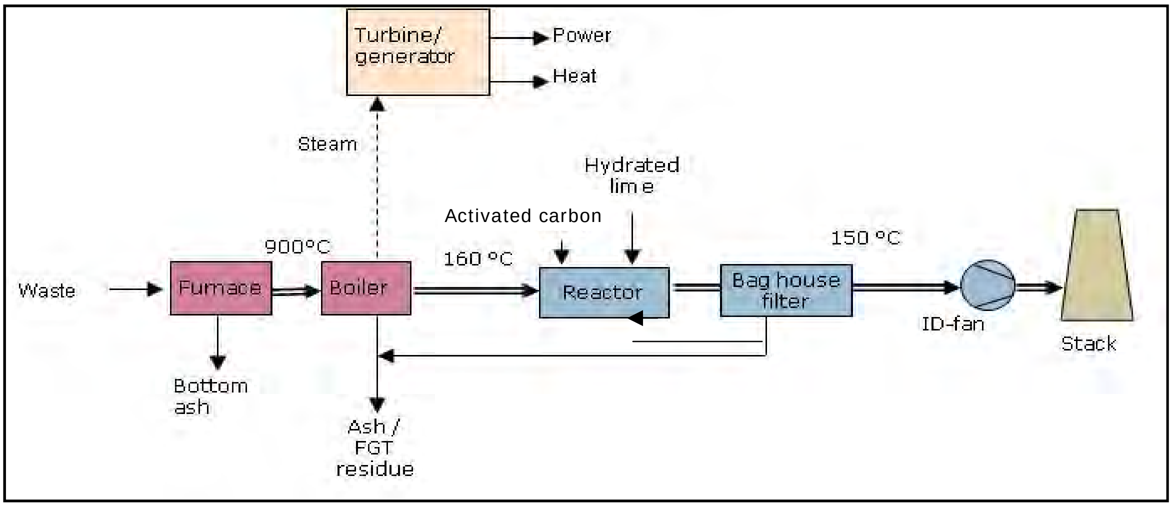

Figure 2: Lime based dry absorption system

The solution comprises the following main components:

- Reactor for the addition of hydrated lime and activated carbon
- Bag house filter for separation of the reaction products and fly ash
- Induced draught fan (ID-fan) and stack

For energy recovery purposes an economiser might be integrated downstream, after the main components of the FGT. The drivers and possibilities are further described in **Section 8 - Energy Recovery**.

The flue gas temperature at boiler exit is typically 160 ° C. The process works in a range of lower temperatures, 160 ° C down to approximately 140 ° C. At higher temperatures efficiency is often reduced, corrosion and clogging can be an issue at lower temperatures.

An absorbent in the form of powdered hydrated lime ($Ca(OH)_2$), is blown into the reactor where a reaction between hydrated lime ($Ca(OH)_2$) and the gaseous flue gas impurities in the form of sulfur dioxide (SO_2), hydrogen chloride (HCl) and hydrogen fluoride (HF) takes place on the surface of the lime particles. This results in the formation of gypsum ($CaSO_4$), calcium sulphite ($CaSO_3$), calcium chloride ($CaCl_2$) and calcium fluoride (CaF_2); all in the form of solid powdery residues. Activated carbon powder is applied as part of the process for the absorption of mercury and dioxins. FGT residues are treated as hazardous waste. The residues also comprise the activated carbon used in the treatment process.

The FGT residues may be recirculated for better reagent use. The reactivation of recirculated reagents can be by humidification or use of steam and depends on the FGT plant supplier. However, a certain excess of hydrated lime cannot be avoided. The consumption rates of hydrated lime for the dry concept are typically in the range of 2.0 to 3.0 times the theoretical minimum consumption rate for the assumed raw gas conditions and the clean gas composition required. Excess of hydrated lime injected into the process remains unused and is discarded as a mixture together with the reaction products.

The temperature drops slightly across the reactor unit due to heat loss and transport air use.

The reaction products, any unreacted powdered hydrated lime ($Ca(OH)_2$) and remaining fly ash from the furnace/boiler are separated in the bag house filter. This residue is collected for storage in a silo and sent to disposal/treatment as hazardous waste.

A frequency controlled centrifugal induced draught fan (ID-fan) is applied to transport flue gas from the combustion chamber through the boiler, the FGT and to the stack. The fan is commonly located at the tail end of the plant and designed to overcome the complete pressure loss of the FGT plant and to maintain a defined vacuum in the furnace/boiler unit in all load cases. The flue gas temperature typically increases in the range of 5 °C up to approximately 145 °C as a result of the compression and friction within the induced draught fan. The ID-fan is the main FGT plant power consumer.

Advantages

The dry hydrated lime based FGT system is relatively simple to install and operate. The relative space requirements are low. Therefore, the associated investment and maintenance costs are also relatively low.

Efficiency of reagent usage may be improved by using a higher grade of lime with improved reactivity.

The process is used in many plants hence the wide availability of references and operational experience.

Disadvantages

The dry process has limited capability when treating elevated levels of pollutants, particularly sulfur dioxide (SO_2) and hydrogen fluoride (HF). Therefore, the process usually results in some emission values which are higher than other systems. Dry systems are less flexible when handling flue gas from waste fractions with highly variable composition, particularly those rich in sulfur. Furthermore, elevated temperatures reduce the effectiveness of mercury capture and the ability to meet stringent mercury emission limits.

A significant excess of hydrated lime is required to treat flue gases to levels that comply with emission limits. This is typically 100 - 200% excess hydrated lime and this results in large quantities of residue generation. Using high volumes of hydrated lime generates high levels of residues because excess of hydrated lime remains unused and can only be discarded as a mixture with the reaction products. Consequently the treatment costs make the process expensive from an operating perspective.

6.4 Dry Bicarbonate Based Systems

Introduction

Bicarbonate based systems are used at many plants in Europe, particularly in France. This system does not require injection of air or water to cool flue gas after the boiler stage because bicarbonate is effective at temperatures of 170 - 190 °C. These temperatures match the flue gas temperatures at boiler exit.

The key components of the dry bi-carbonate based system, flue gas and material flows together with conditions such as typical flue gas temperatures at various stages of the plant are shown in **Figure 3.**

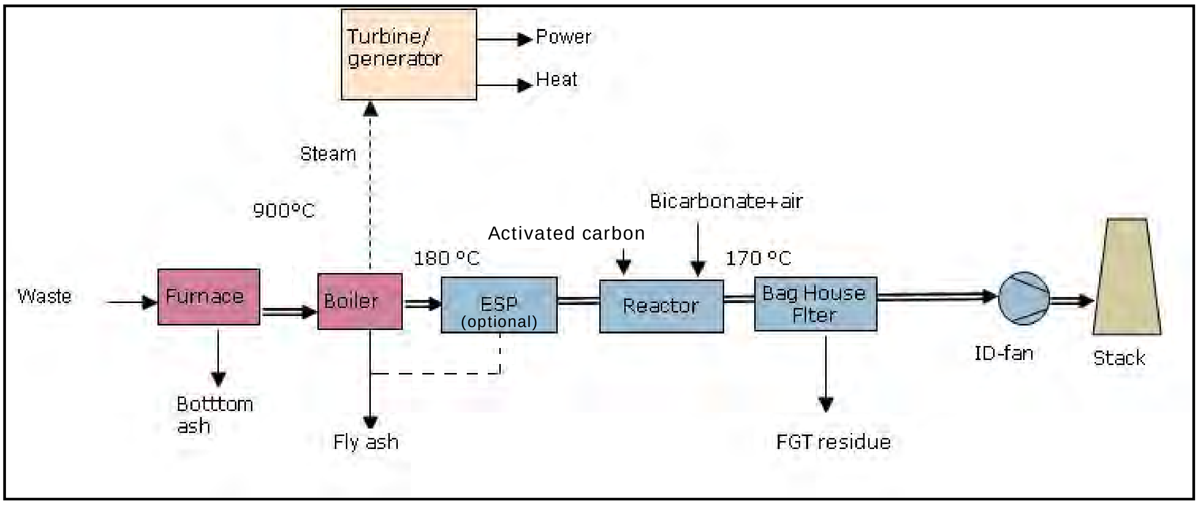

Figure 3: Bicarbonate based dry absorption system

The plant comprises the following main components:

- Electrostatic precipitator - ESP (optional)
- Reactor for the injection of bicarbonate
- Baghouse filter
- ID-fan

For energy recovery purposes an economiser might be integrated downstream, after the main components of the FGT. The drivers and possibilities are further described in **Section 8 - Energy Recovery**.

Flue gas temperature downstream of the boiler is set to 170 - 190 ºC. Compared to the dry lime process, the process needs a higher temperature than for example lime based dry systems to activate bicarbonate (“pop-corn-reaction”).

In cases where fly ash and the residual product is delivered to different outlets, flue gas requires pre-cleaning by an electrostatic separator (ESP) before it enters the dry bicarbonate flue gas cleaning plant.

The use of an ESP facilitates the recovery/recycling of the bicarbonate by preventing fly ash contamination. Bicarbonate is collected separately and sent to recycling facilities. During the recycling process, undertaken at external supplier facilities, chlorides and the sulphates are “washed out” and the bicarbonate is regenerated. The process is common in France and Germany where used bicarbonate is collected from plants for treatment and reuse. Ramboll is not aware of this process currently being used in the UK.

The bicarbonate products from the reaction with sulfur dioxide (SO_2) and hydrogen chloride (HCl), (the sodium salts) are dissolved in water and can be regenerated to bicarbonate before being reused. "Inerts" like fly ash carried to the recycling plant impose extra cost to recycling or can even make it impossible. Therefore, a precondition for the bicarbonate concept is often that the fly ash is separated beforehand and is not mixed together with the bicarbonate product in a common silo.

ESPs are effectively used in operations where bicarbonate is captured for recycling. However, given that there are no known ERF plant bicarbonate recycling schemes in the UK, our analysis assumes no primary ESP filtration.

An absorbent in the form of powdered sodium bicarbonate is injected into the reactor. The bicarbonate in the reactor is activated and reacts with flue gas impurities in the form of sulfur dioxide (SO_2), hydrogen chloride (HCl) and hydrogen fluoride (HF). Activated carbon, which adsorbs mercury and dioxins, is injected at the same time. These reactions occur effectively at high temperatures, thus no flue gas pre cooling is required. In addition, because bicarbonate is more reactive than hydrated lime, less bicarbonate is needed than in lime based solutions. However, when compared to dry or semi-dry systems, activated carbon consumption increases with higher temperatures. This is because mercury adsorption is more effective at lower temperatures.

The resulting reaction products, used activated carbon and unused sodium bicarbonate residues are filtered in the bag house filter and sent to the residue silo. Residues are subsequently sent to landfill or to recycling plants, where bicarbonate recycling schemes are in place.

A frequency controlled centrifugal induced draught fan (ID-fan) is applied to transfer flue gas from the combustion chamber, through the boiler, flue gas cleaning plant and subsequently to the stack. The flue gas fan is most commonly located at the tail end of the plant and designed to overcome the complete pressure loss of the FGT-plant, maintaining a defined vacuum in the furnace/boiler in all load cases. The flue gas temperature typically increases in the range of 5 °C to 175 - 195 °C due to compression and friction within the induced draught fan. The ID-fan is the main FGT plant power consumer.

<u>Advantages</u>

The bicarbonate based FGT system is relatively simple to install and operate. The use of an ESP before the main process results in a chemical residue at the bag filter, which can in principle be recycled. Bicarbonate consumption is moderate because approximately only 20% excess reagent use is required. This reduces the amount of residues produced when compared to a lime based flue gas treatment plant. The process is advantageous if a selective catalytic reduction system is subsequently used to remove oxides of nitrogen (NOx) because the SCR-catalyst can be installed downstream of the bag house filter without the need to reheat the flue gas to temperatures required for this process.

<u>Disadvantages</u>

The dry bicarbonate process has limited capabilities where there are elevated pollutant levels, particularly sulfur dioxide (SO_2) and hydrogen fluoride (HF). Furthermore, elevated temperatures are not ideal for the capture of mercury, and this is of concern where there are more stringent emission limits.

Bicarbonate is relatively expensive and there are a limited number of suppliers. This can cause uncertainty over the security of supply and delivery related issues. It is important that the supplier also provides recycling capability and transport distances are not excessive.

6.5 Semi-Dry System

Introduction

Semi-dry systems were introduced to optimise the chemical reaction between the acidic gases and lime added to the flue gas stream. There are two distinct forms of semi-dry systems:

- Hydrated lime added as slurry. This increases the efficiency of the chemical reaction between the acidic gases (sulfur dioxide (SO_2), hydrogen chloride (HCl), hydrogen fluoride (HF) etc.) and the lime; or

- Recirculation of the residue to reuse un-reacted lime. The residue is typically humidified by water to ‘reactivate’ the re-circulated lime.

Semi dry systems have two advantages. Firstly an increase in reaction efficiency reduces lime overdosing requirements compared to dry systems, hence savings in consumables costs. Secondly there are less FGT residues generated due to reduced lime use and recirculation of unreacted lime.

The key components of the semi-dry system, flue gas and material flows together with conditions such as typical flue gas temperatures at various stages of the plant are shown in **Figure 4.**

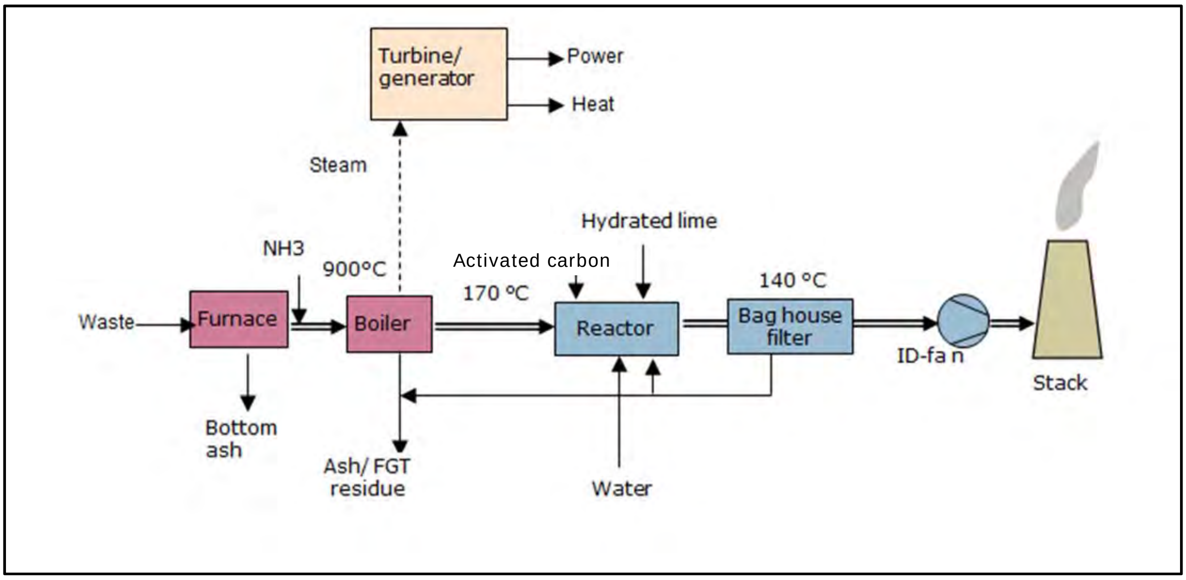

Figure 4: Semi-dry system

The plant comprises the following main components:

- Reactor for the injection of hydrated lime and activated carbon
- Baghouse filter
- ID-fan

For energy recovery purposes an economiser might be integrated downstream, after the main components of the FGT. The drivers and possibilities are further described in **Section 8 - Energy Recovery**.

The process works in a range of temperatures, 200 °C to approximately 170 °C. The amount of acid components in the raw gas and the water content of the injected lime slurry determine the quantity of water to be evaporated in the reactor, thereby defining the requirement for a minimum inlet temperature. Both the water content of the injected slurry as well as the optimal reaction temperatures depend on the system supplier.

Advantages

Semi dry systems are relatively simple to install and operate. Furthermore, space requirements for the plant are relatively moderate.

There are many semi-dry FGT plants in operation. Hydrated lime is a common commodity produced by a range of different suppliers and is easy to source.

Disadvantages

The process is limited in its ability to treat high sulfur dioxide (SO_2) levels in raw flue gas streams, and this needs to be considered where there are more stringent emission requirements.

The system requires an excess of hydrated lime dosing, typically 50 - 130%. Therefore, the process produces significant quantities of FGT residues, although somewhat less than the dry, lime based treatment systems.

Hydrated lime consumption and residues generation increase considerably where there are elevated or varying raw gas hydrogen chloride (HCl) and sulfur dioxide (SO_2) contents.

The mixing system for water and lime requires daily maintenance; a task that entails risk of human contact with hazardous material. The system requires close monitoring to maintain performance.

6.6 Wet Scrubbing Systems

Wet scrubbing systems have not been installed in UK ERF plants. However, the system is common in Europe e.g. Germany and Switzerland. Therefore, the concept is included in this report as a reference and possible alternative solution.

The key components of the wet scrubbing system, flue gas and material flows together with conditions such as typical flue gas temperatures at various stages of the plant are shown below in **Figure 5**.

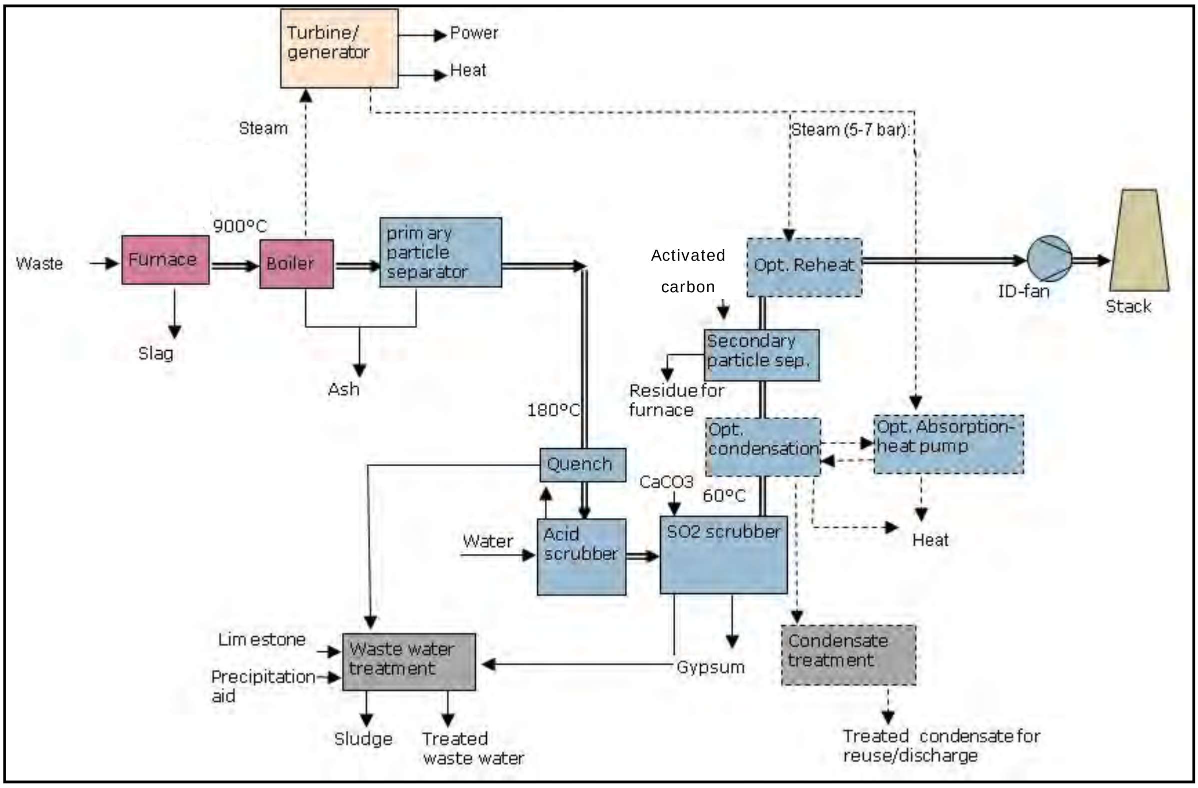

Figure 5: Wet flue gas treatment with SNCR

The solution contains the following main components:

- Primary particle separator
- Quench
- Acidic hydrogen chloride (HCl) scrubber
- Caustic sulphur dioxide (SO_2) scrubber
- Condensation (optional)
- Secondary particle separator
- Reheater (optional)
- Induced draught fan (ID-fan) and stack
- Wastewater treatment
- Condensate treatment (optional)

Wet flue gas cleaning requires the removal of hydrochloric acid (HCl) contents as soluble salts via a wastewater drain. This is a key difference from the dry flue gas cleaning systems where salts are separated and removed in solid form.

In wet flue FGT system hydrochloric acid (HCl) is separated simultaneously with hydrogen fluoride (HF) and mercury (Hg) in an acidic scrubber. The sulfur dioxide (SO_2) content and remaining hydrogen fluoride (HF) content is removed in a caustic or neutral scrubber. By recirculating the liquid in the scrubbers a close contact between the acid gas and the washing liquid is achieved. Depending on the supplier, the scrubber may include special nozzles and internal parts, which are designed to optimize the effectiveness of the process.

Wet FGT systems require dust in the flue gas to be removed in a primary particle separator (e.g. electrostatic precipitator (ESP) to minimize the particle load at the acid scrubber stage. Consequently wet flue gas cleaning systems always consist of at least two steps that can be optimised individually. The process stage for the removal of dioxins is a secondary particle filter (e.g. a bag house filter).

Wet FGT systems produce wastewater that requires treatment before discharge. Furthermore, a solid residue in the form of gypsum, a non-hazardous output, is produced. An additional residue is small amounts of dewatered hydroxide sludge which is considered as hazardous waste that can be mixed with fly ash. Hydroxide sludge contains high amounts of heavy metals in its precipitated form. Therefore, treatment of the small amounts of hydroxide sludge is usually not considered as an option and it is managed as a hazardous waste.

Advantages

Wet FGT plants can achieve efficient flue gas cleaning and are robust with respect to changes in raw gas composition and have the flexibility to meet more stringent emission limits than currently in place.

The consumption of absorption chemicals is low in terms of excess lime and sodium hydroxide use. Sodium hydroxide, though hazardous, is simpler to handle as it ends up in a mixed solution. Low consumption of consumables results in low volumes of residue generation.

Chlorides are transferred to the water phase instead of a solid phase which reduces residue generation.

There are many reference plants employing wet FGT systems outside the UK. Therefore, there are several suppliers and long term operational experience to draw from.

Disadvantages

A wet scrubbing system includes many process steps, hence requiring high capital investment, it is more complex to operate, and requires specialist staff.

The treatment of wastewater is an additional process requiring skilled wastewater treatment plant operators. A wastewater discharge stream is required. This is additional to plants without such systems. The total cost of disposing liquid effluent can be significant.

There is significant plume visibility where flue gas is not reheated prior to stack flow and exit.

6.7 'Combined Dry-Wet' System

The 'Combined Dry-Wet' System comprises the combination of a semi-dry or a conditioned dry FGT-system with a reduced wet FGT system.

The combined ('dry-wet') concept aims to reduce the overdosing of lime in the bag house filter compared to the semi-dry or conditioned dry system, especially in periods with peak concentrations of acidic gases. Flue gas polishing treatment takes place in a wet scrubber. This approach is very efficient for the removal of pollutants during peak flows.

The key components of the combined system, flue gas and material flows together with conditions such as typical flue gas temperatures at various stages of the plant are shown in **Figure 6**.

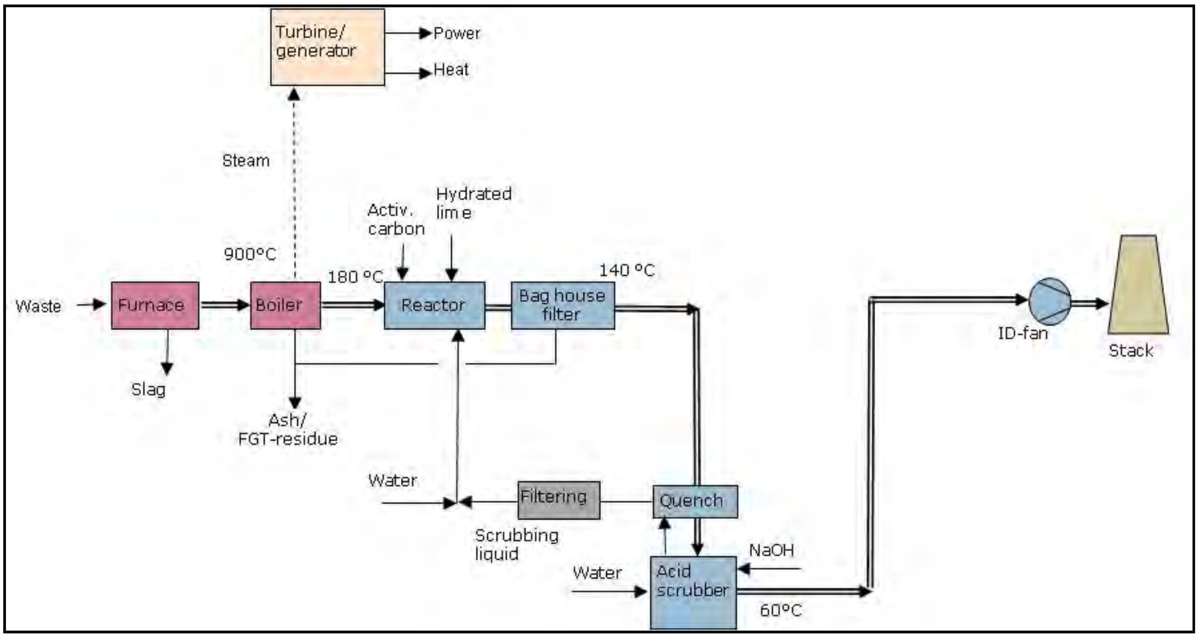

Figure 6: Combined 'dry-wet' system

Details of semi-dry, dry and wet system are described in the respective sections of this study, i.e. **Section 6.3 Dry Lime Based Systems** and **Section 6.6 Wet Scrubbing Systems**. Semi-dry and conditioned dry systems operate in a range of temperatures, 200 ° C down to approximately 170 °C. A temperature of 180 °C is assumed to be sufficient for the necessary evaporation of recirculated water from the acid scrubber, but is dependent on the system supplier.

<u>Advantages</u>

The hydrated lime based semi-dry system is simple to install and operate compared to wet systems.

The addition of a scrubber ensures relatively low excess lime use and offers the capability to handle fluctuating raw gas pollutant contents. The system has the ability to meet even more stringent emission limits than currently in place, particularly for hydrogen chloride (HCl) and sulfur dioxide (SO_2). The amount of wastewater produced in the wet scrubber is reduced compared to the dedicated wet systems. The wastewater produced is used within the overall process, either for humidification of reagent, recirculate or other media. The net impact is that there is no wastewater produced by the system.

There are many operational ERF plants (worldwide) using semi-dry FGT technology with wet scrubber systems.

Hydrated lime, one of the main reagents, is produced by a range of different suppliers and is easy to source.

Disadvantages

Hydrated lime dosing is still significant in spite of the scrubbing system. Therefore, a fairly large amount of residue is generated, though slightly less than the dry and semi-dry systems.

Generally limited, if any, savings in operational cost should be expected when compared to semi-dry systems due to the additional power consumption and manpower requirements associated with the scrubber.

This system will have high plume visibility unless treated flue gas is reheated – e.g. in a gas-gas heat exchanger - downstream of the bag house filter prior to the emission through the stack.

The mixing system for water and hydrated lime requires daily maintenance; a task that entails risk of human contact with hazardous material. The system also requires close monitoring to maintain performance.

6.8 Expected Air Emissions Levels with the FGT Systems Considered

The performance in terms of emission levels for each FGT system is shown in **Table 9** and **Table 10**. The tables show that, in general, all systems are capable of achieving emission limit values that are much lower than IED requirements. The main difference between the FGT technologies is that systems incorporating the use of a scrubber ('combined' and 'wet' systems) can reduce the emissions of hydrogen chloride (HCl) and sulfur dioxide (SO_2) by factors of 10 and 5 times below the EU IED requirements respectively. Therefore, these systems provide significant margins should the need arise to meet more stringent requirements for these emissions.

All systems have very efficient dust removal capabilities with emission levels reduced from 1,000 - 1,500 mg dust/Nm^3 to around 1 mg dust/Nm^3 during normal operation and with good maintenance. Heavy metals – except mercury (Hg) - are bound on the surface of the dust particles. Therefore, equal removal efficiencies are achieved for heavy metal removal as all systems have the same dust removal efficiency.

Expected emissions under normal operation are listed in the tables below.

Note: Values apply under normal operation, and are not limit values.

<table>
<tr><th>Parameter</th><th>Unit</th><th>Bicarbonate</th><th>Semi-dry</th><th>Combined dry-wet</th><th>Wet</th></tr>
<tr><td>Water vapour</td><td>% vol.</td><td>17</td><td>18</td><td>22</td><td>22</td></tr>
<tr><td>CO</td><td>mg/Nm^3</td><td colspan="2">10</td><td>10</td><td>10</td></tr>
<tr><td>TOC</td><td>mg/Nm^3</td><td colspan="2">1</td><td>1</td><td>1</td></tr>
<tr><td>N_2O</td><td>mg/Nm^3</td><td colspan="2">2</td><td>2</td><td>2</td></tr>
<tr><td>NH_3</td><td>mg/Nm^3</td><td colspan="2">5</td><td>0.5</td><td>0.1</td></tr>
<tr><td>Dust</td><td>mg/nNm^3</td><td colspan="2">1</td><td>1</td><td>1</td></tr>
<tr><td>HCl</td><td>mg/Nm^3</td><td colspan="2">6</td><td>1</td><td>1</td></tr>
<tr><td>SO_2</td><td>mg/Nm^3</td><td colspan="2">20</td><td>10</td><td>10</td></tr>
<tr><td>HF</td><td>mg/Nm^3</td><td colspan="2">0.5</td><td>0.1</td><td>0.1</td></tr>
</table>

Table 9: Expected emission to the air (daily average)

Reference conditions are dry flue gas at 11% O2.

Parameter	Unit	Bicarbonate	Semi-dry	Combined dry-wet	Wet
Cd + Tl	mg/Nm^3	0.001	0.001	0.001	0.001
Hg	mg/Nm^3	0.012	0.008	0.004	0.004
Σ9 metals	mg/Nm^3	0.030	0.030	0.030	0.030
Dioxins or furans*, TEQ	ng/Nm^3	0.010	0.005	0.005	0.005

Table 10: Expected indicative concentrations of heavy metals and dioxin

Reference conditions are dry flue gas at 11% O2.
(*) Values based on SNCR. Emission of dioxins and furans may be reduced further as a side effect of catalytic processes (SCR). However levels are low and difficult to measure.

6.9 FGT Technology Costs

6.9.1 Operational Costs

Relative FGT plant operational costs considering consumables, residues and energy use are detailed in **Table 11**.

The bicarbonate process appears to be the least favourable concept from an operating cost perspective. Even though the reactivity of the reagent can be assumed to be close to the theoretical optimum, raw material costs and costs for the regeneration of the residual product are significant disadvantage for this process.

The lime based semi-dry process is shown to be the most advantageous system from an operational cost perspective.

The combined dry-wet process appears to be less attractive than the semi-dry process. This is due to the maintenance of a relatively complex system. The reduction of costs for residue disposal is marginal when compared to the semi-dry system. This cost saving does not compensate for the maintaining the complex dry-wet system.

The wet process yields much smaller amounts of residues, but requires more specialised staff and resources to operate. This is due to the high complexity of the plant. The advantages and disadvantages of the plant are balanced and consequently operating costs of the system are favourable over the other systems considered.

Note: 1 equates to lowest cost and 4 equates to highest cost

	Dry Bicarbonate	Semi-dry	Combined	Wet
Operating Cost Ranking	4	2	3	1

Table 11: FGT Plant Operational Cost Ranking

6.9.2 Capital Costs

Relative FGT plant capital costs are detailed in **Table 12**.

The capital costs for bicarbonate and semi-dry processes are comparable. This is with the exception of the equipment required for humidification of the reagent in the semi-dry process. However, the bicarbonate process requires mills (typically hammer mills) for bicarbonate preparation, thus almost balancing the cost difference.

The wet process requires a variety of sub-systems and machinery, e.g. scrubber circulation pumps, wastewater system, gypsum-dewatering and filtrate system, bleed tanks, etc. and requires the highest capital investment. The combined process usually reuses wastewater in the treatment process and this avoids wastewater treatment/discharge.

Building/housing cost needs are evaluated by excess investment needs compared to the smallest plant, which is typically the semi-dry process.

Note: 1 equates to lowest cost and 4 equates to highest cost

T	Bicarbonate	Semi-dry	Combined	Wet
Capital Cost Ranking	1	2	3	4

Table 12: FGT Plant Capital Cost Rankings

6.9.3 Lifetime Cost

FGT plant capital and operational costs are evaluated to determine lifecycle costs over a period of 20 years

The outcome of this evaluation is set out in the table below.

Note: 1 equates to lowest cost and 4 equates to highest cost

	Bicarbonate	Semi-dry	Combined	Wet
Overall Lifetime Cost Ranking	4	1	3	2

Table 13: FGT Plant Lifecycle Cost Rankings

Our evaluation supports semi dry system as the most attractive process from a financial perspective. This is owed to the simplicity and efficiency of the systems.

7. DENOX SYSTEMS

Waste combustion in grate fired systems results in the production of mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) with flue gas contents of typically around 350 mg/Nm^3 with a reference condition of 11 % Oxygen O_2, dry.

Mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x) is one of the main reasons for acid rain and can also contribute to the formation of smog and ozone, which is believed to cause increased respiratory system issues, including asthma. In addition nitrogen oxide (NO_2) is toxic and reacts with other compounds to form small particles, potentially causing respiratory disease over time.

Optimisation of air injection for combustion, flue gas recirculation and other primary combustion control features can reduce mono-nitrogen oxides (nitric oxide and nitrogen dioxide) (NO_x). However, these processes alone cannot meet the IED requirement to restrict emitted NO_x levels to 200 mg/Nm³ (dry flue gas at 11% O_2). Therefore, a dedicated deNOx process is required to ensure compliance with IED regulations and fulfil plant permitting requirements. The deNOx process options are:

- Selective Non-Catalytic Reduction (SNCR)
- Selective Catalytic Reduction (SCR)

Both systems are based on the injection of either ammonia (NH_3) or urea (carbon acid diamide $(NH_2)_2CO$) in an aqueous solution.

With an SCR process ammonia water is injected as reagent into the flue gas. The water is evaporated and ammonia reacts with NO_x on a catalytically active surface which enables reaction at much lower temperatures and at lower reagent consumption rate than compared to SNCR.

General the predominant chemical main reaction for DeNOx is:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O,$$

where the nitrogen oxide (NO) content of flue gas is reduced to free nitrogen and water, two harmless by-products.

In case of urea usage the process entails an activation of urea ($CO(NH_2)_2$) followed by the neutralizing reaction:

$NH_2 + NO \text{ -> } N_2 + H_2O$

Where urea is used a side reaction generates significant amounts of nitrous oxide (N_2O). This is different from nitrogen oxide (NO) and nitrogen dioxide (NO_2) because it is a greenhouse gas and ozone depleting agent. Urea is more expensive, but is less hazardous than ammonia water. Usually, unless specific requirements apply locally, the use of ammonia water is recommended. The theoretical (stoichiometric) consumption is approximately 1.5 kg of 25 % ammonia water per kg NO_X removed.

7.1 SNCR

The SNCR process entails ammonia water injection in the upper part of the combustion chamber of the furnace where gases are at a temperature of 850 - 950 °C. These temperatures are suitable for ammonia to react with nitrogen oxide (NO) and nitrogen dioxide (NO_2). Excess ammonia is needed at this stage to ensure contact between the ammonia decomposition products and NO/NO_2. More than twice the theoretical minimum ammonia consumption is needed for 70 % NO_X reduction, depending on actual process conditions and allowed emissions. Optimisation of the process requires careful control of ammonia injection, flow rates and stable combustion control.

Depending on the level of optimisation, the process causes some un-reacted ammonia to leave the boiler with the flue gas. This is known as ammonia slip. Excess ammonia (NH_3) can deposit to the ground and adversely impact biological conditions e.g. through nitrification of soils.

In dry and semi-dry FGT-systems a certain amount of the ammonia (NH_3) slip is caught by the residue in the bag house filter. The remaining ammonia leaves the plant with the clean flue gas. A typical requirement for the maximum ammonia slip would be 5 - 10 mg/Nm³, though the slip is not indicated as a limit value in the EU-directive.

Where the FGT system includes a wet scrubber, ammonia will be absorbed in the scrubbing liquid. This is why the resulting wastewater will contain ammonium, which may be removed in an ammonia stripper to fulfil discharge requirements.

7.2 SCR

The SCR process entails ammonia injection upstream of a catalyst at a temperature of 180 - 300 °C. The reaction between nitrogen oxide (NO) and ammonia (NH_3) occurs on the catalytic surface. Most suppliers prefer a reaction temperature close to 250 °C, because higher reaction temperatures reduce unwanted and hindering condensation of salts on catalytic surfaces. The temperature requirement must be observed during the design and operation of the ERF plant.

SCR use can achieve NO_x emission levels lower than 25 mg/Nm³, and limit ammonia consumption close to the theoretically optimal ratios. Ammonia slip is usually very low, i.e. in the range of 0 - 5 mg/Nm³ depending on the NO_x emission requirement, due to even distribution of ammonia over the flue gas cross section and catalyst activity.

Ammonia consumption may be calculated from the NO_x content of the raw flue gas and the NO_x emission limits to be adhered to. The reduction of the NO_X level from 400 mg/Nm^3 to 20 mg/Nm^3 requires less than 4 kg of 25 % ammonia water per tonne of waste processed.

SCR systems are incorporated into FGT plants as either tail end or front end systems.

Tail-end SCR

The catalyst is placed after the first FGT stages with tail-end SCR systems. This requires reheating flue gas. Usually a combination of heat exchangers is used for reheating i.e. a gas/gas exchanger followed by a steam re-heater, if steam is available at the required catalyst temperature. Steam boilers with exit steam parameters of 400 °C and 40 bar yield suitable drum steam temperature for SCR-reheat to about 240 °C, as illustrated in **Figure 7**. If steam is not available, a gas or oil fired duct burner may provide the air heating required.

There are examples of SCR catalysts operated at lower temperatures (190 ºC). However, in these cases in-line regeneration is needed together with a periodically fired burner.

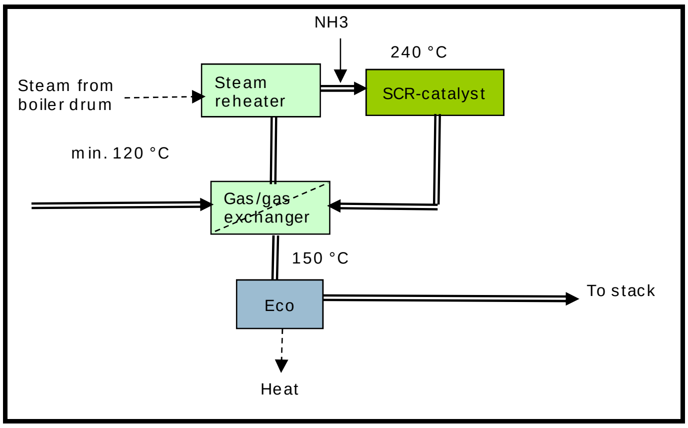

Figure 7: Typical tail-end SCR-system

Front-end SCR, boiler integrated

In pulverized coal fired plants, the SCR-catalyst is usually integrated as high dust catalysts in a boiler section where the temperature range is optimal for the process, thus evading the need for reheating. This system is rarely used in waste incinerators due to the risk of catalyst deactivation, wear and clogging.

Front-end SCR, after ESP

In these systems ammonia injection and the catalyst is placed downstream of an ESP operating at some 270 °C. The high pressure economiser of the boiler is located externally, after the catalyst. This combines the advantage of not requiring reheating with a dust free flue gas downstream of a particle filter. This does not save much investment costs compared to the tail-end SCR system. However, the ERF operation benefits from the avoidance of steam consumption for reheating flue gas.

7.3 Performance of deNOx Systems

The performance of the deNOx systems presented is evaluated below.

Three SNCR variants achieving different nitrogen oxide (NOx) emission levels are assessed; i.e. Nox emissions of 150, 120 and 100 mg/Nm^3. The use of ammonia water depends on the NOx emission levels achieved. The three variants of SNCR are compared with the two variants of the SCR. The resulting performance is summarised in **Table 14**.

In general ammonia water consumption of the catalytic process (SCR) is close to the theoretical optimum, whereas the SNCR consumes significantly higher amounts of ammonia water. SNCR system ammonia consumption increases from SNCR 150 to SNCR 120 and to SNCR 100. Higher ammonia consumption achieves lower NOx emission levels in the SNCR systems. The SCR process removes the most amount of NOx.

Ramboll's experience of the optimal operational range is provided in **Table 14** below for each system.

The process values shown in **Table 14** will also depend on the detail of the chosen process and on the capabilities of the supplier to optimise the process (es).

Consumption, emission	Unit	SNCR 150	SNCR 120	SNCR 100	Tail-End-SCR	Front-End-SCR
NO_x in raw gas without $deNO_x$ **	mg/Nm³ *	400	400	400	400	400
NO_x-emission, expected	mg/Nm³ *	150	120	100	20	20
NO_x Removed	tonnes/year	490	550	580	740	740
Optimal operating range of NO_x-emission	mg/Nm³ *	80-160	80-160	80-160	10-70	10-70

Table 14: DeNOx, Indicative ammonia consumption and NOx-reduction (350 ktpa line)

*) dry flue gas at 11% O2
**) for evaluation purposes the calculation is executed with the conservative figure of 400 mg/Nm^3 NO_x in raw gas instead of 350 mg/Nm^3

Emission level 150 mg/Nm^3

If the permitted emission levels are in the range of 150 mg/Nm^3 SNCR 150 would be the preferred option.

Emission level 100 mg/Nm^3

If the anticipated and permitted emission levels are in the range of 100 mg/Nm^3 SNCR 100 would be the preferred option. However, in the range of 100 mg/Nm^3 and below the quantity of bidders, who are willing to guarantee emissions limits with SNCR technology are limited. Although technical installations are very similar, the capital investment costs will increase with decreasing emission levels from 150 to 100 mg/Nm^3.

Emission level 20 mg/Nm^3

At low emission levels the amount of NOx captured by the catalytic processes exceeds the capability of the SNCR. In this case the SCR would be the preferred option. The amount of NOx removed is considerably higher and it has to be underlined that the NOx footprint is lowered significantly in this case. This somewhat mitigates higher capital cost requirements.

7.4 Cost of DeNOx Systems

7.4.1 Operational Costs

Operational costs for deNOx technologies include consumables, staffing and maintenance. The following are Ramboll's cost rankings for deNOx systems. The cost estimates, considering both operational and capital cost estimates, conclude the SNCR 150 option as the most beneficial from a cost perspective. In general the SNCR process is much more attractive than the SCR perspective from a total cost perspective.

Note: 1 equates to lowest cost and 4 equates to highest cost

Cost	SNCR 150	SNCR 120	SNCR 100	SCR after semi-dry	Front-end SCR
Operating Cost Ranking	2	3	5	4	1
Overall Lifetime Cost Ranking	1	2	3	5	4
Capital Cost Ranking	1	2	3	4	5

Table 15: deNOx System Capital and Operational Cost Rankings

The SCR process captures much more NOx than the SNCR process. Therefore, the SCR process is more cost efficient if evaluated from a perspective of cost per kg of NOx captured. The SCR process is likely to compare favourably from a financial perspective where NOx taxes are in place i.e. Scandinavia.

7.5 Conclusions of deNOx System Considerations

SCR deNOx systems achieve far lower levels of nitrogen oxide (NOx) emissions than SNCR systems. SCR systems also consume less ammonia than SNCR systems.

The costs of deNOx by SCR are higher than SNCR systems due to higher capital requirements. This is to an extent due to the fact that SNCR systems are incorporated into boiler plant and limited additional plant footprint is required. SCR systems require the installation of a separate plant. Front-end SCR systems are susceptible to wear and tear, clogging and deactivation and are rarely used in newer plants. Tail-end-SCR systems have higher operating costs due to heating requirements.

SNCR was often the preferred deNOx technology due to its cost benefit advantages and the fact that the system enables compliance with current IED emission limit requirements.

However, more stringent NO_x emission limits i.e. 100 mg/Nm^3 or lower requirements may be set in the coming years. Local requirements with respect to NOx acceptance and the NOx footprint in the region may also be a decisive factor in the choice of technology. Furthermore the expected NO_x concentration may be decisive for the determination of the stack height. If a 100 m stack allows for 100 mg/Nm^3 of emissions, a lower height may be allowed at lower NO_x concentrations.

Furthermore, some countries could follow Scandinavian countries and also introduce NO_x taxation. Therefore, modern plant designs using SNCR systems often make space allowance for the future replacement with a SCR system to meet more stringent NO_x emission requirements, should they come into force.

8. ENERGY RECOVERY

8.1 General

Energy recovery characteristics are based on the different requirements of the FGT concepts. This provides the variety of opportunities outlined below.

8.2 Economiser Use

The use of economisers in connection with flue gas treatment plants is frequently an opportunity to increase the overall energy efficiency of the plant. The economiser is a heat exchanger located in the flue gas path, and it transfers heat from the hot flue gas to a suitable heat carrier, typically water. The heated water is used to improve overall energy efficiency e.g. by pre-heating combustion air. The description below is based on the conditions prevailing in a dry lime FGT process. However, the technical principles can be adapted to any type of FGT system.

The energy content of the flue gas specified in **Table 4** is circa 70 kW/°C. This represents the potential energy recovery in an economiser located somewhere in the flue gas train.

In a bicarbonate system the flue gas energy content may be recovered in an economiser located downstream of the bag house filter operated around 180 ºC. The economiser may be part of the high pressure system, thereby increasing the total steam output of the boiler, thus the power produced by the plant.

Cooling flue gas as an example by a further 20 °C, has to potential to yield an additional 1.5 MWth steam that would correspond to some 0.45 MWe of power production.

It is possible to recover further energy from the flue gas by use of a corrosion protected economiser operating with its own water circuit at a relatively low pressure and temperature. The economiser can provide heat for condensate pre-heating, air pre-heating or similar low-temperature applications. Such heat would replace steam extraction from the turbine and represent additional power production. Cooling of flue gas by 40 °C would increase power production by some 0.3 - 0.45 MWe as an estimate, thus yielding significant returns over the project lifetime.

Savings in water consumption for cooling will be achieved in the wet and combined semi-dry and wet systems when the flue gas is cooled in an economiser upstream of the wet scrubber.

8.3 Position of the ID-Fan

A fan is applied to produce a draught and to transport the flue gas from the combustion chamber through the boiler, the flue gas cleaning plant and finally to the stack. The fan also ensures negative pressure in the furnace and flue gas path to prevent smoke escaping into the boiler hall. This induced draught fan or “ID-fan” is the central equipment of the ERF. The ID-fan can be located upstream or downstream of the economisers (“hot” or “cold” position). When located in “cold” position at temperatures of approximately 80 °C the actual volume of the flue gas decreases, thus the ID-fan power consumption can be somewhat reduced. However, there is a need to consider protecting the ID-fan against corrosion e.g. by application of acid-proof steel.

8.4 Flue Gas Condensation

Flue gas condensation is primarily aimed at the recovery of latent energy contained in wet flue gases and secondly condensation may serve as a source of process water for the plant or other applications. Furthermore, the reduction of flue gas humidity tends to reduce the plume visibility to a degree, depending on actual weather conditions and flue gas exhaust temperature.

Flue gases from waste combustions typically contain a relatively high content of water vapour. When cooling the flue gas to temperatures below the water dew point, a part of the water vapour content condenses, releasing heat. The water leaves the system as condensate as the flue gas is dehumidified. Heat recovered can then be transferred by heat exchangers to a consumer e.g. a district heating network, air preheaters, a heat pump or another system. Basic principles of how flue gas condensation can be integrated into flue gas cleaning system, and how the produced condensate can be used at the facility are provided below.

Condensation may take place directly in a separate scrubber where circulating water is cooled in a heat exchanger. The condensate leaving the system should be as clean as possible. Therefore, it is recommended that any flue gas condensation step is introduced downstream of the primary cleaning steps, where dust, hydrogen chloride (HCl) and sulfur dioxide (SO_2) is removed.

The condenser system can be integrated into a wet scrubber system, as depicted below, or it can be established as a stand-alone unit.

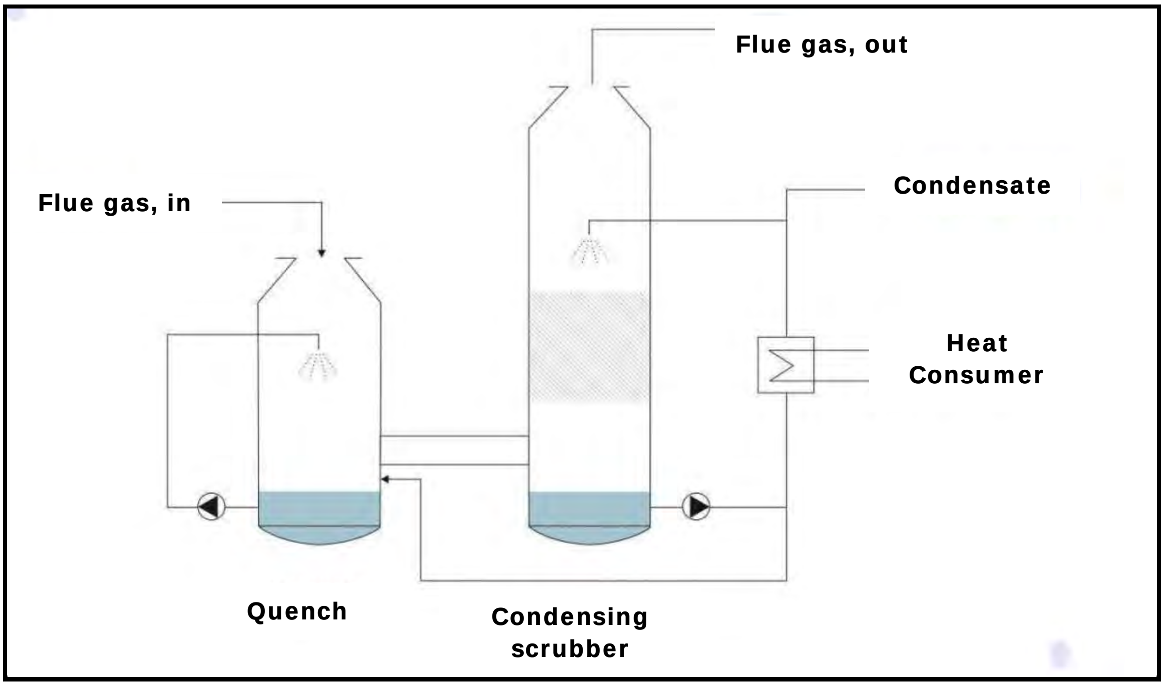

Figure 8: Flue gas condensation principle

Flue gas condensation may be carried out either in a scrubber, or by a heat exchanger. The former is considered to be the most reliable solution.

The principles in a condensing scrubber are as follows:

1. If not already saturated, flue gas is cooled down to dew point by injecting water into the quench
2. The gas is passed through the scrubber cooled by a heat exchanger on the recirculating scrubber liquid
3. The heated scrubber water is pumped through a heat exchanger and recirculated
4. Condensed water is removed from the scrubber circuit and is used as process water or discharged as wastewater
5. Cooled flue gas is passed to the stack

Flue gas condensation will produce approximately 1.0 MWth of heat for each 1.5 t/h of condensate recovered. Waste with a low net calorific value, burnt upstream (in the furnace), yields a high amount of energy recovery downstream (in the condenser).

In semi-dry and wet processes water is injected into the FGT process. Flue gas condensation facilitates the recovery of this water and the energy carried.

Flue gas temperature reduction reduces the actual flue gas flow. This reduces the power of the ID-fan, thus resulting in savings.

A disadvantage of cooled saturated flue gases is an increased droplet precipitation and plume visibility. This can be overcome by reheating or other counter-measures. However, these impact the net efficiency gains of flue gas condensation.

Flue gas condensation is sensitive to the external cooling temperatures. In Ramboll's experience flue gas condensation is rarely an option in the absence of a district heating network with suitable low return temperatures.

9. PLUME VISIBILITY

Plume formation is primarily the result of water vapour condensation when exhaust gas and ambient air mixes. Particles from the FGT plant processes i.e. the formation of salts or other sources only have a minor influence on the visibility of the exhaust gas leaving the stack and can be neglected. Possible water droplets carried through mist eliminators after wet scrubbers can cause droplet fall-out in a limited area around the stack, if the droplet separators are not properly designed. The risk of droplet fall-out can be eliminated, significantly or completely, if the exhaust gas is preheated before being released into atmosphere.

FGT plants using wet scrubbers or condensers are saturated with water (100% humidity). Therefore, unless reheating or dehumidification is applied there will be visible plumes in almost all weather conditions.

The temperature of flue gas derived from a dry or a semi dry FGT-system is significantly higher than flue gas from the wet systems and it is above the corresponding water dew point. As a result there is much reduced plume visibility with dry and semi dry FGT systems, compared to wet systems without flue gas reheating.

10. ASSESSMENT OF FGT SYSTEMS FOR DECISION MAKING

10.1 Flue Gas Treatment Plant

The assessment for decision making set out below is based on Ramboll's experience from feasibilities studies, other projects, development activities and operational plants.

Table 16 presents positive, neutral and negative aspects of the FGT systems against the evaluation criteria set out in this document. No single flue gas treatment concept is advantageous under all the evaluation criteria considered. Therefore, the evaluation criteria needs to be weighed against the specifics of the project, according to the individual priorities and needs of the operator/owner.

Evaluation criteria:	Dry	Bicarbonate	Semi-dry	Combined	Wet
Operational availability					
- **Performance history of reliable operation**	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
Capability					
- **Ability to handle changes in raw gas composition**	✓	✓✓	✓✓	✓✓✓	✓✓✓
Flexibility					
- **Ability to meet more stringent future emission limit**	✓	✓	✓✓	✓✓✓	✓✓✓
Health and safety					
- **Reduced contact with hazardous material**	✓✓	✓✓✓	✓✓	✓✓	✓✓
Sensitivity to local conditions					
- **Limited of plume visibility**	✓✓✓	✓✓✓	✓✓✓	✓	✓
- **Discharge of treated wastewater**	N/A	N/A	N/A	N/A	✓
Other environmental issues					
- **Low chemical consumption**	✓	✓✓✓	✓✓	✓✓✓	✓✓✓
- **Low electricity consumption**	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
- **Low residue production**	✓	✓✓✓	✓✓	✓✓✓	✓✓✓

Table 16: Assessment of base concepts for dry, semi-dry, combined and wet FGT technology

'✓✓✓'= attractive feature, '✓✓'= improved feature, '✓'= acceptable feature

Note: All base concepts are with SNCR for deNOx and without flue gas condensation.

When the key assessment criteria are considered, the following conclusions are drawn:

Most attractive concept

The semi-dry FGT system is recommended as being potentially the most attractive option for NLWA. This is due to:

- The system is optimal for ERFs processing MSW where waste pollutant content will not vary notably in future years;
- There is no production of wastewater requiring specialist treatment and discharge;
- Flue gas condensation is not envisaged to be beneficial for NLWA due to the absence of adequately low cold water return temperatures from a potential district heating network;[3]
- There are relatively simple operational requirements; and
- There is a relatively low capital investment requirement.

A dry bicarbonate based system is considered to be a potential alternative subject to improved availability of reagent and the recycling of the residue thereafter.

Alternatives:

Bicarbonate FGT is an option for NLWA due to:

- Similar investment costs to semi-dry systems
- Non-hazardous nature of the reagent
- Low costs of operation due to relatively simple injection system

However, on the downside;

- Higher cost for reagent and residue disposal

Combined dry-wet FGT is also an option for NLWA due to:

- Improved pollutant removal efficiency
- Lower operational costs due to reduced chemical consumption and residue production.

However, on the down side;

- Higher investment costs as well as higher operational costs due to additional power and additional maintenance.

Wet scrubbing systems are of interest where:

- Wastewater discharge is an option
- The waste pollutant load is high
- There are highly stringent emission requirements and exceptional environmental ambitions
- Low consumption of consumables and/or low residue generation are key factors

The drawbacks of the wet scrubbing system are

- Increased technical complexity
- Wastewater treatment is necessary
- Discharge of treated wastewater (containing salts and trace components) requires approval by the local authorities
- Increased plume visibility and
- Higher capital investment requirements.

[3] It is believed, that the main option for heat supply (outside the FGT system) is the use of medium or low pressure steam extraction from a suitable turbine.

10.2 DeNOx System

The assessment set out below is based on Ramboll's experience from feasibilities studies, other projects, development activities and operational plants.

Table 17 presents positive, neutral and negative aspects of the deNOx systems against the evaluation criteria set out in this document. No single deNOx treatment concept is advantageous under all the evaluation criteria considered. Therefore, the evaluation criteria in the future needs to be weighed against the specifics of the project, according to the individual priorities and needs of the operator / owner.

	SNCR 150	SNCR 100	SCR 20
BAT (current)	✓	✓✓	✓✓✓
References	✓✓	✓	✓✓
NOx-Emissions	✓	✓✓	✓✓✓
Resilience (Pollutant abatement efficiency)	✓	✓✓	✓✓✓
Dispersion / Stack height	✓	✓	✓✓✓
Local Environment	✓	✓	✓✓✓
Consumables	✓✓	✓	✓✓✓
CAPEX	✓✓✓	✓✓	✓
NPV	✓✓✓	✓✓	✓
Risk	Emission and dispersion requirements	Stringent emission requirements and supplier capability	

Table 17: Assessment of concepts for DeNOx systems

'✓✓✓'= attractive feature, '✓'= neutral feature, '✓-'= existing but less attractive feature

'Advanced' SNCR systems can achieve NOx emission guarantees of around 100 mg /Nm³. This corresponds to 50% of the current daily average emission limit set in the IED. However, space should be provided with such systems for future SCR installation to achieve lower emission limits. This is despite the wide belief that more stringent emission requirements for NOx levels well below 100 mg/Nm³ are unlikely to be implemented by European authorities as doing so will have significant impacts on operational plants.

The Edmonton region is recognised as a high NOx region. SCR systems can reduce NOx emissions to 25 mg NOx/Nm³ or lower.

NLWA's air quality modelling should consider the emission limits that can be achieved with SNCR (to a level of 100 mg/Nm³) and SCR systems to facilitate an informed consultation and decision on the deNOX system choice.

It is assumed that no NO_x taxation in the UK will be imposed in the near future, based on a professional judgement of regulatory means traditionally imposed to control environmental impacts in the UK. However, NO_x taxation has been introduced for ERFs in Scandinavia and may be implemented in the UK. The introduction of such taxation will further enhance the case for a more efficient NOx reduction system.

10.3 Energy Recovery

Flue gas condensation is only relevant for NLWA's new ERF at Edmonton under certain circumstances. This is mainly due to the need for a suitable district heating system to be in place and the need for acceptance of increased plume visibility.

The use of economisers provides possibilities for further energy recovery without flue gas condensation. This is especially the case when economisers are integrated into the pressure part of the boiler as external economisers. This will somewhat reduce flue gas temperature to the stack and will increase plume visibility.

11. GLOSSARY

BAT	Best Available Techniques
BATOEL	BAT Operational Emission Levels
BREF	Best Available Technology Reference Documents
$CaCl_2$	Calcium Chloride
CaF_2	Calcium Fluoride
$Ca(OH)_2$	Hydrated Lime
$CaSO_3$	Calcium Sulphite
$CaSO_4$	Gypsum
Catalyst	Term used in chemical reaction engineering. The catalyst facilitates an increased rate of reaction, usually by reducing the reaction temperature requirements.
Cl	Chlorine
Chloride	Ion of the Chlorine and present in salts or in a solution
CH_4	Methane
C&I	Commercial and Industrial
CO	Carbon Monoxide
EU	European Union
ERF	Energy Recovery Facility
ESP	Electrostatic Precipitator
F	Fluorine
Fluoride	An ion of Fluorine and present in salts or in a solution
FGT	Flue Gas Treatment
HCl	Hydrogen Chloride
H_2O	Water
HF	Hydrogen Fluoride
Hg	Mercury
IED	European Union Directive 2010/75/EU on Industrial Emissions
ID-Fan	Induced Draft Fan
IPPC	Integrated Pollution Prevention and Control
LACW	Local Authority Collected Waste
Lime	Common for hydrated lime, $Ca(OH)_2$, or burnt lime, CaO
mg/Nm^3	Milligram per Normal Meter Cubed
MSW	Municipal Solid Waste
MWe	Mega Watt Electric
MWh	Mega Watt Hour
MWth	Mega Watt Thermal
N_2	Nitrogen Gas
$(NH_2)_2CO$	Urea or Carbon Acid Diamide
ng/Nm^3	Nanogram per Normal Meter Cubed (i.e.10^{-9} g/Nm^3)
NH_3	Ammonia
Nm^3	Normal Meter Cubed, i.e. cubic meters of a gas recalculated to the standard temperature and pressure, 0 °C and the standard atmospheric pressure of 101,325 Pa.
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	mono-nitrogen oxides (nitric oxide and nitrogen dioxide)
NLWA	The North London Waste Authority
PAH´s	Polycyclic Aromatic Hydrocarbons
S	Sulfur
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur Dioxide
Sulphide	Sulfur containing ion in solution or in salts, SO_3^{2-}
Sulphate	Sulfur containing ion in solution or in salts, SO_4^{2-}
SRF	Solid Recovered Fuel
t/h	Tonnes Per Hour
TOC	Total Organic Carbon

Appendix E: Cooling plant technology options

E1 OBC technical options appraisal by AEA

E1.1 Introduction

E1.1.1 The most significant initial conclusion is that the scenarios that employ larger amounts of combustion appear to have better overall performance. This is primarily due to:

a. the reduced landfilling of waste under EfW scenarios; and

b. the reduced cost of only handling waste only once through an EfW process, rather than the multiple stages seen with MBT scenarios (i.e. MBT involves the pre-treatment of the residual waste to produce SRF and then subsequent combustion of the materials produced).

E1.2 Assessment of technologies - by AEA

E1.2.1 The table below presents the technologies assessed in this screening process including the judgement for passing/failing a technology option. The colour coding indicates where technology options fail the screening process or where they pass but with a proposed limitation added.

Technology option fails the criteria	Technology option passes the criteria but there are significant concerns and/or risks identified

Treatment/ disposal technology	**Pass/ fail**	**Status of technology**	**Strategy compliance**	**Markets**
Landfill	Fail	Landfill has been used for many years and is accepted as a well proven disposal method worldwide.	Option is not compliant with NLWA Waste Strategy or the Mayor's Strategy. It does not meet the NLWA strategy objectives, e.g. to ensure that NLWA deals with its waste with reference to the waste hierarchy and to take account of the proximity principle. The Strategy aims specifically to maximise recycling and composting and to reduce greenhouse gases by landfilling less organic waste.	No markets required as all residual waste is being landfilled.
Thermal treatment technologies				
EfW (traditional mass burn and fluidised bed)	Pass (but limited to current EfW permitted/design capacity)	EfW facilities are well established with some 800 operational facilities worldwide. There are variants such as moving grates, kiln and fluidised beds but these are details relevant to the wastes processed and suppliers. Most suppliers have multiple references for each of the technology options they supply. The number of suppliers of EfW solutions have been reducing due to mergers in the market but the	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is also followed with a treatment facility within NLWA geographical area. The Mayor's Strategy emphasises that there is no need for additional EfW capacity and that new waste treatment methods (MBT and	The main product from the process will be electricity, which is a relatively secure market. The IBA is also a product that can be further processed to be recycled as aggregate material. However, this has some market risks albeit loss of this market is unlikely to be critical to the project, as it does not influence the BMW diversion provided.

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		basic supply capacity is significant and any of the major potential bidders would be able to provide bankable solutions from one of several EfW suppliers. EfW technology is seen in most countries as the normal treatment option for residual MSW.	other new and emerging advanced conversion technologies) are in preference to any increase in conventional incineration capacity.	Heat may also be selected as a main product from EfW. Whilst the technology for EfW CHP can be provided by a number of reputable suppliers the main limitation is based on the availability of the market for the heat and thus the availability of appropriate sites limits the competition aspects.
Gasification/Pyrolysis (incl. basic pre-treatment)	Pass (but limited in scale to approx 250 kpta)	Gasification and pyrolysis technologies have been on the cusp of being deliverable in Europe for the past 15 years but appear not to have moved from this position to full commercial delivery. There are exceptions where MSW fired plants do operate but these have limited track record at the scales required for NLWA. Other systems have been operating on biomass feedstocks but the issue of MSW feedstocks have yet to be fully addressed. There have been notable failures with large facilities such as the Thermoselect process, Siemens etc. Other systems are marketed but not considered fully commercial for MSW.	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is also followed with a treatment facility within NLWA geographical area. Also in compliance with Mayor's strategy and preference for new technologies. May face difficulties in demonstrating prudence and best value as a local authority investment.	The main product from the process will be electricity, which is a relatively secure market. The IBA is also a product that might be further processed to be recycled as aggregate material but this has some market risks due to the lack of experience in the recycling market of gasifier ashes. Some newer processes propose novel products such as fuel gases or chemicals but these are from less deliverable system given current funding structures. Heat may also be selected as a main product from EfW. Whilst the technology for CHP can be provided by a number of reputable suppliers the main limitation is based on the availability of the market for

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		Overall the risk of this technology is thus considered relatively high. The only solutions that have some track record will be limited to one or possibly two suppliers. This does not promise to give a value for money competitive process.		the heat and thus the availability of appropriate sites limits the competition aspects.
Other residual treatment technologies				
Basic MBT with stabilised material to landfill (no other MBT product outputs)	Fail	The biostabilisation of waste through a composting process has many facilities in Europe where the technology can be seen to operate successfully. However in the UK with the particular structural arrangements of landfill prices, LATS pressures etc has not seen these techniques flourish and whilst there are facilities under consideration for short term LATS delivery, reference facilities under UK conditions are sparse. From a technical perspective the performance of landfills accepting these wastes has not had sufficient time to determine if the long term landfill gas emissions are	This option is not compliant with NLWA Waste Strategy or the Mayor's Strategy. It does not meet the NLWA strategy objectives, e.g. to ensure that NLWA deals with its waste with reference to the waste hierarchy and to take account of the proximity principle. The Strategy aims specifically to maximise recycling and composting and to reduce greenhouse gases by landfilling less organic waste.	There are limited recycling products generated by the MBT process, because the aim of this basic MBT is predominately to stabilise the waste material with shredding carried out prior to the composting process and limited pre-sorting. The bulk of the residue is landfilled.

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		reduced by stabilisation or if the short term (<10-15 years) gas generation is reduced whilst not affecting the long term gas generation potential. Impacts on long term leachate composition are also unknown.		
MBT with AD (no SRF generated)	Fail	AD of mixed waste is performed in a number of plants across Europe and a small number in the UK. There are many suppliers but each generally having only one or two reference facilities and thus there is limited track record from any one supplier.	Generally compliant with Strategy as it ensures increasing recycling, composting and energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is only partially complied with since most product/output will be expected to be exported out of the NLWA geographical area. In compliance with Mayor's strategy and preference of new technologies.	The projects are based on the markets for the recyclables and digestates that have significant market issues in terms of product quality and regulatory uncertainty. The biogas product will generate energy that will have a relatively secure electricity market and receive ROCS.
MBT with IVC (no SRF generated)	Fail	There are a number of MBT suppliers producing a compost-like output (CLO) to be used on soil, landfill cover or landfilled as stabilised material, e.g. Horstmann,	Generally compliant with Strategy as it ensures increasing recycling and composting of waste and reducing landfilling of organic waste.	The MBT systems rely on the market for recyclates and compost-like material (CLO). Use as a soil improver on agriculture land requires high level of maturation and few

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		Biodegma, VKW. These technologies are deliverable and provide biodegradation. However these require substantial land area, which may be questionable in the London context of available sites.	Proximity principle is only partially complied with since most product/output will be expected to be exported out of the NLWA geographical area. Also in compliance with Mayor's strategy and preference of new technologies.	contaminants, but there has been significant issues associated with using MBT derived composts in such applications.
MBT biodrying with SRF	Pass (up to 500ktpa)	The biodrying approach is growing in popularity in some countries e.g. Italy and Germany where a small number of suppliers have delivered reasonable numbers of facilities. It should be noted that two of the principle suppliers Horstmann and Herhof have had financial difficulties and ceased trading although in neither case has the technology failing been at the heart of the companies difficulties and is rather a commercial issue reflecting poor management rather than poor technology. In both cases the technology is expected to be available through alternative suppliers once the administrative issues are	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is complied with if SRF is treated within NLWA geographical area. Also in compliance with Mayor's strategy and preference of new technologies.	This Option is dependent on marketing recyclables as well as the SRF. The current market for SRF is still developing and thus places considerable uncertainty on the project in terms of BMW diversion if the SRF has to be landfilled. Linking of a dedicated combustion facility effectively removes this constraint.

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		addressed and the technology rights sold on or transferred. The number of reference facilities is extensive. Ecodeco is probably the dominant supplier having 11 facilities ranging from 40ktpa up to 180 ktpa with the earliest facility starting in 1996. Herhof as a technology have 6 or 7 reference facilities of which the earliest started operation in 1997. However, data on the current status of these plants is difficult to establish due to the status of the German company, but it is clear that these facilities operated until the closure of the company. Nehlsen has only one facility and has linked it current operations to other Biodegma plants operated by the same company. Horstmann has 16 facilities operational dating back to 1997 although these also include facilities with composting processes. This demonstrates that whilst there are some commercial issues with these companies as they try to expand and overstretch their resources, the technology appears to have track record spanning over 10 years for the key		

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		suppliers. This provides some confidence that the uncertainties and therefore risks are relatively low.		
MBT mixed with AD and SRF	Pass (although should be limited in capacity, e.g. 250 to 300ktpa and limited in how much of compost can be beneficially used)	Similar to above as many of the current providers also offer a mixed approach and a number of the reference facilities separate SRF for combustion and organic material for AD. However, few plant exceed 200 ktpa in size and thus experience and land space issues will constrain this technology and thus facilities should be limited to the available reference capacities.	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is complied with if SRF is treated within NLWA geographical area. Also in compliance with Mayor's strategy and preference of new technologies.	This Option is dependent on marketing recyclables as well as the SRF. The current market for SRF is still developing and thus places considerable uncertainty on the project in terms of BMW diversion if the SRF has to be landfilled. The biogas product will generate energy that will have a relatively secure electricity market. There are issues around marketing of digestates in terms of product quality and regulatory uncertainty. However, the mixed approach of separating out some SRF and generating a digestate (either for beneficial use or landfilled as stabilised material) ensures that there is a balance of risks for the different product materials.
MBT mixed with IVC and SRF	Pass (Organic material composted would be landfilled as	Similar to above as many of the current provider also offer a mixed approach and a number of the reference	Generally compliant with Strategy as it ensures energy recovery from residual waste	This Option is dependent on marketing recyclables as well as the SRF. The current market for SRF is still

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	stabilised material. Limited in capacity, e.g. 250 to 300ktpa and limited in how much of compost can be beneficially used)	facilities separate SRF for combustion and organic material to IVC. However, the mixed approach would relief the pressure on the provider in terms of generating a CLO for beneficial use.	and reducing landfilling of organic waste. Proximity principle is partially complied with if SRF is treated within NLWA geographical area. Also in compliance with Mayor's strategy and preference of new technologies.	developing and thus places considerable uncertainty on the project in terms of BMW diversion if the SRF has to be landfilled. Use of CLO as a soil improver on agriculture land requires high level of maturation, but there has been significant issues associated with using MBT derived composts in such application. However, the mixed approach of separating out some SRF and generating a compost (either for beneficial use or landfilled as stabilised material) ensures that there is a balance of risks for the different product materials.
MHT/Autoclave with SRF	Fail	There are a number of suppliers in the UK market with the primary suppliers, Thermesave, Sterecycle, Estech Europe and Orchid (Fairport) and some newer entrants such as Comex and Prestige. The technology of autoclave processing does have a long history with autoclaves being used for clinical wastes for many years. However, there does not appear to be a track record	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is complied with if SRF is treated within NLWA geographical area Also in compliance with Mayor's strategy and	This Option is dependent on marketing recyclables as well as the SRF/fibre. The current market for SRF is still developing and thus places considerable uncertainty on the project in terms of BMW diversion if the SRF/fibre has to be landfilled. Linking of a dedicated combustion facility effectively removes this constraint.

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		processing residual MSW at commercial scales for any significant time.	preference of new technologies.	
Gas plasma	Fail	This is a new technology, which does not have commercial development above 100ktpa capacity that is operated for any significant period. However, this is a new technology and developments may be made, hence improvements should be monitored.	Generally compliant with Strategy as it ensures energy recovery from residual waste and reducing landfilling of organic waste. Proximity principle is also followed with a treatment facility within NLWA geographical area. Also in compliance with Mayor's strategy and preference of new technologies.	Power generated will have stable markets as electricity as with other technologies, although the internal power consumption will reduce the net energy exported. The ash material is vitrified and therefore very stable and may have therefore better application as construction material compared to standard IBA. Markets for such technologies and their outputs have existed in Japan for some years, but not in Europe, even in Netherlands where over 90% of EfW ash is re-used and there are significant groundwater risks. This leads to a conclusion that, in the foreseeable future the basic framework is unlikely to exist in the UK for development of such a market.

Appendix F: Technology longlist (OBC)

Treatment / Disposal Technology
Landfill
Thermal treatment technologies
EfW
Gasification/Pyrolysis
Other residual treatment technologies
Basic MBT with stabilised material to landfill
MBT with AD (no SRF generated)
MBT with IVC (no SRF generated)
MBT biodrying with SRF
MBT mixed with AD and SRF
MBT mixed with IVC and SRF
MHT/Autoclave with SRF

Series 05 Technical Documents

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