

Site Name: Energy From Waste Facility		Proposed Site Location: Honeycomb Drive, Eastern Creek, NSW	Project No: 60442781
Plate No. 13	Date: 28/09/2015		
Direction Photo Taken: Location 7 – North-east			
Description: Land south-west of the proposed EFW Facility – grazing land.			

Site Name: Energy From Waste Facility		Proposed Site Location: Honeycomb Drive, Eastern Creek, NSW	Project No: 60442781
Plate No. 14	Date: 28/09/2015		
Direction Photo Taken: Location 7 – East			
Description: Land south-west of the proposed EFW Facility – grazing land.			

Two thin black lines intersect diagonally on the left side of the page. One line slopes upwards from left to right, and the other slopes downwards from left to right.

Appendix I

Memorandums

MEMORANDUM

To:	Damon Roddis	Organisation:	Pacific Environment
cc:	Skye Playfair Redman	Organisation:	Urbis
From:	Rosalind Flavell	Our Ref:	S1624-0010-0163RSF
Date:	29 January 2015	No. of Pages:	5
Subject:	Advice To Address EPA Comments		

Damon,

Please find enclosed a detailed description of how we would propose to assess the impact of the facility operating during periods of upset, start up and shut down. In addition we have provided some advice on likely emissions of ammonia.

1 PERIODS OF UPSET OPERATING CONDITIONS

1.1 Definition

Article 46(6) of the Industrial Emissions Directive (IED) (Directive 2010/75/EU) states that:

"... the waste incineration plant ... shall under no circumstances continue to incinerate waste for a period of more than 4 hours uninterrupted where emission limit values are exceeded.

The cumulative duration or operation in such conditions over 1 year shall not exceed 60 hours."

Article 47 continues with:

"In the case of a breakdown, the operator shall reduce or close down operations as soon as practicable until normal operations can be restored."

In addition Annex VI, Part 3, 2 states the emission limit values applicable in the circumstances described in Article 46(6) and Article 47:

"The total dust concentration in the emissions into the air of a waste incineration plant shall under no circumstances exceed 150 mg/Nm³ expressed as a half-hourly average. The air emission limit values for TOC and CO set out in points 1.2 and 1.5(b) shall not be exceeded."

The conditions detailed in Article 46(6) are considered to be "Upset Operating Conditions".

1.2 Reasons for occurrence

Upset operating conditions such as those defined may occur as a result of the following:

- reduced efficiency of the Selective Non-Catalytic Reduction (SNCR) system as a result of blockages or failure of the reagent injection system, leading to elevated oxides of nitrogen emissions;
- reduced efficiency of particulate filtration system due to bag failure and inadequate isolation, leading to elevated particulate emissions and metals in the particulate phase;
- reduced efficiency of lime injection system such as through blockages or failure of fans leading to elevated acid gas emissions;

- complete failure of the lime injection system leading to unabated emissions of hydrogen chloride. (Note: this would require the plant to have complete failure of the bag filter system. As a plant of modern design, the plant would have shut down before reaching these operating conditions); or
- complete failure of the activated carbon injection system and loss of temperature control leading to elevated concentrations of metals and dioxin reformation and their unabated release.

1.3 Likely emission concentrations

There is no monitoring data available from existing facilities during 'upset operations'. In the absence of monitoring data plausible worst-case assumptions are used based on consultation with the UK Environment Agency based on their knowledge of plausible upset emissions. It will be worth consulting with HZI to ensure that they agree with the predicted NO_x emissions under upset operating conditions.

No data on flow characteristics (flow rate, temperature etc) during these upset operating conditions is available and there is no reason to expect these parameters to change, so for the purposes of any assessment the design flow characteristics are applied.

Table 1: Emission Concentrations

Pollutant	Permitted Emission (mg/Nm ³ unless stated)		Plausible Upset Emission (mg/Nm ³ unless stated)	% Above Max Permitted Emission
	Daily Average	½ hourly max		
Oxides of nitrogen	200	400	550 ⁽¹⁾	38
Particulate matter (PM _{10S})	10	30	150 ⁽²⁾	400
Sulphur dioxide	50	200	450	125
Hydrogen chloride	10	60	900 ⁽³⁾	1,400
Hydrogen fluoride	1	4	90 ⁽⁴⁾	2,150
TOC (VOCs)	10	20	20 ⁽²⁾	0
CO	50	100	100 ⁽²⁾	0
Dioxins	0.1 ng/Nm ³		10 ng/Nm ³ ⁽⁴⁾	9,900
Group 1 Metals - Mercury	0.05		0.75	1400
Group 2 Metals - Cadmium etc	0.05		0.75	1400

Reference conditions for all emissions dry, 11% oxygen, 283K.

(1) To be confirmed with HZI.

(2) Taken from the Annex VI Part 3 of the IED.

(3) Based on information presented in an Environment Agency document.

(4) As requested by the Environment Agency.

It is assumed that all metals are in the particulate phase, therefore metal emissions during predicted upset operation will increase in proportion to the increase in particulate emissions. Reference monitoring methods for metals require periodic monitoring with emission concentrations expressed as an average over a sampling period of up to 8 hours. For the purpose of any assessment the ratio applied to the daily limit for particulates should be applied to the metals emissions. As such the predicted plausible upset emissions for each group of metals (Groups 1 and 2) should be calculated as 15 times the predicted emission concentration.

1.3.1 Plausible upset emissions of group 3 metals

For the purposes of assessing upset operating conditions a number of assumptions are usually made with regard to the plausible upset emissions of the group 3 metals.

- (1) The group 3 metals which have a short or long term EAL are considered (antimony, arsenic, chromium, copper, lead, manganese, nickel, vanadium).
- (2) The permitted emission concentrations for each group 3 metal is taken as the maximum monitored from "Environment Agency Guidance to Applicants on Metals Impact Assessment for Stack Emissions (September 2012, Version 3)".
- (3) The permitted emission concentration of chromium (VI) is based on the ratio of the effective chromium (VI) emission concentration to total metal emissions, as presented in the "Environment Agency Guidance to Applicants on Metals Impact Assessment for Stack Emissions (September 2012, Version 3)".
- (4) It is assumed that metals are in the particulate phase, therefore metal emissions during predicted upset operation will increase in proportion to the increase in particulate emissions. Reference monitoring methods for metals require periodic monitoring with emission concentrations expressed as an average over a sampling period of up to 8 hours. For the purpose of any assessment the ratio applied to the daily limit for particulates is applied to the group 3 metals. As such the predicted plausible upset emission for each group 3 metal is calculated as 15 times the predicted emission concentration.

The plausible upset emissions concentrations are presented in Table 2 for group 3 metals.

Table 2: Predicted Group 3 Metal Emission Concentrations

Pollutant	Permitted Emission based on Max Monitored Emission Concentrations ($\mu\text{g}/\text{Nm}^3$)	Predicted Plausible Upset Emission ($\mu\text{g}/\text{Nm}^3$)	% Above Max Permitted Emission
Antimony	11.5	172.5	1,400
Arsenic	3	45	1,400
Chromium	52.1	781.5	1,400
Chromium (VI)	0.01355	0.20319	1,400
Copper	16.3	244.5	1,400
Lead	36.8	552	1,400
Manganese	36.5	547.5	1,400
Nickel	136.2	2,043	1,400
Vanadium	1	15	1,400
<i>Reference conditions for all emissions dry, 11% oxygen, 283K</i>			

1.4 How assessed

In the UK we assess the impact of the plant operating at the upset operating conditions against the relevant short term EALs. For instance an assessment is not made of the plant continually operating at the upset operating conditions for a continuous period of more than 4 hours.

To determine the impact for comparison with the long term objectives it is assumed that the plant operates at the plausible upset operating conditions for 60 hours and the remaining 8,700 hours at the daily limit. The impact is then assessed against the relevant long term EALs.

2 PLANT START-UP AND SHUTDOWN

Start-up of the facility from cold will be conducted with clean support fuel (low sulphur light fuel oil). During start-up waste will not be introduced onto the grate unless the temperature within the oxidation zone is above the 850°C as required by Article 50, paragraph 4(a) of the IED. During start-up, the flue gas treatment plant will be operational as will be the combustion control systems and emissions monitoring equipment.

The same is true during plant shutdown where waste will cease to be introduced to the grate. The waste remaining on the grate will be combusted, the temperature not being permitted to drop below 850°C through the combustion of clean support auxiliary fuel. During this period the flue gas treatment equipment is fully operational, as will be the control systems and monitoring equipment. After complete combustion of the waste, the auxiliary burners will be turned off and the plant will be allowed to cool.

Start-up and shutdown are infrequent events. The facility is designed to operate continuously, and ideally only shutdown for its annual maintenance programme.

In relation to the magnitude of dioxin emissions during plant start-up and shutdown, research has been undertaken by AEA Technology on behalf of the Environment Agency. Whilst elevated emissions of dioxins (within one order of magnitude) were found during shutdown and start-up phases where the waste was not fully established in the combustion chamber, the report concluded that:

"The mass of dioxin emitted during start-up and shutdown for a 4-5 day planned outage was similar to the emission which would have occurred during normal operation in the same period. The emission during the shutdown and restart is equivalent to less than 1 % of the estimated annual emission (if operating normally all year)."

There is therefore no reason why such start-up and shutdown operations will affect the long term impact of the facility.

3 AMMONIA SLIP

We have assumed that the facility will use Selective Non-Catalytic Reduction (SNCR) rather than Selective Catalytic Reduction (SCR). The IED NO_x limit is easily achieved using SNCR. SCR can achieve much lower NO_x levels but at a significant cost to the project.

The BREF states that ammonia slippage from a SNCR system normally range from 1 to 10 mg/Nm³, with an average of 4 mg of NH₃/Nm³. For the purpose of the permit and planning application in the UK we would normally assume the upper end of the range (i.e. 10 mg/Nm³) to allow for some flexibility. However, if local sites are highly sensitive to ammonia or nitrogen deposition a more stringent limit may be requested. It will be worth requesting the guarantee from HZI.

If you have any questions please feel free to contact us.

Yours sincerely
FICHTNER Consulting Engineers Limited

Rosalind Flavell
Environmental Consultant

Stephen Othen
Technical Director

Job **Compilation of COPC Memos**
Client **EfW Facility TNG NSW**
Date **2016-10-20**
To **To Whom it may concern**
From **Martin Brunner (Ramboll)**
Copy to **Ian Malouf (DADI)**
Phill Andrew (Savills)
Amanda Lee (AECOM)
Lesley Randall (AECOM)
Rachael Snape (Urbis)
Damon Roddis (Pacific Environment)

Compilation and update of memos on compounds of potential concern (COPC)

Over the course of the project several memos concerning COPC for the HHRA have been established. Following a summary and overview of the memos with subject, date of issue and revision date is shown.

	Job	Date of Issue	Revision date
Memo 1	Compounds of Potential Concern (COPC) for HHRA	13.09.2015	-
Memo 2	COPC for HHRA	20.09.2015	19.10.2016
Memo 3	COPC for HHRA – Cr(VI)	03.11.2015	19.10.2016
Memo 4	VOC for HHRA	20.10.2016	-
Memo 5	Bromine in Waste	14.10.2016	-

These memos shall serve as an input to the air quality assessment (AQA) and the human health risk assessment (HHRA)

In summary the most important changes compared to the memos edited until end of 2015 are:

- Update of appendix B of Memo 2 (maximum TOC/VOC concentrations)
- Update Cr(VI) emissions
- Evaluation of further VOC compounds
- Assessing bromine emissions

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Attachments

Memos 1 - 5

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MEMO

Job **Compounds of Potential Concern (COPC) for HHRA**
 Client **DADI TNG NSW**
 Memo no. **1**
 Date **13/09/2015**
 To **Lesley Randall (AECOM)**
Damon Roddis (Pacific Environment)
 From **Martin Brunner**
 Copy to **Ian Malouf (DADI)**
Phill Andrew (Savills)
Mary Likar (Savills)
Amanda Lee (AECOM)
Skye Playfair Redmann (Urbis)
Geert Stryg (Ramboll)
Tore Hulgaard (Ramboll)
Ruedi Frey (HZI)

1. Reference and basis

Date 13/09/2015

Reference is made to the following memos:

- a) "TNG Energy from Waste Facility – Inputs to Human Health Risk Assessment", dated 11. September 2015 by Damon Roddis (Pacific Environment)
- b) "Advice to address EPA comments", dated 29. January 2015 by Rosalind Flavell (Fichtner)

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In line with the above information we have evaluated the in stack concentrations for normal and upset operation based on real data of 4 plants (7 lines and 7 different measuring campaigns) with identical Air Pollution Control system (APC) as planned to be installed at the TNG facility. We have further considered general literature on emission factors of WtE plants. Where no such data was available the concentration was calculated on the expected particulate emission and appropriate concentration of the compound in fly ash. More detailed description of the data used will follow in a separate memo. All values are given based on the following assessment:

Normal operation: Maximum value out of the following:

- Any measured value from the plants with identical APC system
- Literature emission factor for WtE plants

Upset operation: Definition of "Upset Operating Conditions" see memo b) chapter 1. Maximum value out of the following:

- Particulate emission of 150 mg/Nm³, emission based on specific compound concentration in fly ash
- Gas flow of 10% of total gas flow to stack bypassing APC (e.g. bag failure)
- Value of 10 times normal operation

When evaluating these data we found that in the memo b) some values were far above operational data. As a result we have re-evaluated the values of memo b) for normal operation. Further some in stack concentrations during upset operation (mainly HF and Dioxins) seem to be highly exaggerated, however (from footnote to table 1) we understand these values were requested by the EPA.

2. Table 1: Missing COPC

Compound All values at 11%O ₂ , dry gas		Operation condition	
		normal	upset
Beryllium	mg/Nm ³	7.00E-06	5.25E-04
Silver	mg/Nm ³	3.40E-04	2.55E-02
Cobalt	mg/Nm ³	4.00E-03	4.00E-02
PCB (WHO TEQ humans/mammal)	mg/Nm ³	1.60E-08	1.60E-07
PAH (WHO TEQ humans/mammal)	mg/Nm ³	5.00E-04	5.00E-03
Zinc	mg/Nm ³	3.70E-02	5.09E+00
Tin	mg/Nm ³	3.33E-03	2.50E-01
Molybdenum	mg/Nm ³	2.20E-05	2.63E-03
Selenium	mg/Nm ³	2.12E-03	2.12E-02
HCB	mg/Nm ³	8.21E-06	8.21E-05

3. Table 2: Overestimated COPC

Compound All values at 11%O ₂ , dry gas		Operation condition	
		normal	upset
Mercury	mg/Nm ³	0.004	0.013
Cadmium	mg/Nm ³	0.009	0.090
Thallium	mg/Nm ³	0.001	0.009
Nickel	mg/Nm ³	0.021	0.208
PCDD/F TEQ (WHO humans/mammal)	ng/Nm ³	0.010	0.500

4. Relevant flue gas volume

For calculation of the ground level concentration the methodology described in memo a) should be used. In case of any doubt the following revised flue gas flow shall be applied.

Parameter	Value		
	Design Point (LPN)		
Number of streams	1	2	4
Stack Height (m)	100		
Stack Diameter each stream inside (m)	2.2		
Temperature (°C)	120		
Flue Gas Flow (Nm ³ /s)	57.4	114.8	229.6
Gas Exit Flow Rate (Am ³ /s)	82.6	165.2	330.5
Gas Exit Velocity (m/s)	21.7		
Flue Gas Flow (Nm ³ /s) @ 11% O ₂	63.5	127.0	254.0
Flue gas composition (v/v)			
H ₂ O	15.90%		
O ₂	6.60%		
N ₂	67.80%		
CO ₂	9.70%		

5. Conclusion

For the further HHRA the data listed in table 1 (above) shall be used.

In case that as a result of the HHRA for one of the compounds listed in table 2 "overestimated COPC" (above) shows to be critical (when using the concentrations in memo b)) we suggest to use the values given in table 2 (above).

MEMO

Job **COPC for HHRA**
 Client **EfW Facility TNG NSW**
 Memo no. **2 – Rev 1**
 Date **19/10/2016**
 To **To Whom it May Concern**
 From **Martin Brunner (Ramboll)**
 Copy to **Ian Malouf (DADI)**
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1. Background and goal

In the context of the input to the Human Health Risk Assessment (HHRA) there has been some discussion on the list of Compounds of Potential Concern (COPC). The following memo gives an explanation on why the current COPC's have been chosen.

Date 19/10/2016

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2. Basis of the current list of COPC's

An initial list of COPC's was established as a basis of the report "energy from waste facility - air quality and greenhouse gas assessment" produced by Pacific Environment in March 2015.

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The COPC's chosen were based on the primary emissions from any Energy-from-Waste (EfW) facility, as defined by emission limits for waste incineration set by the European Union (EU) Industrial Emissions Directive (IED; Directive 2010/75/EU).

The emissions defined by the EID and chosen as COPC's are listed in Appendix A.1. In addition to the emissions identified in the IED, the substances listed in A.2 were included. As a result of the submissions from the Public Exhibition the substances listed in A.3 were added.

The current list of COPC's is substantially broader than substances usually taken into account in an Environmental Impact Assessment for an EfW plant in Europe. Nevertheless it is reasonable to question whether this list is complete. The following shall provide the rational for our opinion that the current list is sufficient to perform the HHRA.

3. **The legislation principle of primary emissions and “lead substances”**

While emissions in general cover a broad range of toxic, carcinogenic, mutagenic, etc. substances every industry has a specific set of primary emissions which - for reasons of human health and environmental protection - have to be reduced. It is therefore obvious that legislation focuses on the relevant emissions for any industry.

Besides the primary emissions so-called “lead substances” can be defined. Lead substances are representative for an entire group of comparable compounds and either relevant in their toxicity or present in high concentration. These substances are often difficult to capture by an Air Pollution Control (APC) system. Measuring low concentrations of these lead substances therefore is the proof that the separation mechanisms of the APC control are working. Typical lead substances of an EFW plant are: HCl, SO₂, NO_x, TOC, CO, dioxins and furans, cadmium, mercury and further heavy metals as nickel, lead or arsenic.

The chosen approach to primarily focus on substances defined in the IED and further lead substances therefore is rational and good industry practice.

4. **The implications of the “lead substance approach”**

When considering the emissions of an Energy-from-Waste plant the following categories of compounds can be defined:

- particulate matter
- acid gases (HCl, HF, SO₂)
- NO_x
- heavy metals with low boiling point (mercury, cadmium) and volatile compounds, to a high degree present in vaporised form
- heavy metals with high boiling point (nickel, vanadium, etc.), predominantly present in particle form
- Organic substances (expressed as total organic carbon TOC)
- dioxins and furans

Every one of these substances (and therefore the appropriate category) has a specific reduction mechanism in combustion and the APC process. While the lime injection reduces the acid gases, the bag filter eliminates the particulates and any substance in particulate form (mainly heavy metals with high boiling point). Finally the activated carbon injection reduces organic substances and heavy metals with low boiling point by adsorption.

As mentioned earlier a low emission of any lead substance is the proof of an efficient reduction of the category they represent in general.

The COPC’s recently added (appendix A.3) all can be classified in the above categories, e.g.:

- Copper, Molybdenum: metals with high boiling point
- PCBs and PAHs: organic substances
- Selenium, Beryllium: metals with low boiling point
- etc.

As a result any further substance can be classified in the above categories and therefore the reduction efficiency (respectively a low emission) can be assured.

5. TOC as guarantee for low organic emissions

While there is a limited number of toxic metals (including their compounds) there is an indefinite number of organic substances. The most important ones have been listed in the relevant regulations and are part of the current list of COPC's. However it is impossible to supply a complete list of individual organic substance and their emission data.

For this reason an additional emission parameter "total organic carbon" (TOC) has been introduced to legislation. The TOC measurement ensures that no relevant amount of organic substances is emitted. The TOC measurement is usually based on "Flame Ionisation Detection" (FID or FIA) and part of the continuous emission monitoring of any EfW plant. The TOC is a summary parameter for organic substances in general, the result is expressed in "carbon equivalent". Average TOC results of energy from waste plants are in the range of 1 - 2 mg/Nm³ (Nm³ is normal cubic meters, i.e. at standard temperature (0 °C) and pressure (101.3 kPa)).

In Europe extensive research has been done on the composition of the TOC of Energy-from-Waste plants. In total less around 50% of the TOC can be allocated to substances with higher molecular weight (see attachment B). The other 50% (or more) are "light" substances like methane, propane, etc. This is further underlined by theoretical considerations [2] which predict that a part of the TOC will be methane, ethane and propane.

To illustrate the low expected emission level, it can be mentioned that the background ambient air concentration of methane is around 1,800 ppb (volume basis) equivalent to around 1 mg/Nm³ TOC.

6. Operational Data

The above considerations are further supported by operational data (see appendix C). The appendix C.1 shows publicly available emission data from plants exclusively fired by C&I and C&D waste with semi dry APC system (as used for the TNG project) as well as plants with mixed waste (MSW plus C&I, C&D). In summary all values are comparable and far below the emission limits. Further details on operational data are found in appendix C.2 and C.3.

7. Summary and conclusions

The current list of COPC has been established on the following considerations:

- Compounds regulated by recent legislation (in this case the IED; Directive 2010/75/EU) and therefore relevant for the EfW Industry
- Additional COPC's which are not of primary relevance for a EfW plant but might be of public concern
- Lead substances which demonstrate the ability of the APC system to reduce pollutant categories and therefore not only assures a low emission of the substance itself, but also of the entire category
- TOC as an overall guaranty for low organic emissions which – as research has shown – contain very low concentrations of potentially harmful substances

As a result of the above and "real data" from comparable plants we are of the opinion that the current list of COPC is exhaustive and a sufficient basis to perform a robust and trustworthy HHRA.

Appendix A

1. The emissions defined by the EID and chosen as COPC's

- Particulate matter (PM), assumed to be emitted as PM10 and PM2.5.
- Hydrogen Chloride (HCl).
- Hydrogen Fluoride (HF).
- Carbon Monoxide (CO).
- Sulfur Dioxide (SO₂).
- Oxides of nitrogen (NO_x) (expressed as Nitrogen Dioxide (NO₂)).
- Heavy metals (including Mercury (Hg), Cadmium (Cd), Arsenic (As) and Chromium (Cr)).
- Gaseous and vaporous organic substances (expressed as total organic carbon (TOC)).
- Dioxins and furans.

2. In addition the following substances were included:

- Hydrogen sulfide (H₂S).
- Chlorine (Cl₂).
- Ammonia (NH₃).
- Polycyclic aromatic hydrocarbons (PAHs).

3. As a result of the submission the list was amended by the following substances:

- Beryllium (Be)
- Silver (Ag)
- Asbestos
- Copper (Cu)
- Cobalt (Co)
- Manganese (Mn)
- Vanadium (V)
- Polychlorinated Biphenyls (PCBs)
- PAHs (as benzo(a)pyrene equivalent).
- Zinc (Zn)
- Tin (Sn)
- Molybdenum (Mo)
- Selenium (Se)
- Hexachlorobenzene (HCB)

Appendix B

TOC composition in emissions from an EfW plant [1].

Measurement based on adsorption and condensation. Detection limit 5 µg/Nm³.

Characterisation of Emissions from a Waste Incineration Plant

Total organic carbon (TOC)	1.2 mg/m ³
Identified single components	0.53 mg/m ³
Not identified aliphatic hydrocarbons	56% of TOC

Main Components (µg/m ³)	
Benzoic Acid	100
Hexadecanoic Acid	37
Ethyl Benzoic Acid	35
Toluene	30
Phthalates	20
Dichloromethane	20
Acetone (propanone)	18
Tetradecanoic Acid	15
Benzene	15
Acetonitrile	14
Xylene	10
Trichlorophenol	9
Methylhexane	6
Trichloroethylene	5
Heptane	5

Note: There is little literature on the above subject. Most dates from mid 1990ies, when new emission regulations were issued in Europe. The concentrations of the organic substances were consistently low and therefore no further research or measurements were performed.

For any other TOC compound a maximum in stack concentration of 5 µg/Nm³ can be assumed. In case of a compound listed as group (e.g. Phthalates) for a conservative approach a maximum concentration for each speciation according to the above value can be chosen.

Literature references

- [1] Ergebnisbericht über Forschung und Entwicklung 1994, Institut für Technische Chemie, Forschungszentrum Karlsruhe, Wissenschaftliche Berichte, FZKA 5531, S. 9
- [2] Stand der Gesamtkohlenstoff-Messung im Abgas von Abfallverbrennungsanlagen, Staub – Reinhaltung der Luft, 49 (1989), S. 221-225
- [3] Emissions from decentralized CHP plants 2007 - ENERGINET.DK
Environmental project No. 07/1882 – National Environmental Research Institute (NERI)
Technical Report no. 786, 2010 (available from <http://www2.dmu.dk/Pub/FR786.pdf>).

Emission Data from plants with C+I / C+D and/or semi dry APC

Publicly available Data

	Plant	EEW Hürth-Knapsack		EEW Heringen		EEW Premnitz	EEW Grossräschen		Riverside			TIRME Mallorca				IED
	Country	DE		DE		DE	DE		UK			E				
	Waste	C&I, C&D		C&I, C&D, RDF from MSW		C&I, C&D	C&I, C&D		Municipal Solid Waste, C&I			Municipal solid waste, C&I, Hospital waste, sewage sludge, tyres				IED limit value
	unit	Line 1	Line 2	Line 1	Line 2		Line 1	Line 2	Line 1	Line 2	Line 3	Line 1	Line 2	Line 3	Line 4	
Total Dust	mg/m³	0.01	0.2	0.4	0	0.2	0.2	0.2	1	1	1	0.3	0	0.4	0.4	10
Total Organic Carbon (TOC)	mg/m³	0.2	0.1	1	0	0.5	0.8	0.5	5	5	3	0.05	0.03	0	0	10
Inorganic chlorine compounds (HCl)	mg/m³	9	9	6	7	6	6.6	3.5	6	3	6	0.5	0.1	0	0.1	10
Inorganic fluorine compounds (HF)	mg/m³	0	0	-	-	0	-	-								1
Sulphur dioxide (SO₂)	mg/m³	2	1	27	11	7.5	18	18	0	0	5	4	2	15	11	50
Oxides of nitrogen (expressed as NO₂)	mg/m³	188	188	183	185	180	174	176	175	175	175	55	38	60	68	200
Mercury (Hg)	µg/m³	4	23	1	0	3	0.3	0.1								50
Carbon monoxide (CO)	mg/m³	23	23	6	7	12.5	8	8				2.5	5	2.5	2.5	50
Ammonia (NH₃)	mg/m³	2	2				0.4	0.9	0	1	2					
Dioxines and furanes	ng/m3	0.01	0.02	-	-	0.015	-	-	-	-	-	-	-	-	-	0.1

all values at standard conditions, 11% O₂ dry

all values (except Hg and dioxines & furanes) as daily average, Hg and dioxines & furanes as spot sampling

all plants except Mallorca with SNCR DeNox, Mallorca with SCR

Sources

EEW Hürth-Knapsack

http://www.chemiepark-knapsack.de/fileadmin/user_upload/EEW_Emissionswerte_2013.pdf

EEW Heringen

<http://www.eew-energyfromwaste.com/de/emissionswerte-heringen.html>

EEW Premnitz

<http://www.eew-energyfromwaste.com/de/standorte/hannover.html#c347b>

EEW Grossräschen

<http://www.eew-energyfromwaste.com/de/standorte/heringen.html#c399b>

Riverside

<http://www.coryenvironmental.co.uk/energy-from-waste/riverside-resource-recovery-facility/>

TIRME Mallorca

http://www.tirme.com/uk/incineration_02f3s25.html

Extended values from plants with semi-dry APC

Detailed emission measurements from HZI plants with semi-dry APC

Metal	Symbol	Unit	Riverside			Newhaven		Cleveland	Evreux	Ingolstadt	Average	EU IED
			Line 1	Line 2	Line 3	Line 1	Line 2	Line 3		see note		
Mercury	Hg	mg/m³	0.0015	0.0004	0.0002	0.004	0.003	0.0017			0.002	< 0.05
Cadmium	Cd	mg/m ³	0.00270	0.00085	0.00111	0.009	0.001	0.004	0.004		0.00324	
Thallium	Tl	mg/m ³	0.00005	0.00003	0.00002	0.000	0.000	0.0009			0.00017	
Sum Cd+Tl	Cd + Tl	mg/m³	0.00275	0.00087	0.00113	0.009	0.001	0.0049			0.003	< 0.05
Arsenic	As	mg/m ³	0.0006	0.0003	0.0004	0.003	0.000	0.0013	0.004		0.0009	
Antimony	Sb	mg/m ³	0.0148	0.0047	0.0047	0.007	0.001	0.0026			0.0058	
Chromium	Cr	mg/m ³	0.0179	0.0115	0.0399	0.014	0.002	0.0467	0.004		0.0220	
Cobalt	Co	mg/m ³	0.0003	0.0002	0.0001	0.003	0.000	0.0006	0.004		0.0007	
Copper	Cu	mg/m ³	0.0085	0.0085	0.0263	0.051	0.001	0.0049			0.0167	
Lead	Pb	mg/m ³	0.0452	0.0137	0.0170	0.172	0.002	0.0094			0.0432	
Manganese	Mn	mg/m ³	0.0084	0.0041	0.0037	0.095	0.005	0.0051			0.0202	
Nickel	Ni	mg/m ³	0.0118	0.0058	0.0041	0.006	0.002	0.0208			0.0084	
Vanadium	V	mg/m ³	0.0003	0.0002	0.0004	0.003	0.000	0.0004			0.0007	
Sum heavy metal	As-V	mg/m³	0.11	0.049	0.097	0.35	0.015	0.092			0.12	< 0.5
Dioxins and Furan	PCDD/F TEQ (WHO humans/mammal)	ng/m³	0.004	0.004	0.001	0.0015	0.0004				0.0022	
Dioxin-like PCB's	PCB (WHO TEQ humans/mammal)	ng/m³	0.016	0.011	0.014	0.00001	0.00001				0.008	
Hexachlorbenzol	HCB	µg/m ³									0.001	
Benzo(a)pyren	B(a)P	µg/m ³							0.002	< 0.0012 < 0.0013	0.002	
PAH's	PAH (WHO TEQ humans/mammal)	µg/m³				0.4	0.5				0.45	

all concentrations in gas ref. to STP and 11% O₂ dry

note: Ingolstadt has APC with wet scrubber and bag house filter

Appendix C.3

Extract of the revised 2006 (2007 for natural gas fuelled plants) emission factors for Danish decentralised CHP plants < 25MW_e. [3]

Note: For calculation to/from GJ to/from mg/m³ the report uses the flue gas amount of 523 Nm³ (dry, at 11% O₂) per GJ for MSW.

	Unit	Natural gas fuelled engines	Biogas fuelled engines	Natural gas fuelled gas turbines	Gas oil fuelled engines	Gas oil fuelled gas turbines	Fuel oil, steam turbines	Biomass producer gas, engines	MSW incinera- tion	Straw	Wood
SO ₂	g per GJ	-	-	-	-	-	-	-	< 8.3	49	< 1.9
NO _x	g per GJ	135 ⁸⁾	202	48	942	83	136	173	102	125	81
UHC (C)	g per GJ	435 ⁸⁾	333	2.5 ⁹⁾	(46) ¹⁰⁾	-	(1.6) ¹⁰⁾	12	< 0.68	< 0.94 ⁵⁾	< 6.1 ⁶⁾
NMVOC	g per GJ	92 ⁴⁾ 8)	10 ⁴⁾	1.6 ⁴⁾	(37) ¹⁰⁾	-	(0.8) ¹⁰⁾	2.3 ⁴⁾	< 0.56 ⁴⁾	< 0.78 ⁴⁾	< 5.1 ⁴⁾
CH ₄	g per GJ	481 ⁴⁾ 8)	434 ⁴⁾	1.7 ⁴⁾	24	-	< 1.3	13 ⁴⁾	< 0.34 ⁴⁾	< 0.47 ⁴⁾	< 3.1 ⁴⁾
CO	g per GJ	58 ⁸⁾	310	4.8	130	2.6	2.8	586	< 3.9	67	90
N ₂ O	g per GJ	0.58	1.6	1.0	2.1	-	5.0	2.7	1.2	1.1	0.83
NH ₃	g per GJ	-	-	-	-	-	-	-	< 0.29	-	-
TSP	g per GJ	-	-	-	-	-	9.5	-	< 0.29	< 2.3	10
As	mg per GJ	< 0.045	< 0.042	-	< 0.055	-	-	0.116	< 0.59	-	-
Cd	mg per GJ	< 0.003	0.002	-	< 0.011	-	-	< 0.009	< 0.44	< 0.32 ³⁾	0.27
Co	mg per GJ	< 0.20	< 0.21	-	< 0.28	-	-	< 0.22	< 0.56	-	-
Cr	mg per GJ	0.048	0.18	-	0.20	-	-	0.029	< 1.6	-	-
Cu	mg per GJ	0.015	0.31	-	0.30	-	-	< 0.045	< 1.3	-	-
Hg	mg per GJ	< 0.098 ³⁾	< 0.12	-	< 0.11	-	-	0.54	< 1.8	< 0.31 ³⁾	< 0.40 ³⁾
Mn	mg per GJ	< 0.046	0.19	-	0.009	-	-	0.008	< 2.1	-	-
Ni	mg per GJ	0.045	0.23	-	0.013	-	-	0.014	< 2.1	-	-
Pb	mg per GJ	0.043	0.005	-	0.15	-	-	0.022	< 5.5	-	-
Sb	mg per GJ	< 0.049 ³⁾	0.12	-	< 0.055	-	-	< 0.045	< 1.1	-	-
Se	mg per GJ	(0.01) ⁷⁾	< 0.21	-	< 0.22	-	-	< 0.18	< 1.1	-	-
Tl	mg per GJ	< 0.20 ³⁾	< 0.21	-	< 0.22	-	-	< 0.18	< 0.45 ³⁾	-	-
V	mg per GJ	< 0.048	< 0.042	-	0.007	-	-	< 0.045	< 0.33	-	-
Zn	mg per GJ	2.9	4.0	-	58	-	-	0.058	2.3	0.41	2.3
PCDD/-F	ng per GJ	< 0.57	< 0.96 ¹⁾	-	< 0.99	-	-	< 1.7 ¹⁾	< 5.0	< 19	< 14
PBDD/-F	ng per GJ	-	< 5.0 ¹⁾	-	-	-	-	< 7.2 ¹⁾	< 6.3 ¹⁾	-	-
PAH (BaP)	µg per GJ	< 13	< 4.2	-	< 33	-	-	< 4.9	< 2	< 125	< 13
ΣPAH	µg per GJ	< 1025	< 606	-	< 8988	-	-	< 181	< 37	< 5946	< 664
Naphthalene	µg per GJ	2452	4577	-	17642	-	-	8492	< 129 ³⁾	12088	2314
HCB	µg per GJ	-	0.19	-	< 0.22	-	-	0.80	< 4.3	< 0.11	-
PCB	ng per GJ	-	< 0.19 ¹⁾	-	< 0.13 ¹⁾	-	-	< 0.24 ¹⁾	< 0.32	-	-
Formalde- hyde	g per GJ	14.1	8.7	-	1.3	-	< 0.002	1.5	-	-	-
HCl	g per GJ	-	-	-	-	-	-	-	< 1.14	56	-
HF	g per GJ	-	-	-	-	-	-	-	< 0.14	-	-

¹⁾ Emission measurements were below detection limits for all congeners.

²⁾ Based on 1 emission measurement. The emission measurement was below the detection limit.

³⁾ All emission measurements were below the detection limit.

⁴⁾ Based on disaggregation of the total unburned hydrocarbon (UHC) emission factor.

⁵⁾ Only 1 out of 7 emission measurement was above the detection limit.

⁶⁾ Two out of three emission measurements were below the detection limit.

⁷⁾ Two emission measurements were performed, both below the detection limit. These results have been ignored and instead the lower emission factor 0.01 mg per GJ based on EEA (2009) have been applied.

⁸⁾ The increased emission level during start up and stop of the gas engines have been included in this emission factor.

⁹⁾ Based on emission measurements performed in 2003-2006.

¹⁰⁾ The emission factor based on emission measurements performed within this project has been ignored. Instead the NMVOC emission factor refers to EEA (2009). The UHC emission factor has been estimated based on the emission factors for NMVOC and CH₄.

MEMO

Job **COPC for HHRA – Cr(VI)**
 Client **EfW Facility TNG NSW**
 Memo no. **3 – Rev 1**
 Date **19/10/2016**
 To **To Whom it May Concern**
 From **Martin Brunner (Ramboll)**
 Copy to **Ian Malouf (DADI)**
Lesley Randall (AECOM)
Amanda Lee (AECOM)
Damon Roddis (Pacific Environment)
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1. Background and goal

Chromium (Cr) is widely used metal and appears in different valences, mostly as trivalent Cr(III) but also as hexavalent Chromium Cr(VI). Cr(VI) is toxic and carcinogenic and therefore of major concern.

In case of emissions from Energy from Waste (EfW) facilities Chromium is considered as part of the sum of heavy metals and measured as total Chromium. In the context of the Human Health Risk Assessment (HHRA) for the TNG facility Ramboll has been requested to give a forecast on the emission of Cr(VI).

Date 19/10/2016

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2. Basis of the Cr(VI) forecast

As mentioned earlier, Chromium emissions are limited as total Chromium and therefore very little data on Cr(VI) emissions are available. Existing data date back to the 1980 and these emissions are not comparable to today's Air Pollution Control (APC) systems.

The forecast for updated Cr(VI) emissions therefore is based on total Cr emission, the APC removal behaviour and recent data of Cr(VI) values in APC residues.

3. Existing data on Cr(VI) in APC residues

There is a variety of data on total Chromium in EfW fly ash. The values for total Chromium typically range from 500 to 1000 mg/kg of fly ash.

Few measurements exist on Cr(VI) in fly ash. While many are below the detection limit (< 0.05 mg/kg) some values in the range of 1 - 3 mg/kg are found.

Chromium in the flue gas is predominantly present in form of particulates; the vapour pressure is very low and not relevant for the emission level. As a result it can be expected that the in stack concentrations will have a similar distribution as the fly ash.

4. Data considered for total Cr emissions

The following plants with a flue gas cleaning system identical to TNG were considered

Plant	No of Measurements	Max value mg/Nm ³	Mean value mg/Nm ³
Riverside UK	3	0.040	0.023
Newhaven UK	2	0.014	0.008
Cleveland UK	1	0.047	0.047
Mallorca ES	2	0.002	0.002
Phitiviers FR	1	0.002	0.002
Perpignan FR	1	0.024	0.024
Le Mans FR	3	0.009	0.005
Evreux FR	2	0.007	0.006
Ludwigslust DE	6	0.007	0.004
Zorbau DE	6	0.014	0.011
Total/max/mean	27	0.047	0.010

All values refer to 11% O₂, dry

5. Evaluation of Cr(IV) in APC residues

The Cr(VI) content in APC residues is in the order of 1-3 mg/kg in relation to a total Chromium content of 500-1000 mg/kg. Expressed as fraction this is 0.1 to 0.3% of the total. To allow for uncertainties due to variations a content of 0.5% as average and 1% as worst case is assumed

6. Conclusion

Based on results of 27 emission measurements of existing plants with identical APC equipment a maximum of total Chromium of 0.047 mg/Nm³ and a mean of 0.010 mg/Nm³ (see table above) is reported. This is well in line with a report of the UK EPA (see attachment) which lists a maximum of 0.052 mg/Nm³ and a mean of 0.011 mg/Nm³ as a result of measurements in 10 plants in the UK.

As a worst case scenario during normal operation therefore a Cr(VI) emission of 0.0005 mg/Nm³ (1% of 0.052 mg/Nm³) and an average of 0.00005 mg/Nm³ (0.5% of 0.010 mg/Nm³) can be assumed.

The above results are well in line with a recent publication by the Environment Agency of the UK (see attached) which predicts maximum Cr(VI) levels of 0.00013 mg/Nm³ and a mean value of 0.000035 mg/Nm³.

Releases from municipal waste incinerators

September 2012 version 3

Guidance to applicants on impact assessment for group 3 metals stack

Scope

This paper provides guidance to Applicants on how we will consider air quality impact assessments from Group 3 metals stack emissions from Municipal Waste Incinerators when we determine permit applications in respect of Schedule 1 activities under the Environmental Permitting Regulations 2010 (EPR). Metals assessments from other plant subject to the Waste Incineration Directive may use the method in this guidance if they can justify the data as representative.

Background

In April 2010, the Environment Agency published revised Environmental Assessment Levels (EALs) for arsenic, nickel and chromium(VI) in our H1 Guidance ([H1 Environmental Risks Assessment](#)). The revised EALs are substantially lower than the former EALs:

- Arsenic – 3 ng/m³
- Nickel – 20 ng/m³
- Chromium (VI) – 0.2 ng/m³

The EALs refer to that portion of the metal emissions contained only within the PM₁₀ fraction of particulates in ambient air.

Arsenic, nickel and (total) chromium are three of the nine Group 3 metals whose emissions are subject to a mandatory minimum emission limit by the Waste Incineration Directive (WID). WID sets an aggregate limit of 0.5 mg/m³ for nine “Group 3” metals (Sb, As, Pb, Cr, Co, Cu, Mn, Ni and V and their compounds (total)). Previous air dispersion modelling studies supporting permit applications typically made very conservative assumptions that emissions of each individual metal occurs at the WID aggregate limits. Such an analysis may conclude that there is a risk that the current EALs might be exceeded. Where such a theoretical risk exists, a more detailed assessment is required to determine whether the impact of the release is acceptable.

Detailed Modelling Assessment Methodology

Step 1 - Screening scenario

Predictions made assuming each metal is emitted at 100% of the WID ELV (i.e. 0.5 mg/m³). Where the impact of any metal exceeds the assessment criteria (below), relative to their respective EALs, we consider that there is a potential for significant pollution. Under these circumstances, proceed to Step 2.

Assessment Criteria:

- Long-term Process Contribution (PC) <1% or Short-term Process Contribution (PC) <10%; or
- Long-term and Short-term Predicted Environmental Concentration (PEC) <100% [taking likely modelling uncertainties into account].

[For screening only, assume Cr(VI) comprises 20% of the total background chromium). Selection of all other background data should be justified.]

Step 2

Worst case scenario based on currently operating plant – make predictions based on assuming each metal comprises 11% of the total group (i.e. 0.5 mg/m³ apportioned across the nine metals). Our emissions monitoring data indicates that it is reasonable to assume that each Group 3 metal comprises no more than 11% of the Group ELV.

Where the impact of any metal is above the assessment criteria given in Step 1 above proceed to Step 3.

Step 3 - Case specific scenario

We will require Applicants to justify their use of percentages lower than 11% of the Group 3 WID ELV or Cr(VI) background levels of <20% for their Step 3 assessment. Assessments should be made using the criteria below Step 1. We will review any use of Applicants' data to identify whether they can achieve the levels proposed and whether that data can be justified as representative.

Appendix A of this guidance contains summary of measured metals stack releases from a range of operating Municipal Waste Incinerators between 2007 and 2009, presented as a range and a mean of actual release and percentage of the WID ELV. The data in Appendix A should be considered as indicative only. Note that although the maximum Nickel concentration is greater than 11%, this represents one single measurement outlier; the mean value is around 4% of the Group ELV.

Appendix B contains data showing the effective Cr(VI) concentration from a range of Municipal Waste Incinerators. Measurement of Cr(VI) at the levels anticipated at the stack emission points is expected to be difficult, with the likely levels being below the level of detection by the most advanced methods. The concentrations presented in the table are based on stack measurements for total chromium and measurements of the proportion of Cr(VI) to total chromium in APC residues collected at the same plant. We have considered the concentration of total chromium and Cr(VI) in the Air Pollution Control (APC) residues collected upstream of the emission point for existing Municipal Waste Incinerators (MWI) and have assumed these to be similar to the particulate matter released from the emission point.

Appendix A – Monitoring Data from Municipal Waste Incinerators

	Measured Concentrations mg/m ³			Percentage of WID Group 3		
	Mean	Max	Min	Mean	Max	Min
Antimony	0.0033	0.0115	0.0001	0.7%	2.3%	0.02%
Arsenic	0.0007	0.0030	0.0003	0.14%	0.6%	0.06%
Chromium	0.0109	0.0521	0.0004	2.2%	10.4%	0.08%
Cobalt	0.0004	0.0039	0.0002	0.07%	0.8%	0.04%
Copper	0.0077	0.0163	0.0025	1.5%	3.3%	0.50%
Lead	0.0158	0.0368	0.0003	3.2%	7.4%	0.06%
Manganese	0.0172	0.0365	0.0015	3.4%	7.3%	0.30%
Nickel	0.0220	0.1362	0.0000	4.4%	27.2%	0.00%
Tin		0.0024	0.0024		0.48%	0.48%
Vanadium	0.0003	0.0010	0.0002	0.06%	0.20%	0.04%

Values correspond to the distribution from 19 measurements at 13 plant between 2007 and 2009. The data differs slightly from previous guidance notes.

* Minimum values correspond in some cases to the detection limit

Appendix B – Chromium VI analysis from APC Residues

	Effective Cr(VI) emission concentration ^a (mg/Nm ³)
Mean	3.5*10 ⁻⁵
Minimum	2.3*10 ⁻⁶
Maximum	1.3*10 ⁻⁴

These data are taken from ten MWI plant in England and Wales. We are in the process of gathering more data in order to fully understand the implications of metals emissions.

^a Note the maximum total chromium concentration does not coincide with the plant where the maximum chromium VI fraction in the APC residue was observed.

MEMO

Job **COPC for HHRA - VOC**
 Client **EfW Facility TNG NSW**
 Memo no. **4**
 Date **2016-10-20**
 To **To Whom it may concern**
 From **Ahmet Erol (Ramboll)**
 Copy to **Ian Malouf (DADI)**
Phill Andrew (Savills)
Amanda Lee (AECOM)
Lesley Randall (AECOM)
Rachael Snape (Urbis)
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VOC for HHRA/ Air quality Assessment

Background

In Ramboll Memo 2 COPC for HHRA, dated 20.09.2015 the COPC for AQA and HHRA have been listed. The selected COPC were based on the primary emissions from any Energy-from-Waste (EfW) facility, as defined by emission limits for waste incineration set by the European Union (EU) Industrial Emissions Directive (IED; Directive 2010/75/EU). It has been questioned if this list is covering all necessary compounds.

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File; TNGWTE-141-022-VOC for
 HHRA.docx
 Ver. 2

Further input to the selection of COPC

The study "Site specific risk assessment of an energy-from-waste thermal treatment facility in Durham Region, Ontario, Canada. Part A: Human health risk assessment"¹ (following referred to as "the study") has considered a wide range of COPC. This study is one of the most comprehensive investigations on the relevance of emissions from EfW facilities currently available.

The study categorizes the COPC's in five groups:

1. Metals
2. Chlorinated Polycyclic Aromatics
3. Chlorinated Monocyclic Aromatics
4. Poly Aromatic Hydrocarbons (PAH)
5. Volatile Organic Chemicals (VOC)

Methodology

COPC listed in the study and not selected so far for the TNG project were extracted. Then they were evaluated if the study found that they contribute to more than 1% of the background concentration.

¹ Site specific risk assessment of an energy-from-waste thermal treatment facility in Durham Region, Ontario, Canada. Part A: Human health risk assessment, dated 4th of July 2013 (attached)

Evaluation

Below the COPC are listed according to the categories of the study and evaluated if they are already part of the AQA/HHRA. If they have not been selected so far then to what extent they contribute to an increase of the ground level concentration compared to the baseline.

1. Metals

The metals listed in the study are already included in the AQA. Therefore no further assessment is needed.

2. Chlorinated Polycyclic Aromatics

Chlorinated Polycyclic Aromatics listed in the study are already included in the AQA. Therefore no further assessment is needed.

3. Chlorinated Monocyclic Aromatics (CMA)

The table below shows all COPC categorized under CMA in the study and the evaluation if they have already been included in the AQA.

	Listed in the study	TNG Air quality Assessment Memo 2, Appendix A
1,2-Dichlorobenzene	x	not included
1,2,4,5-Tetrachlorobenzene	x	not included
1,2,4 – Trichlorobenzene	x	not included
Pentachlorophenol	x	not included
Hexachlorobenzene	x	x
Pentachlorobenzene	x	not included
2,3,4,6-Tetrachlorophenol	x	not included
2,4,6-Trichlorophenol	x	not included
2,4-Dichlorophenol	x	not included

Only hexachlorobenzene has been considered for the AQA so far. The assessment concerning impact of the EfW facility on the ground level concentration found in the study is shown below.

The concentration ratio values are listed below (see study table 5)

Chlorinated Monocyclic Aromatics	Baseline	Project Alone	Effect level
1-hour	0.0006	7.5E-05	12,5%
24-hour	0.0001	5.2E-07	0,5%
Annual	0.002	3.0E-06	0,15%

Only the 1-hour value is higher than 1%. All other values are below 1%.

Conclusion

Hexachlorobenzene is the most relevant CMA compound present in the emissions from EfW plants. The concentrations measured during normal operation are in the range of below 1 up to max. 10 ng/Nm³.

The other CMA are mostly expressed as the sum of compounds with identical number of chlorine atoms (dichlorobenzene, trichlorobenzene, dichlorophenol, etc.). The measured values for such a group are in the range of below 1 up to max. 10 ng/Nm³. For any assessment a concentration of max. 10 ng/Nm³ per group during normal operation and 100 ng/Nm³ (ten-fold value) during upset operation can be assumed.

4. Poly Aromatic Hydrocarbons

Poly Aromatic Hydrocarbons (PAH) listed in the study have been included in the AQA. No further assessment is needed.

5. Volatile Organic Chemicals (VOC)

The table below shows all COPC categorized under Volatile Organic Chemicals (VOC) in the study and the evaluation if they have already been included in the AQA.

	Listed in the study	TNG Air quality Assessment Memo 2, Appendix A
Acetaldehyde	x	not included
Benzene	x	x (Appendix B)
Biphenyl	x	not included
Bromodichloromethane	x	not included
Bromomethane	x	not included
Dichlorodifluoromethane	x	not included
Dichloroethene	x	not included
1,1 -, Ethylbenzene	x	not included
Ethylene Dibromide (1,2-dibromoethane)	x	not included
Formaldehyde	x	not included
Tetrachloroethylene	x	not included
Toluene	x	x (Appendix B)
Trichloroethylene	x	x (Appendix B)
1,1,2, Vinyl chloride (chloroethene)	x	not included
Xylenes	x	x (Appendix B)
m-, p- and o-Bromoform (tribromomethane)	x	not included
Carbon tetrachloride	x	not included
Chloroform	x	not included
Dichloromethane	x	x (Appendix B)
O-terphenyl	x	not included
Trichloroethane	x	not included
1,1,1 -, Trichlorofluoromethane	x	not included

The concentration ration values are listed below (see assessment EfW facility table 5)

Volatile Organic Chemicals (VOC)	Baseline	Project Alone	Effect level
1-hour	0.55	0.005	0,9%
24-hour	0.41	0.002	0,5%
Annual	0.18	0.0002	0,1%

All effect levels are below 1%. No further assessment for VOC is needed.

Summary and conclusion

Except for chlorinated monocyclic aromatics all compounds evaluated in the study "Site specific risk assessment of an energy-from-waste thermal treatment facility in Durham Region, Ontario, Canada. Part A: Human health risk assessment" are either already included in the AQA or their effect level found in the study is below 1% under all conditions.

For the chlorinated monocyclic aromatics hexachlorobenzene (HCB) - the most relevant compound - is already included in the AQA. Measured values of HCB in EfW plants range from 1-10 ng/Nm³. For any other group of compound (as sum of compounds with identical number of chlorine atoms) a concentration of 10 ng/Nm³ during normal operation and 100 ng/Nm³ (tenfold value) during upset operation can be assumed.



Site specific risk assessment of an energy-from-waste thermal treatment facility in Durham Region, Ontario, Canada. Part A: Human health risk assessment

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HIGHLIGHTS

- Human health risk assessment was performed for an Energy-From-Waste facility
- Results suggest minimal risks to humans expected at approved operating capacity
- Future expansion may cause slightly elevated risks under upset conditions
- Further risk assessment required if/when future expansion is pursued

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Thermal mass burn technology

ABSTRACT

The regions of Durham and York in Ontario, Canada have partnered to construct an energy-from-waste thermal treatment facility as part of a long term strategy for the management of their municipal solid waste. This paper presents the results of a comprehensive human health risk assessment for this facility. This assessment was based on extensive sampling of baseline environmental conditions (e.g., collection and analysis of air, soil, water, and biota samples) as well as detailed site specific modeling to predict facility-related emissions of 87 identified contaminants of potential concern. Emissions were estimated for both the approved initial operating design capacity of the facility (140,000 tonnes per year) and for the maximum design capacity (400,000 tonnes per year). For the 140,000 tonnes per year scenario, this assessment indicated that facility-related emissions are unlikely to cause adverse health risks to local residents, farmers, or other receptors (e.g., recreational users). For the 400,000 tonnes per year scenarios, slightly elevated risks were noted with respect to inhalation (hydrogen chloride) and infant consumption of breast milk (dioxins and furans), but only during predicted 'upset conditions' (i.e. facility start-up, shutdown, and loss of air pollution control) that represent unusual and/or transient occurrences. However, current provincial regulations require that additional environmental screening would be mandatory prior to expansion of the facility beyond the initial approved capacity (140,000 tonnes per year). Therefore, the potential risks due to upset conditions for the 400,000 tonnes per year scenario should be more closely investigated if future expansion is pursued.

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1. Introduction

The Regions of Durham and York in Ontario, Canada partnered in 2005 to seek a long-term sustainable solution for managing their municipal solid waste. Both Regions have made considerable commitments to decreasing waste production and increasing waste diversion (e.g. through recycling or composting initiatives), but a management strategy is still required for residual waste not diverted through these strategies. Previously, this residual waste was largely exported out of the Regions (primarily to Michigan) for landfill. However, when it was announced that the Michigan border would be closed to municipal waste from Canada as of December 2010, it became imperative to identify a viable waste management alternative.

Abbreviations: CAC, Criteria air contaminant; COPC, Contaminant of potential concern; CR, Concentration ratio; CSF, Cancer slope factor; EA, Environmental assessment; EFW, Energy-from-waste; ERA, Environmental risk assessment; HHRA, Human health risk assessment; HQ, Hazard quotient; ILCR, Incremental lifetime cancer risk; LADD, Lifetime average daily dose; LCR, Lifetime cancer risk; LRASA, Local risk assessment study area; MDL, Method detection limit; RfC, Reference concentration; RfD, Reference dose; TEF, Toxic equivalency factor; TRV, Toxicity reference value; UR, Unit risk.

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Due to public opposition, establishment of a new local landfill was considered unacceptable. In addition, it was recognized that continuing to ship the waste to an external landfill could not provide a stable and secure alternative due to the vulnerability of this option to public policy decisions made by external governments. Therefore, processing and treatment options such as mechanical, biological, and thermal treatment were considered. Through an extensive public consultation process as well as a detailed evaluation of environmental, social and economic considerations, the preferred option was determined to be the construction of an Energy-From-Waste (EFW) thermal treatment plant. Such facilities have the capacity to reduce the volume of waste by >90% while also recovering metals and producing energy that can be sold to offset annual operating costs (Rushton, 2003).

EFW facilities are widespread in Europe and other jurisdictions (Bogner et al., 2008). Research and monitoring programs around these facilities suggest that in light of strict emissions guidelines and modern engineering controls, these facilities are unlikely to be hazardous to human health or the environment (Bordonaba et al., 2011; Cangialosi et al., 2008; Lee et al., 2007; Morselli et al., 2011; Rovira et al., 2010; Schuhmacher and Domingo, 2006). However, a new EFW facility had not been built in Ontario for over 20 years. As part of the approval process for construction of this new facility in Ontario, extensive human health and ecological risk assessments were performed to determine the potential effects of this project on surrounding communities and ecosystems. This paper describes the methods and results of human health risk assessment; the methods and results of the ecological risk assessment are provided in a separate publication (Ollson et al., 2014). These risk assessments formed an important component of the final Environmental Assessment for this project, which was submitted to the Ontario Ministry of the Environment (MOE) in 2009 and received final approval in 2010. On the basis of this approval, the project was permitted to proceed to the construction phase, which was initiated in 2011. Facility start-up is currently projected to occur by the end of 2014.

2. Material and methods

2.1. Scope of the assessment

This risk assessment examined the potential for emissions from the proposed project (i.e., construction, operation, and eventual decommissioning of a modern EFW thermal treatment facility) to pose an unacceptable risk to human health over both short-term and long-term (i.e., after 30 years of operation). Existing conditions at the proposed location for the facility were also assessed in order to provide a baseline for the assessment (Table 1). The entire assessment was carried out following the US EPA human health risk assessment protocol for hazardous waste combustion facilities (US EPA, 2005).

The initial operating design capacity of the proposed facility was 140,000 tonnes per year, with a capacity for expansion to 400,000 tonnes per year within the 30-year planning period. As the expansion

of the facility beyond the initial approved capacity of 140,000 tonnes per year would require additional environmental screening under provincial regulations, the present risk assessment focused primarily on the potential risks from the facility with respect to operation at the 140,000 tonnes per year level. However, for comparison purposes, consideration was also given to the potential risks associated with the maximum design capacity of 400,000 tonnes per year.

2.2. Facility description

Facility design information for this assessment was provided by Covanta Energy Corporation, which was selected by the Regions as the preferred vendor for this project. Covanta, the largest provider of thermal treatment services in North America (with 40 facilities in the United States and one in Canada), was contracted by the Regions to direct the design, engineering, construction and operation of the facility. Therefore, they were able to provide detailed information, specific to the planned facility, which also reflects the features and functionality of existing modern EFW facilities elsewhere in North America.

This facility will be accepting municipal solid waste from typical Ontario curbside waste collection (i.e. household waste excluding separated recyclable materials and organics). No additional feed stock separation will occur at the facility. The facility will use a thermal mass burn technology, wherein municipal solid waste is fed into a furnace and burned at very high temperatures. For the initial operating design capacity of 140,000 tonnes per year, there will be two independent waste processing trains consisting of a feed chute, stoker, integrated furnace/boiler, dry recirculation acid gas scrubber, a fabric filter bag house and associated ash and residue collection systems. Expansion to the maximum design capacity (400,000 tonnes per year) would include the addition of two more waste processing trains. Steam produced in each boiler will drive a turbine-generator to produce electricity for delivery to the grid, for in-plant use and/or district heating. After the removal of residual metals for recycling, ash produced by the process will be shipped to landfill for use as daily cover or will be reused, possibly as road construction material or other civil projects. Air pollution control equipment throughout the facility will ensure that emissions do not exceed the provincial guidelines outlined by the Ontario Ministry of the Environment (MOE, 2004a) and specific conditions of Certificate of Approval 7306-8FDKNX issued June 28, 2011 for the Facility.

2.3. Identification of chemicals of potential concern (COPC)

Chemicals that could potentially be released by the facility to the atmosphere were identified by reviewing sources such as existing provincial guidelines for municipal incinerators (MOE, 2004a), the Canadian National Pollutant Release Inventory for waste incinerators (Environment Canada, 2007), and the results of stack testing of an existing waste incinerator in nearby Brampton, Ontario. From this review, a COPC list consisting of 87 chemicals was developed (Table 2) that consisted of both Criteria Air Contaminants (CACs,

Table 1
Project scenarios considered in the human health risk assessment.

Project Scenarios	Case	Conditions assessed
Existing Conditions	Baseline	Existing conditions in the assessment area. No Facility-related emissions or exposures were included as this was completed prior to construction and operation of the Facility.
Construction Operation	Baseline Traffic	Offsite vehicle traffic emissions prior to the start-up of the Facility.
	Construction	Construction and commissioning of the Facility.
	Project Alone	Emissions from the Facility alone.
	Project (Baseline + Project)	Emissions from the Facility combined with existing/baseline conditions.
	Process Upset	Emissions from the Facility operating at upset conditions (i.e., Facility start-up, shutdown, and loss of air pollution control).
	Process Upset Project (Baseline + Upset)	Emissions from the Facility operating at upset conditions combined with existing/baseline conditions.
Decommissioning	Traffic	Emissions from offsite and onsite traffic associated with the Facility combined with baseline traffic conditions and onsite stationary source emissions for the Facility.
	Decommissioning (Closure Period)	Emissions related to the removal of infrastructure and rehabilitation of the Site.

for which regulatory limits already exist) and non-CACs (substances that are capable of causing environmental or health effects for which no regulatory limits were identified).

All COPC were evaluated for their potential to pose a risk to human health via inhalation as this was expected to be the primary route of human exposure to facility-related air emissions (Table 2). In addition, COPC that were considered to be persistent and/or bioaccumulative (i.e., half-life in soil ≥ 6 months and/or $\text{Log } K_{ow} \geq 5$) were also included in a multi-pathway risk assessment that addressed the possibility that these compounds may persist in and/or be transferred to various environmental media (e.g., soil, water, and food) following their release to air (Table 2).

2.4. Study area

The selected location for the facility is located within the Municipality of Clarington, Ontario, Canada (approximately 80 km east of Toronto, Ontario). This location is bordered by Lake Ontario to the south, commercial properties to the north and agricultural lands to the east and west. The Darlington Nuclear Generating Station is located approximated 2 km to the east.

In order to define the study area, the CALPUFF dispersion model (Scire et al., 1995) was applied to predict ground level concentrations of COPC as well as wet and dry deposition fluxes over a 40×40 km grid around the proposed facility location. The inputs to this model included geophysical (terrain and land use) and meteorological data specific to the region (Environment Canada, 2008; USGS, 2007; UCAR, 2008) as well as COPC physical-chemical properties. Stack parameters (i.e., location, base elevation, stack height, stack diameter, gas exit velocity, gas exit temperature, and emission rates) were provided by the vendor with respect to the planned facility. Potential stack emissions of COPC were estimated based on manufacturer's guarantees of maximum emissions, emission levels measured by the preferred vendor at one or more of their existing facilities that utilise similar technologies (measured at maximum load), and literature sources for other facilities.

Results of the CALPUFF model showed that the highest concentrations of emissions and depositions would be located in the area immediately surrounding the facility with a radius of approximately 10 km. Therefore, this area was defined as the Local Risk Assessment Study Area (LRASA) for consideration in this risk assessment. This LRASA includes the urban centers of Oshawa, Courtice, Bowmanville, and Port Darlington, Ontario.

2.5. Receptor identification and exposure pathways

Residential land use in the LRASA is mainly suburban residential and rural residential. The rural residential areas include large, dispersed lots that may be used for agricultural purposes (e.g., cash crops or livestock). Within the larger urban centers there are numerous commercial and institutional developments. Recreational opportunities in the area include hiking, camping, equestrian activities, hunting, fishing and swimming.

In light of these identified land uses, the human receptors considered in this risk assessment included local residents, local farmers, daycare/school attendees, and recreational users (sport and/or camping) (Table 3). Potential exposure pathways determined for each receptor included inhalation of vapours and particulate emissions, ingestion and dermal exposure to soil and/or dust, and food chain exposures (Table 3). It was also assumed that some receptors may incur additional exposures to COPC via hunting, fishing, or swimming within the LRASA. Therefore, additional exposures related to these activities that can be added to any of the identified receptors were also assessed (Table 3). Consumption of local drinking water was not considered since it was found that residents in the LRASA obtain their drinking water from municipal water supply services, which would not be affected by facility-related emissions. Similarly, consumption of grocery store bought foods was not considered.

The life stages considered for each receptor and for the hunting/angling and swimming additional exposures were selected to represent those with the greatest sensitivity and/or exposure to each COPC. For non-carcinogenic COPC, which act via a threshold mechanism, the

Table 2
Contaminants of potential concern (COPC) considered in this assessment.

COPC	Inhalation	Multi-Pathway
Criteria Air Contaminants:		
Sulfur Dioxide (SO ₂), Hydrogen Chloride (HCl), Hydrogen Fluoride (HF), Nitrogen Dioxide (NO ₂), Particulate Matter (PM ₁₀), Particulate Matter (PM _{2.5}), Total Particulate Matter (TSP), Ammonia (Slip at Stack)	✓	
Chlorinated Polycyclic Aromatics:		
Dioxins and Furans as Toxic Equivalents (TEQ), Total PCBs (as Aroclor 1254)	✓	✓
Metals:		
Antimony, Arsenic ^b , Barium, Beryllium ^b , Boron, Cadmium ^b , Chromium (hexavalent) ^b , Total Chromium (and compounds) ^b , Cobalt, Lead, Mercury ^a , Nickel, Phosphorus, Silver, Selenium, Thallium, Tin, Vanadium, Zinc	✓	✓
Chlorinated Monocyclic Aromatics:		
1,2-Dichlorobenzene, 1,2,4,5-Tetrachlorobenzene, 1,2,4 – Trichlorobenzene, Pentachlorophenol ^b , Hexachlorobenzene ^b , Pentachlorobenzene	✓	✓
2,3,4,6-Tetrachlorophenol, 2,4,6-Trichlorophenol ^b , 2,4-Dichlorophenol	✓	
Poly Aromatic Hydrocarbons:		
Acenaphthylene ^b , Acenaphthene ^b , Anthracene, Benzo(a)anthracene ^b , Benzo(b)fluoranthene ^b , Benzo(k)fluoranthene ^b , Benzo(a)fluorene, Benzo(b)fluorene, Benzo(ghi)perylene ^b , Benzo(a)pyrene TEQ ^b , Benzo(e)pyrene ^b , Chrysene ^b , Dibenzo(a,c)anthracene ^b , Dibenzo(a,h)anthracene ^b , Fluoranthene ^b , Fluorene, Indeno(1,2,3 – cd)pyrene ^b , Perylene ^b , Phenanthrene ^b , Pyrene ^b	✓	✓
1 – methylnaphthalene, 2 – methylnaphthalene, Naphthalene	✓	
Volatile Organic Chemicals (VOC):		
Acetaldehyde ^b , Benzene ^b , Biphenyl, Bromodichloromethane, Bromomethane, Dichlorodifluoromethane, Dichloroethene, 1,1 – , Ethylbenzene, Ethylene Dibromide (1,2-dibromoethane) ^b , Formaldehyde ^b , Tetrachloroethylene ^b , Toluene, Trichloroethylene, 1,1,2 ^b , Vinyl chloride (chloroethene) ^b , Xylenes, m-, p- and o-	✓	
Bromoform (tribromomethane), Carbon tetrachloride ^b , Chloroform ^b , Dichloromethane ^b , O-terphenyl, Trichloroethane, 1,1,1 – , Trichlorofluoromethane	✓	✓

^a Inorganic and methylmercury.

^b This chemical was evaluated as a non-carcinogen and a carcinogen.

Table 3
Exposure pathways and life stages evaluated for identified receptor types.

	Receptor Type					Additional Exposures ^a	
	Resident	Farmer	Recreation User – Sport	Recreation User - Camping	Daycare	Swimming	Hunting/Angling
<i>Exposure Pathway</i>							
Direct Inhalation	✓	✓	✓	✓	✓		
Soil Ingestion	✓	✓	✓	✓	✓		
Dermal Contact – Soil	✓	✓	✓	✓	✓		
Dermal Contact – Water						✓	
Incidental Surface Water Ingestion						✓	
Garden Produce	✓	✓					
Fish							✓
Breast Milk	✓	✓					
Wild Game							✓
Agriculture		✓					
<i>Life stage considered for threshold (non-carcinogenic) COPC</i>							
Infant (0 to 6 mo)	✓	✓					
Toddler (7 mo to 4 yr)	✓	✓	✓	✓	✓	✓	✓
<i>Life stage considered for non-threshold (carcinogenic) COPC</i>							
Adult (20 to 75 yr)					✓		
Composite	✓	✓	✓	✓		✓	✓

^a Exposures through these pathways can be added to identified receptors.

toddler life stage (i.e., 6 months to 4 years) was considered to represent the most sensitive life stage based on receptor characteristics (e.g., lower body weights) combined with behavioural patterns (e.g., higher soil ingestion rates). Therefore, all health risks associated with exposures to non-carcinogenic COPC were estimated for the toddler receptor (Table 3). In addition, the infant life stage (i.e., 0 to 6 months) was evaluated for farmer and resident receptors in the multi-pathway risk assessment for non-carcinogenic COPC in order to address the potential health risks associated with consumption of breast milk (Table 3). For carcinogenic COPC (non-threshold), a composite life stage for most receptors was considered that combines the characteristics of infant (i.e., 0 to 6 months), toddler (i.e., 7 months to 4 years), child (i.e., 5 years to 11 years), adolescent (i.e., 12 to 19 years), and adult (i.e., 20 years to 75 years) life stages (Health Canada, 2007) (Table 3). However, for the daycare/school receptor, exposure to carcinogenic COPC was assessed only for the adult stage (Table 3) since this class of receptor has the potential to have the longest duration of exposure to the daycare/school conditions (assuming employment from youth to retirement at that location).

2.6. Collection of baseline data

In order to characterize pre-project baseline conditions, ambient air monitoring and soil, water, and biota sampling was performed in the vicinity of the proposed facility location. All laboratory analyses of the collected samples were conducted by ALS Laboratory Group using standard methods (See Supporting Information Section S1).

2.6.1. Baseline ambient air monitoring

An air monitoring station was set up approximately 2 km southwest of the proposed facility location. Data was collected and analyzed over a 15 month period (September 2007 to December 2008). The station continuously monitored Sulfur Dioxide (SO₂), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Ozone (O₃), and Particulate Matter smaller than 2.5 microns (PM_{2.5}). Hi-volume air samplers were also installed to collect 24-hour average samples of Total Suspended Particulate (TSP) and metals, Polycyclic Aromatic Hydrocarbons (PAHs), and Dioxins and Furans (PCDD/F).

In addition, baseline offsite vehicle emissions prior to the start up of the facility were estimated using traffic volume estimates provided by URS Canada Inc. These traffic estimates were combined with the existing baseline ambient air conditions in the airshed to produce the baseline traffic case.

2.6.2. Baseline soil and biota sampling

Additional baseline soil and biota samples were collected and analyzed for the COPC identified for consideration in the multi-pathway risk assessment. The sampling program included collection of soil, terrestrial vegetation (forage, browse, and crops), small mammals, surface water, sediment and fish sampled within a 1 km radius of the proposed facility location. Where possible, samples were collected in areas where air modeling predicted maximum rates of deposition for various COPC, and locations were also selected to be representative of different land uses. In addition, agricultural products (beef, chicken, pork, dairy and eggs) and produce were collected from farms and markets located outside a 1 km radius due to limited availability. However, efforts were made to ensure that farms were located as close as possible to the proposed facility location, and therefore the collected samples are considered sufficient to represent baseline conditions for this assessment.

2.7. Fate and transport modeling of COPC from project-related emissions

The potential impacts of facility-related emissions on the concentrations of COPC in the surrounding environment were predicted using best available data (i.e., results of the CALPUFF modeling described in Section 2.4, physical-chemical properties of the COPC, and detailed geophysical and meteorological data specific to the LRSA) and accepted modeling techniques as described in the US EPA human health risk assessment protocol for hazardous waste combustion facilities (US EPA, 2005). Specifically, the contributions of facility-related emissions to ambient air concentrations were predicted for all COPC at 309 distinct receptor locations selected to represent a variety of land uses as well as areas where initial modeling suggested the highest acute (1-hr or 24-hr) or chronic (annual) ground level concentrations were likely to occur. Additionally, for the persistent and/or bioaccumulative COPC considered in the multi-pathway risk assessment (Table 2), facility-related changes in COPC concentrations in soil, surface water, garden and farm produce and fruit, agricultural products (i.e., beef, chicken, pork, dairy and eggs), wild game, fish, and breast milk were predicted at 133 of the 309 locations.

In addition to predictions made for emissions from the normal operating scenarios at both 140,000 and 400,000 tonnes per year, the potential emissions under 'process upset' conditions (i.e., facility start-up, shutdown, and loss of air pollution control) were modeled following protocol suggested by the US EPA (2005). Specifically, for determining short-term (1-hour to 24-hour average) ground level COPC concentrations under upset conditions, the emission rates for

the facility under normal operation were conservatively increased by a factor of ten. This factor was applied to all COPC except for SO₂ and NO_x for which emissions were increased by factors of 16 and 1.63 respectively, based on data received from the vendor. As per US EPA (2005) guidance, for metals and CACs it was assumed that the facility would operate under upset conditions for 5% of the year. Therefore, emission rates for these COPC were increased by a factor of 1.45 $[(0.95 \times 1) + (0.05 \times 10) = 1.45]$, with the exception of SO₂ and NO_x, for which emission rates were increased by factors of 1.75 and 1.03, respectively using the same assumptions. For the remaining COPC (organics), annual average concentrations for the process upset case were increased by a factor of 2.8 based on an assumption that the facility would operate under upset conditions for 20% of the year $[(0.80 \times 1) + (0.20 \times 10) = 2.8]$ (also as suggested by US EPA, 2005). This upset case is considered an absolute extreme scenario, given that the Ministry of the Environment would not allow the facility to operate in upset conditions for 20% of the year.

2.8. Exposure assessment

The sources of chemical concentrations used in the exposure assessment are described in Sections 2.5 and 2.6. In order to ensure a conservative estimate of risk, all exposure assessments were conducted deterministically using exposure point concentrations representative of reasonable maximum exposure. For the baseline values (described in Section 2.6), a single baseline exposure point concentration (i.e., the maximum detected concentration, 95% upper confidence limit of the mean, or method detection limit as described in Supporting Information, Section S2) was used to model exposure for each environmental medium collected for all receptor types. Although individual baseline concentrations were not obtained at the location of each receptor group evaluated, the baseline exposure point concentrations used are considered representative of reasonable maximum exposure, to all receptors, from background concentrations. A different approach was applied for the modeled facility-related contributions of COPC to the environment. In this case, the receptor locations were grouped by similar land use and the maximum or 95% upper confidence limit of the mean (selected as described in Supporting Information, Section S2) of the air and/or deposition concentration of each COPC within each receptor grouping was used to calculate the level of exposure for the entire grouping.

Physiological and behavioural characteristics of the receptors (e.g., respiration rate, soils/dusts intake, time spent at various activities and in different areas) were selected, if available, from existing guidance documents (Health Canada, 1994, 2007; MOE, 2005; Richardson, 1997; US EPA, 1997, 2005). In addition, oral and dermal bioavailability factors were compiled from Health Canada (2007) or the US Department of Energy's Oak Ridge National Laboratory Risk Assessment Information System (RAIS) database (ORNL, 2008). Whenever possible, preference was given to Canadian guidance documents and literature (e.g. Health Canada, 2007; Richardson, 1997). More details regarding the specific assumptions, input parameters and calculations used for each exposure pathway and receptor are provided in the Supporting Information (Section S3).

Exposure estimation was facilitated through the use of an integrated multi-pathway environmental risk assessment model developed by the Study Team. The model is spreadsheet based (Microsoft Excel™) and incorporates the techniques and procedures for exposure modeling developed by the MOE and Health Canada, and the US EPA (Health Canada, 1994, 2007; MOE, 2005; Richardson, 1997; US EPA, 1997, 2005).

2.9. Hazard assessment

2.9.1. Identification of toxicity reference values (TRVs)

For chemicals that follow a threshold dose-response (i.e., non-carcinogens), a threshold level must be exceeded in order for toxicity to occur, and it is possible to derive a reference concentration (RfC, for

inhalation receptors) or reference dose (RfD, for multi-pathway receptors) that is expected to be safe to sensitive subjects following exposure for a prescribed period of time (US EPA, 1989). For chemicals that follow non-threshold dose-responses (i.e., carcinogens), a specific dose where toxic effects manifest themselves cannot be identified as any level of long-term exposure to carcinogenic chemicals is associated with some hypothetical cancer risk. As a result, risk assessment of these types of chemicals typically considers evaluation of the incremental lifetime cancer risk (ILCR) associated with exposure to the chemical (US EPA, 1989). This may be estimated based on the unit risk (UR) or cancer slope factor (CSF) of the chemical, where UR represents the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/L in water, or 1 µg/m³ in air and CSF provides an upper bound estimate of the increased cancer risk from lifetime exposure to an agent (US EPA, 1989).

Literature and public guidance documents were reviewed to identify RfCs, RfDs, URs or CSFs for inclusion as toxicity reference values (TRVs) for each COPC. Regulatory benchmarks, which are also health-based but often also policy derived, were also considered as TRVs for some COPC. A summary of the non-carcinogenic and carcinogenic TRVs used in both the inhalation and multi-pathway exposure assessment are presented in Supporting Information (Section S4).

2.9.2. Chemical mixtures and additivity of risks

In order to properly assess health risks to the human receptors, certain groups of chemicals were assessed as mixtures. Specifically, dioxin and furan congeners and carcinogenic PAHs were assessed using the toxic equivalency factor (TEF) approach (Supporting Information, Section S5). TEFs for dioxin and furan congeners represent their potency relative to 2,3,7,8 TCDD (Van den Berg et al., 2006), while TEFs for carcinogenic PAHs represent their toxicity relative to benzo(a)pyrene (IPCS, 1998).

Additional groups of chemicals were identified that may have additive, synergistic, or antagonistic effects due to their similar toxic modes of action (see Table S7 in Supporting Information, Section S5). However, there is currently very little available toxicological data or regulatory guidance to support the prediction of the effects of simultaneous exposure to these chemicals. In the original risk assessment an approach assuming additivity of the effects was used (see details in Supporting Information, Section S5). However, as this approach is not based on actual toxicological study results and cannot consider more complex interactions (i.e. synergism or antagonism), it is considered highly speculative and was presented for information purposes only. In light of these uncertainties, the effects of simultaneous exposure to multiple pollutants are not discussed further in the present manuscript. It is acknowledged that the interpretation of the potential effects of simultaneous exposure to chemical mixtures remains a considerable source of uncertainty in human health risk assessments conducted in Ontario.

2.10. Risk characterization

2.10.1. Threshold chemicals (non-carcinogens)

The risk associated with threshold chemicals was assessed using a Concentration Ratio (CR) for the inhalation pathway. CR values were calculated by dividing the predicted ground level air concentration (1-hour, 24-hour or annual average) by the appropriate toxicity reference value (reference concentration [RfC] or health based inhalation benchmark), according to Eq. (1):

$$CR_{duration} = \frac{[Air]_{duration}}{RfC_{duration} \text{ or health benchmark}} \quad (1)$$

Where CR_{duration} represents a duration specific Concentration Ratio (unitless), calculated for 1-hr, 24-hr and chronic durations as

appropriate; $[Air]_{duration}$ represents the predicted ground-level air concentration ($\mu\text{g}/\text{m}^3$) for that duration and $RfC_{duration}$ represents the selected (duration specific) reference concentration ($\mu\text{g}/\text{m}^3$). A CR less than or equal to one signifies that the estimated exposure is less than or equal to the exposure limit; therefore, no adverse health risk is expected. Conversely, a CR greater than one signifies the potential for adverse health effects.

For the multi-pathway risk assessment, a Hazard Quotient (HQ) approach was applied. HQ values were calculated by dividing the predicted exposure dose (via multiple pathways) by the appropriate toxicity reference value (reference dose [RfD]), according to Eq. (2):

$$HQ = \frac{\sum Exp}{RfD} \quad (2)$$

Where $\sum Exp$ represents the chronic exposure estimate resulting from the sum of multiple exposure pathways ($\mu\text{g}/\text{kg}/\text{day}$) and RfD represents the selected chronic reference dose ($\mu\text{g}/\text{kg}/\text{day}$). For the purposes of this assessment, it was considered that the intake of the COPC by all routes of exposure was unlikely to exceed the tolerable intake level when the HQ was less than 0.2. This conservative approach allows 80% of the tolerable daily intake of a COPC to be received from other sources not considered in this risk assessment.

2.10.2. Non-threshold chemicals (carcinogens)

Incremental lifetime cancer risk (ILCR) and lifetime cancer risk (LCR) estimates resulting from direct air inhalation were calculated described in Eqs. (3) and (4):

$$ILCR = [Air]_{project\ alone} \times UR \quad (3)$$

$$LCR = [Air]_{all\ sources} \times UR \quad (4)$$

Where $[Air]_{project\ alone}$ represents the predicted annual average ground-level air concentration from the Project Alone ($\mu\text{g}/\text{m}^3$), $[Air]_{all\ sources}$ represents predicted annual average ground-level air concentrations from all sources, and UR represents COPC-specific unit risk ($\mu\text{g}/\text{m}^3$)⁻¹.

For the multi-pathway risk assessment, ILCR/LCR estimates resulting from a lifetime of exposure through multiple pathways were calculated using Eqs. (5) and (6):

$$ILCR = \sum LADD_{project\ alone} \times CSF \quad (5)$$

$$LCR = \sum LADD_{all\ sources} \times CSF \quad (6)$$

Where $\sum LADD_{project\ alone}$ represents the sum of average daily dose via multiple pathways from the project alone ($\mu\text{g}/\text{kg}/\text{day}$), $\sum LADD_{all\ sources}$ represents the sum of average daily dose via multiple pathways from the all sources ($\mu\text{g}/\text{kg}/\text{day}$), and CSF represents the cancer slope factor ($\mu\text{g}/\text{kg}/\text{day}$)⁻¹.

In this risk assessment, an ILCR of 1-in-1,000,000 was considered acceptable, as outlined in relevant provincial guidelines (MOE, 2005). As no regulatory guidance exists for LCRs, this value was compared with the typical observed cancer incidence in the Canadian population, which is 38% for women and 44% for men (Canadian Cancer Society, 2007).

3. Results and discussion

3.1. Risk characterization: Existing conditions

Human health risks resulting from baseline exposures to individual COPC in the baseline scenario (prior to construction of the facility) were estimated using the results of the baseline ambient air monitoring and the baseline soil and biota sampling (Supporting Information, Section S6).

3.1.1. Inhalation risk assessment: Non-carcinogens

For criteria air contaminants (CACs, for which regulatory limits already exist), no baseline case acute (1-hr or 24-hr) or chronic (annual) CR risk estimates exceeded the regulatory benchmark (CR = 1), therefore no adverse health risks were expected from exposure to baseline air concentrations of these compounds (Table 4). Additionally, baseline case CACs (including NO₂, SO₂, PM_{2.5}, and PM₁₀) were also compared to WHO benchmarks for informational purposes and no exceedances were observed (Table 4). Similar results were noted for the baseline traffic case, in which estimated offsite vehicle emissions were added to the measured baseline ambient air conditions, except for a slight exceedance (CR = 1.1) for annual nitrogen dioxide compared to the WHO benchmark (Supporting information Section S8). However, the concentration of nitrogen dioxide measured in the baseline ambient air monitoring program in the LRASA was similar to that observed in other urbanized areas such as Toronto, Hamilton, and Windsor (Supporting information, Section S7), therefore this observation does not represent a unique property-specific risk. For non-criteria air contaminants (for which no relevant criteria were identified) baseline case concentrations were also shown not to exceed the acute (1-hr or 24-hr) or chronic (annual) CR regulatory benchmark (Table 5).

3.1.2. Inhalation risk assessment: Carcinogens

For non-criteria air contaminants assessed as possible carcinogens, the estimated lifetime cancer risk (LCR) values associated with their baseline ambient air concentrations were calculated (Supporting information Section S8). Because there are no acceptable benchmarks for comparison of LCR values, the implications of baseline results for each receptor group and scenario are not discussed in detail. However, to put these values in context, the maximum LCR associated with an individual baseline ambient air concentration for a COPC addressed in this study was $3.1 \times 10^{-3}\%$ (Supporting information Section S8), while the typical observed cancer incidence in the Canadian population is 38% for women and 44% for men (Canadian Cancer Society, 2007).

3.1.3. Multi-pathway risk assessment: Non-carcinogens

For all non-carcinogens, baseline chronic risk estimates (via multiple exposure pathways) were expressed as HQ values (Tables 6, 7, and Supporting Information Section S8). For most receptors and COPC, the predicted hazard quotients did not exceed the regulatory benchmark of 0.2 for the Baseline Case. However, some exceedances were noted for resident and farmer infants and toddlers. Also, addition of the swimming or hunting/angling exposures to the toddler receptor also led to some exceedances. Therefore, these cases were examined further.

3.1.3.1. Resident infant. For the resident infant receptor, the multi-pathway assessment indicated that potential risks may exist from exposure to baseline concentrations of PCBs and dioxins/furans (Table 6, HQ values of 11 and 3.8, respectively). The identified risk from these compounds was entirely related to the ingestion of breast milk, for which the COPC concentrations had been predicted based on exposure of the infant's mother to measured or estimated background COPC concentrations in relevant exposure media (i.e., soil) and food items (e.g., produce, poultry, etc.). However, in the results of the baseline sampling program, concentrations of PCBs, dioxins and furans were frequently below detection limit for these exposure media and food items (Supporting Information, Section S6). In these cases, the method detection limit (MDL) was substituted for the contaminant concentration in order to provide a 'worst-case scenario' estimate of exposure. However, it is possible that actual contaminant concentrations were significantly lower than the MDL (or not present at all). Therefore, the HQ values for PCBs and dioxins/furans that were calculated in this assessment for the resident infant receptor may represent a significant overestimation of the actual risk.

Table 4

Concentration Ratio (CR) Values for Baseline and 140,000 tpy for Criteria Air Contaminants at the Maximum Ground Level Concentration. A bolded cell indicates exposure for that particular scenario and COPC exceeded the selected benchmark.

COPC	Concentration Ratio (CR) Values					Concentration Ratio (CR) Values –WHO Benchmarks ^f				
	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
<i>1-Hour</i>										
Ammonia ^a	-	0.0006	0.0006	0.006	0.006	-	-	-	-	-
Carbon Monoxide (CO)	0.07	0.001	0.07	0.01	0.08	-	-	-	-	-
Hydrogen Chloride (HCl) ^a	-	0.04	0.04	0.44	0.44	-	-	-	-	-
Hydrogen Fluoride (HF) ^a	-	0.01	0.01	0.13	0.13	-	-	-	-	-
Nitrogen Dioxide (NO ₂)	0.16	0.11	0.27	0.18	0.34	0.32	0.22	0.54	0.36	0.68
Particulate Matter - PM ₁₀ ^{a, b, e}	-	-	-	-	-	-	-	-	-	-
Particulate Matter - PM _{2.5} ^{b, e}	-	-	-	-	-	-	-	-	-	-
Particulate Matter - Total ^{b, e}	-	-	-	-	-	-	-	-	-	-
Sulfur Dioxide (SO ₂)	0.03	0.02	0.05	0.29	0.32	-	-	-	-	-
<i>24-Hour</i>										
Ammonia ^a	-	0.003	0.003	0.03	0.03	-	-	-	-	-
Carbon Monoxide (CO) ^c	-	-	-	-	-	-	-	-	-	-
Hydrogen Chloride (HCl) ^a	-	0.02	0.02	0.23	0.23	-	-	-	-	-
Hydrogen Fluoride (HF) ^{a, c}	-	-	-	-	-	-	-	-	-	-
Nitrogen Dioxide (NO ₂)	0.29	0.03	0.32	0.05	0.34	-	-	-	-	-
Particulate Matter - PM ₁₀ ^{a, e}	-	0.01	0.01	0.11	0.11	-	0.01	0.01	0.11	0.11
Particulate Matter - PM _{2.5} ^e	0.68	0.02	0.70	0.18	0.86	0.82	0.02	0.84	0.21	1.0
Particulate Matter - Total ^e	0.29	0.004	0.30	0.04	0.34	-	-	-	-	-
Sulfur Dioxide (SO ₂)	0.07	0.006	0.08	0.10	0.17	0.15	0.01	0.17	0.22	0.38
<i>Annual</i>										
Ammonia ^a	-	7.8E-05	7.8E-05	0.0001	0.0001	-	-	-	-	-
Carbon Monoxide (CO) ^d	-	-	-	-	-	-	-	-	-	-
Hydrogen Chloride (HCl) ^a	-	0.0007	0.0007	0.0010	0.0010	-	-	-	-	-
Hydrogen Fluoride (HF) ^{ad}	-	-	-	-	-	-	-	-	-	-
Nitrogen Dioxide (NO ₂)	0.62	0.003	0.62	0.003	0.62	0.93	0.005	0.93	0.005	0.93
Particulate Matter - PM ₁₀ ^{a, d, e}	-	-	-	-	-	-	0.0008	0.0008	0.001	0.001
Particulate Matter - PM _{2.5} ^{d, e}	-	-	-	-	-	0.98	0.002	0.98	0.002	0.98
Particulate Matter - Total ^e	0.35	0.0003	0.35	0.0004	0.35	-	-	-	-	-
Sulfur Dioxide (SO ₂)	0.20	0.002	0.21	0.003	0.21	-	-	-	-	-

^a Baseline Data Not Available.

^b 1-hr TRV Not Available.

^c 24-hr TRV Not Available.

^d Annual TRV Not Available.

^e Particulate Matter results include contribution of Secondary Particulate.

^f “-” indicates WHO benchmark not available.

3.1.3.2. Resident toddler. The multi-pathway assessment for exposure of the toddler resident receptor to COPC indicates that potential risks may exist from exposure to baseline concentrations of PCBs (HQ = 0.49), arsenic (HQ = 0.32) and thallium (HQ = 0.25) (Table 6). For PCBs, it was determined that the majority of risk was associated with ingestion of homegrown produce and fruit. However, as was previously noted in the discussion of the risk of PCBs to resident infants, the PCB concentrations in these media in the baseline sampling program were below detection limits and were replaced with the value of the MDL in the risk assessment. Therefore, the HQ value for PCB exposure for the toddler resident likely overestimates the actual risk.

For arsenic, risk to the toddler resident receptor was attributed to incidental ingestion of soil. In contrast to PCBs, arsenic was widely detected in soil in the baseline sampling program. However the maximum detected soil arsenic concentration (8 mg/kg) used in the risk characterization was within the range of concentrations previously reported in natural, uncontaminated soils in Canada (Wang and Mulligan, 2006) and was less than the current Ontario Ministry of the Environment regulatory soil chemical standard of 11 mg/kg for arsenic at sensitive sites (MOE, 2004b). Therefore, this soil is not likely to cause any undue risk to human receptors within the LRSA. The elevated HQ values observed for the resident toddler receptors for arsenic can likely be attributed to conservative model assumptions applied throughout the risk assessment process.

For thallium, the relevant exposure pathways that contributed to the potential risk to resident toddlers were incidental soil ingestion and produce and fruit ingestion. However, none of the soil, produce, or fruit samples collected during the baseline sampling program had detectable levels of thallium. Therefore, the risk assessment for thallium was based entirely on the substitution of the method detection limit (1 mg/kg) for the undetected values and likely provides a significant overestimation of risk. In addition, the detection limit (1 mg/kg) was less than the Ontario Ministry of the Environment regulatory soil chemical standard for sensitive sites of 2.5 mg/kg (MOE, 2004b). This also suggests that the elevated HQ values observed in this assessment for thallium for the resident toddler are likely due to conservative model assumptions applied throughout the risk assessment process.

3.1.3.3. Farmer Infant. The multi-pathway assessment for exposure of the farmer infant receptor to COPC also suggested potential risks may exist from exposure to baseline concentrations of PCBs, dioxins/furans, and 1,2,4-trichlorobenzene (Table 6, HQ values of 118, 20, and 0.21, respectively). However, as was noted for the resident infant receptor, PCBs and the majority of dioxins/furans were not detected in any media relevant to exposure of farmers (i.e., soil, home-grown produce, or farm-raised livestock) (Supporting Information, Section S6). Furthermore, 1,2,4-trichlorobenzene was also not detected in any samples collected in the baseline sampling program (Supporting Information, Section S6). Therefore, these HQ values may also represent a significant

Table 5
Concentration Ratio (CR) Values for Baseline and 140,000 tonnes per year operating scenarios at the Maximum Ground Level Concentration. Each value represents the maximum observed CR value for an individual COPC within each chemical class. A bolded cell indicates exposure for that particular scenario and COPC exceeded the selected benchmark.

COPC	Concentration Ratio (CR) Values – 140,000 tpy															
	1-hour						24-hour						Annual			
	Baseline	Project Alone	Project	Process Upset	Process Project	Process Project	Baseline	Project Alone	Project	Process Upset	Process Project	Baseline	Project Alone	Project	Process Upset	Process Project
Metals	0.04	0.03	0.04	0.25	0.27	0.16	0.12	0.003	0.12	0.004	0.12	0.12	0.003	0.12	0.004	0.12
Chlorinated Polycyclic Aromatics	0.001	0.0003	0.001	0.003	0.004	0.01	0.005	0.0006	0.005	0.006	0.01	0.002	9.0E-06	0.002	2.0E-05	0.002
Chlorinated Monocyclic Aromatics	0.0006	7.5E-05	0.0007	0.0008	0.001	0.0001	5.2E-07	0.0001	5.0E-06	0.0001	0.0001	0.002	3.0E-06	0.002	1.0E-05	0.002
Polycyclic Aromatic Hydrocarbons (PAH)	0.01	6.9E-05	0.01	0.0007	0.01	0.07	0.002	0.07	0.002	0.002	0.07	0.002	1.0E-06	0.002	2.0E-06	0.002
Volatile Organic Chemicals (VOC)	0.55	0.005	0.55	0.05	0.56	0.41	0.18	0.002	0.41	0.02	0.41	0.18	0.0002	0.18	0.0005	0.18

overestimation of the actual risk due to the substitution of the MDL for non-detect values.

3.1.3.4. Farmer Toddler. HQ values greater than 0.2 were observed for the farmer toddler receptor for total PCBs, bromoform, carbon tetrachloride, chloroform, dichloromethane, 1,2,4,5-tetrachlorobenzene, 1,2,4-trichlorobenzene, antimony, arsenic, beryllium, thallium, and dioxins/furans (Table 6). When the risks to the farmer toddler from each COPC were apportioned into their respective exposure pathways, it was observed that ingestion of dairy was the primary exposure pathway associated with risks to the farmer toddler (>65% of total exposure for all chemicals except for arsenic for which only 47% of exposure was related to ingestion of dairy). However, none of these chemicals were actually detected in dairy products in the baseline sampling program and risk assessment was performed using the method detection limit. Therefore, as has been observed for other receptors and COPC in this assessment, the hazard quotients resulting from this substitution likely represent overestimations of the true risk. Furthermore, as toddler-specific ingestion rates for food items produced on farms were not available, child-specific ingestion rates were adopted from US EPA (2005) as a conservative measure that may also have resulted in an overestimate of exposure since ingestion rates are typically proportional to body weight (Health Canada, 2007).

The farmer toddler also received a significant proportion of its exposure to arsenic via soil and dust ingestion (26%). As was previously discussed with respect to the resident toddler, the maximum soil arsenic concentration used for risk characterization in this assessment (8 mg/kg) is within the expected range for uncontaminated soils in Canada and is also less than the Ontario Ministry of the Environment regulatory soil chemical standard for sensitive sites (MOE, 2004b). Therefore, it is not considered likely that soil and dust ingestion will pose significant undue risk with respect to arsenic exposure for any of the human receptors in the LRASA.

3.1.3.5. Additional Risks Related to Swimming and Hunting/Angling. Additional risks from exposure to surface water while swimming, wading or playing in surface water bodies, as well as from engaging in hunting and angling activities within the LRASA were assessed (Table 7). Results of the swimming exposure assessment indicate that the incremental risks associated with exposure to surface water are between one to six orders of magnitude less than the acceptable multi-pathway HQ benchmark of 0.2 (Table 7). When this additional exposure pathway was added to an existing receptor (e.g., the resident Toddler), the only HQ exceedances noted were for COPC that exceeded the regulatory guideline prior to addition of the swimming pathway (Table 7). In contrast, results of the hunter/angler assessment suggested that this pathway alone may be sufficient to increase COPC exposure above the regulatory guideline for arsenic, cadmium, total PCBs and dioxins/furans (Table 7, HQ values of 0.43, 0.46, 0.67, and 0.38, respectively). Some of these contaminants were not detected in small mammals or fish collected in the baseline sampling program (Supporting Information, Section S6), therefore some of the perceived risk may relate to the replacement of non-detect values with the method detection limit. Furthermore, the concentrations of COPC that were detected in fish (PCBs, arsenic, cadmium, and certain dioxins/furans) and small mammals (arsenic and cadmium), were similar to what would be expected at other areas across Ontario and are therefore not unique to this project (Supporting Information, Section S7).

3.1.4. Multi-pathway risk assessment: Carcinogens

The baseline case multi-pathway assessment also provided oral/dermal lifetime cancer risk (LCR) estimates for all carcinogenic COPC for the defined multi-pathway receptors and for the incremental exposures resulting from recreational swimming and/or hunting/angling (Supporting Information, Section S8). As discussed in Section 3.1.2, there is no acceptable benchmark for comparison of LCR values, as

they represent an individual's lifetime cancer risks associated with all potential exposures to a given carcinogenic COPC within the environment. However, the maximum LCR observed under baseline conditions for these COPC was 0.03%, which is much lower than the typical observed rates of cancer in Canada (38% for women and 44% for men) (Canadian Cancer Society, 2007).

3.2. Risk characterization: Construction case

For consideration of the construction case, it was assumed that construction activities would occur intermittently, during daylight hours, over a period of approximately 30 months. The primary concerns related to these activities with respect to human health were considered to be dust emissions from construction activities and exhaust emissions from fuel combustion by vehicles on the site. In addition, construction activities such as welding, use of solvents, sand blasting and painting may also affect air quality in the construction area. However, relative to the anticipated operational emissions, construction emissions will be minor, short-term and transitory. Therefore, it was expected that the assessment of operational scenarios (Sections 3.3–3.4) will be protective of any potential health risks that could arise during periods of construction and this case was not assessed in detail.

3.3. Risk characterization: Operational scenarios (140,000 tonnes per year)

3.3.1. Inhalation risk assessment: Non-carcinogens

For CACs, predicted maximum 1-hour, 24-hour and annual air concentrations for predicted operational scenarios at 140,000 tonnes per year (i.e. Project Alone Case, Project Case, Process Upset Case or Process Upset Project Case) did not exceed their relevant exposure limits (Table 4); therefore, no adverse health risk is expected from potential exposure to CACs. Additionally, when predicted CAC concentrations were compared to WHO benchmarks for informational purposes, no exceedances were noted for any of the considered assessment scenarios, except for $PM_{2.5}$ in the Process Upset Project Case ($CR = 1.01$, Table 4). The exceedance of fine particulate matter is driven by baseline concentrations as the CR for baseline conditions alone is 0.82, while the CR for process upset conditions is only 0.21 (Table 4). However, the baseline concentration of $PM_{2.5}$ in this area is similar to other urban areas in Ontario (Supporting Information, Section S7). In addition, frequency analysis of the baseline monitoring performed as part of this assessment showed that 24-hour $PM_{2.5}$ concentrations exceeding the WHO benchmark of $25 \mu g/m^3$ are very rare (Supporting Information, Section S9). No exceedance was noted in comparison to the selected 24-hour $PM_{2.5}$ Canada-Wide Standard (Table 4).

In addition, for the CACs, the Traffic Case (which combined emissions from offsite and onsite traffic with the anticipated onsite stationary source emissions for the facility) was contrasted with the baseline traffic case. In this case, the predicted 1-hour, 24-hour and annual air concentrations for the CAC at 140,000 tonnes per year did not exceed their relevant exposure limit for either the Baseline Traffic Case, or the Traffic Case (Supporting Information, Section S8). Therefore, no adverse health risk is expected from potential exposure to CACs due to the combined effect of facility emissions at 140,000 tonnes per year and local vehicular traffic. When compared to WHO benchmarks for informational purposes, an exceedance was noted for annual nitrogen dioxide ($CR = 1.2$) for both the baseline traffic case and the traffic case (Supporting Information, Section S8). However, as discussed in Section 3.1.1, this exceedance was driven by baseline concentrations, which were within a normal range for an urban area in Ontario (Supporting Information, Section S7). Therefore, this does not represent an unusual level of risk associated with this location.

For remaining COPC, none of the predicted maximum 1-hour, 24-hour or annual air concentrations exceeded their relevant exposure limit for any of the operational scenarios (Table 5).

3.3.2. Inhalation risk assessment: Carcinogens

For all carcinogenic COPC, chronic incremental lifetime cancer risks (ILCR) values were calculated for the 140,000 tonnes per year Project Alone Case and Process Upset Case at the maximum predicted ground level concentration (Supporting Information, Section S8). As outlined in Section 2.10.2, an ILCR less than or equal to 1-in-1,000,000 (i.e., 1×10^{-6}) signifies that the incremental lifetime cancer risk is less than the regulatory benchmark (i.e., the assumed safe level of exposure); therefore, no adverse risk is expected. Conversely, an ILCR greater than 1×10^{-6} indicates that the potential for an elevated level of risk may be present and suggests further investigation should be pursued to confirm the identified risk. In this assessment, none of the predicted ILCR exceeded the regulatory benchmark for the carcinogenic COPC in either the Project Alone Case or Process Upset Case (Supporting Information, Section S8). Therefore, it is not expected that concentrations of carcinogenic COPC from the facility at 140,000 tonnes per year will pose any individual adverse carcinogenic risk to the health of human receptors via inhalation.

3.3.3. Multi-pathway risk assessment: Non-carcinogens

For most receptors, COPC, and operational scenarios, the HQ values did not exceed the regulatory benchmark of 0.2 (Tables 6, 7). The only exceedances noted were for operational scenarios that also incorporated the baseline conditions (i.e., the Project Case and Process Upset Project Case). In these cases, the source of the exceedance was always the baseline case. For instance, for the local resident infant and toddler receptors neither the Project Alone Case nor the Process Upset Case ever represented more than approximately 0.5% of the Project Case or Process Upset Project Case risk, respectively. Similarly, for the farmer infant and toddler receptors, the Project Alone Case or Process Upset Case never represented more than approximately 2% of the Project Case or Process Upset Project Case risk, respectively.

As discussed in Section 3.1.3, the exceedances observed in the baseline conditions were related to a number of issues such as the use of laboratory method detection limits as environmental media concentrations and the conservative nature of risk assessment exposure calculations. In addition, some COPC concentrations actually exceeded relevant guidelines in specific media. However, the baseline COPC concentrations were found to be no different in the LRASA than in other similar areas of Ontario and are therefore not unique to this project.

3.3.4. Multi-pathway risk assessment: Carcinogens

Incremental lifetime cancer risks (ILCR) were estimated for all receptors under the Project Alone Case and Process Upset Case assessment scenarios (Supporting Information, Section S8). In addition, activity specific ILCR values were calculated with respect to hunting/angling and swimming and were added to that of the worst case resident receptor. None of the predicted ILCR values exceeded the accepted regulatory benchmark for the Project Alone Case or Process Upset Case; therefore, it is not expected that the facility will pose any additional adverse cancer risk to the health of local receptors at 140,000 tonnes per year.

3.4. Risk characterization: Operational scenarios (400,000 tonnes per year)

For comparison purposes, a human health risk assessment was also performed that considered the possible expansion of the facility to its maximum design operating capacity of 400,000 tonnes per year. This assessment was performed using identical methods and assumptions as those described for the 140,000 tonnes per year assessment, except that the facility related emissions were increased. Most of the conclusions of this assessment were similar to those identified for operational scenarios at 140,000 tonnes per year (i.e., most observed risks were related to existing baseline conditions rather than facility-related emissions). However, in the Process Upset Case,

Table 6
Summary of Multi-Pathway Risk Assessment Hazard Quotient (HQ) Results for Baseline and 140,000 tonnes per year operating scenarios for a. the worst-case resident infant and toddler and b. farmer infant and toddler receptors. Each value represents the maximum observed HQ value for an individual COPC within each chemical class. A bolded cell indicates exposure for that particular scenario and COPC exceeded the selected benchmark.

a.										
	Worst-case resident infant					Worst-case resident toddler				
	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
<i>PAHs</i>										
Maximum observed	6.3E-06	3.4E-11	6.3E-06	9.6E-11	6.3E-06	2.0E-05	5.7E-10	2.0E-05	1.6E-09	2.0E-05
<i>PCBs</i>										
Aroclor 1254 (Total PCBs)	10.8	0.0003	10.8	0.0008	10.8	0.49	3.4E-05	0.49	9.6E-05	0.49
<i>VOCs</i>										
Max	0.0002	1.0E-12	0.0002	2.8E-12	0.0002	0.03	2.7E-09	0.03	7.6E-09	0.03
<i>Chlorinated Monocyclic Aromatics</i>										
Maximum observed	0.003	1.2E-08	0.003	3.4E-08	0.003	0.06	1.2E-07	0.06	3.5E-07	0.06
<i>Inorganics</i>										
All except Arsenic and Thallium	0.02	4.0E-05	0.02	5.9E-05	0.02	0.07	0.0002	0.07	0.0004	0.07
Arsenic	0.10	5.0E-07	0.10	7.3E-07	0.10	0.32	3.2E-06	0.32	4.6E-06	0.32
Thallium	0.05	0.0004	0.05	0.0006	0.05	0.25	0.002	0.25	0.003	0.26
<i>Dioxins/Furans and Lead</i>										
2,3,7,8-TCDD Equivalent	3.8	0.002	3.8	0.004	3.8	0.17	0.0002	0.17	0.0006	0.17
Lead	0.04	0.0002	0.04	0.0002	0.04	0.12	0.0005	0.12	0.0007	0.12
b.										
	Farmer infant					Farmer toddler				
	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
<i>PAHs</i>										
Maximum observed	6.8E-06	4.7E-11	6.8E-06	1.3E-10	6.8E-06	5.8E-05	1.5E-09	5.8E-05	4.1E-09	5.8E-05
<i>PCBs</i>										
Aroclor 1254 (Total PCBs)	117.5	0.004	117.5	0.01	117.5	4.2	0.0001	4.2	0.0004	4.2
<i>VOCs</i>										
1,1,1-Trichloroethane	1.8E-07	1.6E-14	1.8E-07	4.6E-14	1.8E-07	0.0006	5.1E-11	0.0006	1.4E-10	0.0006
Bromoform	6.6E-05	4.4E-11	6.6E-05	1.2E-10	6.6E-05	0.32	1.9E-07	0.32	5.3E-07	0.32
Carbon Tetrachloride	0.003	4.0E-11	0.003	1.1E-10	0.003	4.6	6.3E-08	4.6	1.8E-07	4.6
Chloroform	3.1E-05	2.3E-13	3.1E-05	6.4E-13	3.1E-05	0.32	2.0E-09	0.32	5.6E-09	0.32
Dichloromethane	2.8E-05	2.1E-12	2.8E-05	6.0E-12	2.8E-05	0.65	4.9E-08	0.65	1.4E-07	0.65
Trichlorofluoromethane	5.9E-06	1.2E-11	5.9E-06	3.4E-11	5.9E-06	0.02	3.8E-08	0.02	1.1E-07	0.02
<i>Chlorinated Monocyclic Aromatics</i>										
Maximum observed (excepting 1,2,4,5-Tetrachlorobenzene and 1,2,4-Trichlorobenzene)	0.03	4.0E-08	0.03	1.1E-07	0.03	0.17	3.2E-07	0.17	9.0E-07	0.17
1,2,4,5-Tetrachlorobenzene	0.02	1.6E-08	0.02	4.4E-08	0.02	0.40	2.4E-07	0.40	6.8E-07	0.40
1,2,4-Trichlorobenzene	0.21	1.7E-10	0.21	4.8E-10	0.21	20.1	1.3E-08	20.1	3.7E-08	20.1
<i>Inorganics</i>										
Maximum observed (excepting antimony, arsenic, beryllium, and thallium)	0.02	4.2E-05	0.02	6.1E-05	0.02	0.18	0.0006	0.18	0.0009	0.18
Antimony	0.01	5.9E-06	0.01	8.6E-06	0.01	0.24	8.3E-05	0.24	0.0001	0.24
Arsenic	0.10	7.0E-07	0.10	1.0E-06	0.10	0.57	7.6E-06	0.57	1.1E-05	0.57
Beryllium	0.001	6.6E-07	0.001	9.6E-07	0.001	0.42	2.8E-06	0.42	4.1E-06	0.42
Thallium	0.05	0.0006	0.05	0.0008	0.05	1.2	0.01	1.2	0.02	1.2
<i>Dioxins/Furans and Lead</i>										
2,3,7,8-TCDD Equivalent	20.3	0.05	20.3	0.13	20.4	0.72	0.002	0.72	0.004	0.73
Lead	0.04	0.0002	0.04	0.0003	0.04	0.20	0.0010	0.20	0.001	0.20

slightly elevated potential risks above the government benchmarks for human health were noted that were not explained by baseline conditions. Maximum exposure to the 1 hour hydrogen chloride concentration at the commercial/industrial receptor location resulted in a CR of 1.0 (benchmark CR = 1.0) and exposure of farmer infant to breast milk of a mother living in close proximity to the facility under the Process Upset Case resulted in an infant dioxin and furan HQ of 0.22, which was slightly in excess of the government benchmark of 0.2. However, these slight exceedances of benchmark risk levels

were seen only under upset conditions, it is possible that they may be prevented through the application of adequate engineering controls. Regardless, in the event that a 400,000 tonnes per year expansion of the facility is eventually contemplated, special consideration should be given at that time to ensure that Process Upset Conditions do not result in an undue risk to people living and working in the area surrounding the facility. Overall, the results suggest that a 400,000 tonnes per year facility could be safely sited in Clarington, Ontario using the pollution control technology suggested by Covanta.

Table 7

Summary of multi-pathway risk assessment hazard quotient (HQ) results for baseline and 140,000 tonnes per year operating scenarios for additional exposure via a. swimming and b. hunting/angling. The results of adding these exposure pathways to the worst case resident toddler are also shown. Each value represents the maximum observed HQ value for an individual COPC within each chemical class. A bolded cell indicates exposure for that particular scenario and COPC exceeded the regulatory benchmark.

a.	Hazard quotients for swimming exposure alone (toddler)					Swimming exposure added to worst case resident toddler				
	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
<i>PAHs</i>										
Maximum observed	1.2E-06	2.8E-11	1.2E-06	7.8E-11	1.2E-06	2.1E-05	5.7E-10	2.1E-05	1.6E-09	2.1E-05
<i>PCBs</i>										
Aroclor 1254 (Total PCBs)	0.03	6.8E-07	0.03	1.9E-06	0.03	0.52	3.5E-05	0.52	9.8E-05	0.52
<i>VOCs</i>										
Maximum observed	0.001	2.1E-08	0.001	5.8E-08	0.001	0.03	2.6E-08	0.03	7.3E-08	0.03
<i>Chlorinated Monocyclic Aromatics</i>										
Maximum observed	0.0007	1.1E-07	0.0007	3.0E-07	0.0007	0.06	2.3E-07	0.06	6.5E-07	0.06
<i>Inorganics</i>										
Maximum observed excepting arsenic, cadmium, and thallium	0.02	1.3E-05	0.02	1.9E-05	0.02	0.07	0.0002	0.07	0.0003	0.07
Arsenic	0.01	2.7E-06	0.01	3.9E-06	0.01	0.33	5.8E-06	0.33	8.5E-06	0.33
Cadmium	0.0003	2.6E-05	0.0003	3.8E-05	0.0003	0.03	0.0003	0.03	0.0004	0.03
Thallium	0.005	0.001	0.006	0.001	0.008	0.26	0.003	0.26	0.004	0.26
<i>Dioxins/Furans and Lead</i>										
2,3,7,8-TCDD Equivalent	0.003	2.8E-07	0.003	8.0E-07	0.003	0.17	0.0002	0.17	0.0006	0.17
Lead	0.0008	2.3E-05	0.0008	3.4E-05	0.0008	0.12	0.0005	0.12	0.0007	0.12
b.										
	Hazard quotients for hunter/angler exposure alone (toddler)					Hunter/angler exposure added to worst case resident toddler				
	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
<i>PAHs</i>										
Maximum observed	2.1E-05	3.4E-12	2.1E-05	9.6E-12	2.1E-05	4.1E-05	5.7E-10	4.1E-05	1.6E-09	4.1E-05
<i>PCBs</i>										
Aroclor 1254 (Total PCBs)	0.67	0.002	0.67	0.006	0.68	1.20	0.002	1.20	0.006	1.20
<i>VOCs</i>										
Maximum observed	–	6.2E-09	–	1.7E-08	–	0.03	6.2E-09	0.03	1.7E-08	0.03
<i>Chlorinated Monocyclic Aromatics</i>										
Maximum observed	0.06	8.3E-06	0.06	2.3E-05	0.06	0.11	8.4E-06	0.11	2.4E-05	0.11
<i>Inorganics</i>										
Maximum observed excepting arsenic, cadmium, and thallium	0.16	0.001	0.16	0.002	0.16	0.17	0.001	0.17	0.002	0.17
Arsenic	0.43	3.3E-05	0.43	4.7E-05	0.43	0.75	3.6E-05	0.75	5.2E-05	0.75
Cadmium	0.47	0.008	0.47	0.01	0.48	0.49	0.008	0.50	0.01	0.50
Thallium	0.17	0.002	0.17	0.003	0.17	0.42	0.004	0.42	0.006	0.43
<i>Dioxins/Furans and Lead</i>										
2,3,7,8-TCDD Equivalent	0.38	0.002	0.38	0.005	0.38	0.54	0.002	0.54	0.005	0.55
Lead	0.04	0.0006	0.04	0.0009	0.04	0.15	0.001	0.15	0.002	0.15

3.5. Risk characterization: Decommissioning and abandonment

Decommissioning and abandonment of the facility is not expected to occur for several decades. Similar to the construction case, it is expected that this process would entail short-term, localized emissions of air contaminants. While it is unlikely that these activities would significantly increase any potential risk to human health, it is expected that a more current assessment of these potential risks would be conducted prior to the commencement of decommissioning activities. Consequently, the prediction of risks to human health from decommissioning and abandonment were not undertaken in this assessment.

4. Uncertainty Analysis

As part of this risk assessment, it was necessary to make certain assumptions in order to be able to quantitatively evaluate the risks to human health from exposure to the Project. These assumptions

inherently add an element of uncertainty to the risk assessment. Where variability and uncertainty are known to exist, it is standard risk assessment practice to make assumptions and select data that are likely to overestimate, rather than underestimate, potential exposure and effects. As a result, risk assessments tend to overstate the actual level of risk. Some of the conservative assumptions applied in this risk assessment include the use of method detection limits to represent chemical concentrations and use of child-specific ingestion rates to represent toddler rate of ingestion. A full accounting of the assumptions and uncertainties relied upon in this HHRA is provided in the Supporting Information (Section S10).

5. Conclusions

Overall, the results of the human health risk assessment indicate that it is not expected that the proposed project (i.e., construction, operation, and eventual decommissioning of a modern EFW thermal

treatment facility) will result in any adverse health risk to local residents, farmers or other receptors in the Local Risk Assessment Study Area at 140,000 tonnes per year. Although some risk has been identified through the assessment of Baseline Case concentrations, this risk can be attributed to conservative modeling assumptions that overestimate the actual risk present (e.g., use of method detection limits to represent chemical concentrations and use of child-specific ingestion rates to represent toddler rate of ingestion) and/or pre-existing natural or anthropogenic conditions that correlate to baseline risk. These pre-existing natural or anthropogenic conditions were generally shown not to differ from those of similar urbanized areas in Ontario.

Based on the success of this human health risk assessment and an accompanying ecological risk assessment (see Ollson et al., 2014), the regions of Durham and York were able to move forward with this project, and the described facility is currently under construction, with operational start-up anticipated in Fall 2014. This facility will be capable of processing 140,000 tonnes of post-diversion residual waste annually while recovering metals and energy.

Conflict of interest

The authors have no actual or potential conflicts of interest to declare.

Acknowledgements

The authors wish to acknowledge the contribution of Greg Crooks and his Air Quality team at Stantec who provided the required air input data. We would also like to thank the Chair Anderson, Council, and Cliff Curtis and his staff at Durham Region; without them this project would not have been undertaken. The direction of the overall environmental assessment was provided by James McKay, now with HDR Canada.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.scitotenv.2013.07.019>.

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MEMO

Job **Bromine in Waste**
 Client **EfW Facility TNG NSW**
 Memo no. **5**
 Date **2016-10-14**
 To **To Whom it may concern**
 From **Ahmet Erol (Ramboll)**
 Copy to **Ian Malouf (DADI)**
Phill Andrew (Savills)
Amanda Lee (AECOM)
Lesley Randall (AECOM)
Rachael Snape (Urbis)
Damon Roddis (Pacific Environment)

Bromine Emissions from WtE

Background

The most common use of brominated flame retardants (BFRs) is in building materials, textiles and electronic supplies, e.g. TVs, PCs and photocopiers. In incineration plants with good combustion BFRs will decompose and form other brominated compounds (Söderström, G. et al, 2000), mainly hydrogen bromide (HBr) (Vehlow, J. et al, 1998).

In addition, other brominated compounds will also be formed, in particular brominated organic compounds, such as dioxins where chlorine is fully or partly substituted by bromine (brominated and brominated/chlorinated dioxins).¹

Characterization of the brominated waste

Data from literature regarding bromine content in municipal waste from households and small businesses indicates typical bromine content of 0,003-0,006 % by weight of bromine.

Floc waste TNG

Analysis of 17 floc samples from TNG facility done by HRL Technology shows that the average bromine content is 0,01 % on dry basis (db). Maximal bromine content was 0,04 % (db). TNG has 14,4% floc waste in the design waste.

Increase of bromine content by floc waste

Assuming an average content of 0.0045% bromine (average of reported minimum and maximum content of 0.003% and 0.006%) in all waste streams except floc waste and 0,01% bromine in floc this results in an increase of bromine in the total waste from 0.0045% to 0.00529%. The final concentration of 0.00529% is still within the reported range of MSW.

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¹ Emission Measurements During Incineration of Waste Containing Bromine, TemaNord 2005:529

Effect of increased bromine content in waste

The most extensive measurements were performed at the largest municipal waste incineration plant in Oslo (Klemetsrud Plant). The plant has two incinerator lines, each with the capacity of incinerating 10 tons of waste per hour. Each line is equipped with a flue gas cleaning system, consisting of a bag house filter with active coal injection, and a wet scrubber.

At this plant sampling and analysis were carried out in three different situations:

- No addition of brominated waste
- Mix with 5 % by weight brominated waste; i.e. approximately 0,05 % by weight bromine in total waste.
- Mix with 10 % by -weight brominated waste; i.e. approximately 0,1 % by weight bromine in total waste.

Results

The in stack (after flue gas treatment) concentration of gaseous bromine (HBr and Br₂) was reported to be < 2,2 mg/Nm³ even in the case of addition of 10% brominated waste.

The in stack concentration of BFR in case of the Klemetsrud Plant was 14-22 ng/Nm³, in case of the Energos Plant (Ranheim) <5 ng/Nm³. The BFR detected where DekabDE and TBBPA, in the flue gas DekabEDE has the highest concentration level.

Brominated waste has no adverse effect on dioxin formation nor on additional formation of brominated and chlorinated/brominated dioxins.

Conclusions

Using floc waste as a fuel has no adverse effect on the emissions of a WtE facility.

In case of TNG (with a comparable flue gas cleaning technology as the Energos plant) the in stack concentrations for gaseous bromine can be assumed to be below 2 mg/Nm³, BFR below 5 ng/Nm³ and total brominated dioxins far below 0,05 ng/Nm³.

Reference (attached):

Emission Measurements During Incineration of Waste Containing Bromine, TemaNord 2005:529, © Nordic Council of Ministers, Copenhagen 2005

Emission Measurements During Incineration of Waste Containing Bromine

Emission Measurements During Incineration of Waste Containing Bromine

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Co-operation was formalised in 1952 when *the Nordic Council* was set up as a forum for parliamentarians and governments. The Helsinki Treaty of 1962 has formed the framework for Nordic partnership ever since. The *Nordic Council of Ministers* was set up in 1971 as the formal forum for co-operation between the governments of the Nordic countries and the political leadership of the autonomous areas, i.e. the Faroe Islands, Greenland and Åland.

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Preface

Background

The most common use for BFRs is in building materials, textiles and electronic supplies, e.g. TVs, PCs and photocopiers. In incineration plants with good combustion BFRs will decompose and form other brominated compounds, mainly hydrogen bromide (HBr).

In addition, other brominated compounds will also be formed, in particular brominated organic compounds, such as dioxins where chlorine is fully or partly substituted by bromine (brominated and brominated/chlorinated dioxins).

There have been few Studies regarding incineration of plastics containing BFRs at full-scale incineration plants with a modern flue gas cleaning system.

The Norwegian Ministry of the Environment presented in the autumn of 2002 a working plan for reducing the emissions and discharges of BFRs. One action is to investigate the emissions from incineration of waste containing BFRs.

The project has been organised as follows:

Management group:

- Håkon Jentoft, Norwegian Solid Waste Association (NRF)
- Bernt Ringvold, Norwegian Pollution Control Authority (SFT)
- Ole Viggo Svendsen, Elektronikkretur AS
- Tor Christian Svendsen, Hvitevareretur AS
- Hallgeir Betele, Renas
- Fredrik Eide Aas, Stena Miljø AS
- Gerhard Dürbeck, Oslo kommune renovasjonsetaten
- Nordic working group for Thermal Treatment

Reference group:

- NRF's working group for Thermal Treatment
- NRF has been the secretary for the project.

The work has been done by Kjelforeningen Norsk Energi. Authors are Dag Borgnes and Bente Rikheim.

Abstract

Project objective

The objective of the project is to investigate the emissions of dioxin-compounds that may occur from incineration of plastic waste containing brominated flame retardants (BFRs) together with waste from households and the commercial sector. The decomposition of BFRs will also be investigated.

The project results will serve as a basis for both the authorities and the owners of incineration plants, to make decisions about whether, and under what conditions, this type of waste may be incinerated.

Literature search and initial studies

The objective of the literature search and initial studies is to establish a detailed program for measurements. It should also be the basis for comparison and evaluation of the results from the measurements.

Studies in small-scale pilot plants

Incineration tests with waste containing BFRs have been carried out in small-scale pilot plants in Sweden (University of Umeå) and in Germany (TAMARA Plant).

The results from Sweden, where the content of bromine was increased up to 1-2 % by weight, showed that the concentration of halogenated dioxins in untreated flue gas was significantly higher with BFRs than without.

At the TAMARA-Plant, the content of bromine varied from 0 to approximately 0,2 % by weight. Increasing the content of bromine showed no increase in the concentration of chlorinated dioxins, or in brominated or brominated/chlorinated dioxins in untreated flue gas.

Measurements on full-scale plants

Studies of emissions of brominated dioxins to air were earlier carried out on incineration plants in Denmark, Sweden and Norway. Measurements performed in Denmark also included brominated/chlorinated dioxins. All plants were equipped with advanced flue gas treatment systems. Measurements were performed during incineration of waste from households and the commercial sector (waste with low BFR content), and results showed very low levels for all analysed dioxins.

There is little relevant data of emissions of BFRs from waste incineration plants. We have found results from emission measurements carried out at a Japanese incineration plant burning plastic waste containing

BFRs, mixed with waste from households and the commercial sector. Total input of BFRs was less than 500 g/hr, and the emission to air of PBDE (polybrominated diphenyl ethers) and TBBPA (tetrabromobisphenol) was respectively 3,5 and 8 ng/Nm³.

Incineration tests at three Norwegian plants

The main goal of the incineration tests was to establish the flue gas concentration of brominated, chlorinated and brominated/chlorinated dioxins before and after flue gas cleaning, and with different proportions of plastic waste containing BFRs. To verify the input, the contents of bromine and chlorine in all output flows (bottom ash, fly ash, scrubber water and flue gas) were analysed. The decomposition of BFRs was investigated by analysing BFRs in output flows.

Execution of tests

The incineration test included sampling and analysis at two larger plants for mixed municipal waste, and one smaller plant for ground/shredded industrial waste. The brominated waste added was waste from a plant for demolition of electric and electronic devices. It was estimated to contain approximately 1 % by weight bromine. Approximately 80% of this contained PBDE.

The most extensive measurements were performed at the largest municipal waste incineration plant in Oslo (Klemetsrud Plant). The plant has two incinerator lines, each with the capacity of incinerating 10 tons of waste per hour. Each line is equipped with a flue gas cleaning system, consisting of a bag house filter with active coal injection, and a wet scrubber.

At this plant sampling and analysis were carried out in three different situations:

- No addition of brominated waste
- Mix with 5 % by weight brominated waste; i.e. approximately 0,05 % by weight bromine in total waste.
- Mix with 10 % by -weight brominated waste; i.e. approximately 0,1 % by weight bromine in total waste.

At the second plant (FREVAR Plant, Fredrikstad) measurements were carried out with no addition of BFRs.

At the third and smaller plant (Energos Plant, Ranheim) measurements were performed incinerating a mix with 0 and 20 % by weight bromine containing waste (i.e. 0,2 % by weight bromine in the total mix).

Results and conclusions

The incinerating conditions during sampling and measurements at Klemetsrud Plant (Oslo) were normal for the plant, with average CO-levels at approximately 20-30 mg/Nm³. During sampling at the FREVAR Plant average CO-levels were approximately 50 mg/Nm³. At FREVAR Plant they also experienced some problems with the fabric filters during the measurements.

At the Energos Plant (Ranheim) CO was not detectable, which indicates that incineration was good.

Bromine in output flows

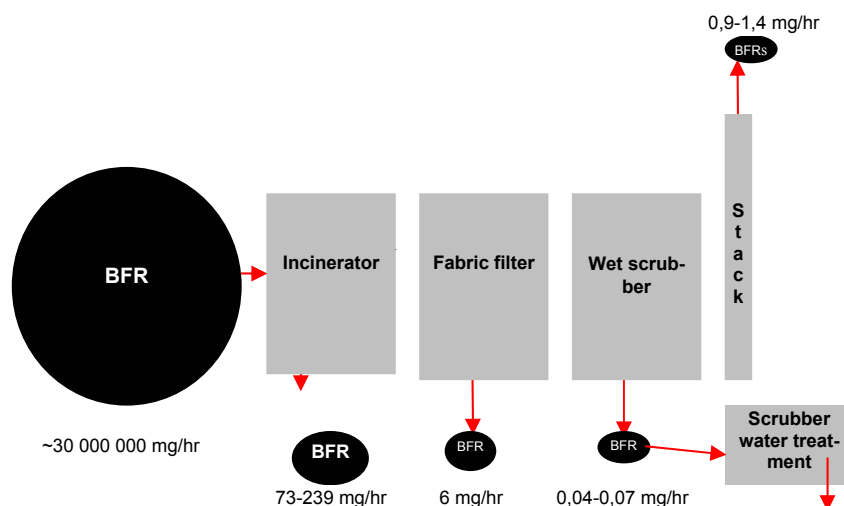
Measured results for gaseous bromine in untreated flue gas during incineration of normal waste mix indicates a bromine content equal to or lower than what is common for waste from households and the commercial sector.

Measured results of bromine in output flows at Klemetsrud Plant (Oslo) and at the Energos Plant (Ranheim) indicate that the content of bromine in the plastic mixture was correctly estimated.

Brominated flame retardants (BFRs)

The amount of BFRs in the waste mixture used in the tests at Klemetsrud Plant (Oslo) was not analysed, but calculated/estimated to be approximately 30 kg/hr. The measured results confirm that BFRs decompose in the incineration process. The amount of BFRs in output flows is less than 0,001 % by weight of the total amount of BFRs in the waste mix (see figure below).

Observed input and output flows of brominated flame retardants at Klemetsrud Plant (Oslo) with 10 % by weight addition of brominated waste.



The concentration of BFRs in flue gas from Klemetsrud Plant (Oslo) was 14-22 ng/Nm³. This equals 0,9-1,4 mg/hour and approximately 0,01 kg/year, assuming 8000 running hours/year at the same emission level. A Danish study (Miljøstyrelsen, 1999) estimates the total national Danish emissions of BFRs from incineration to be < 0,04 tons. A report from the Norwegian National State Pollution Control Authority (SFT), estimates the national emissions from combustion in Norway to be < 0,01 tons (1998), i.e. < 10 kg/year.

At the Energos Plant (Ranheim) the reported concentration of BFRs in the flue gas was <5 ng/Nm³.

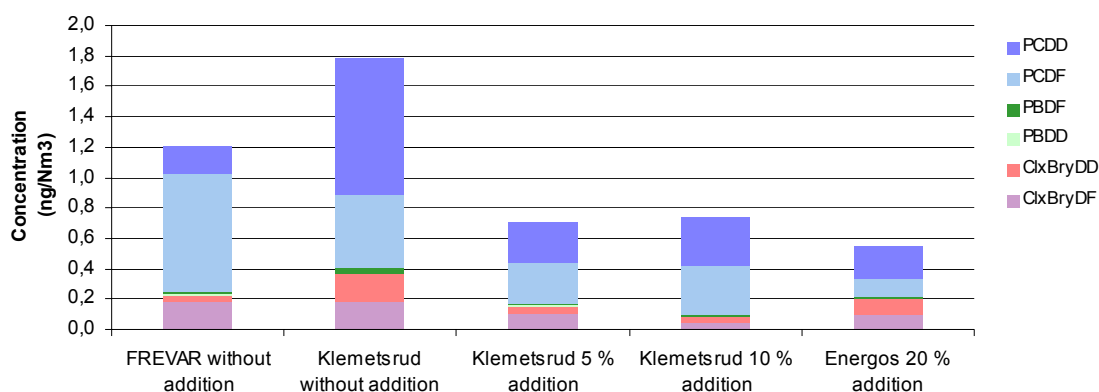
The concentration of BFRs in bottom ash from the tests at Klemetsrud Plant (Oslo) shows levels far below the threshold value stated in the Hazardous Waste Directive.

DekaBEDE and TBBPA (Tetrabrombisphenol A) are the dominating compounds of BFRs in the bottom ash at Klemetsrud Plant (Oslo). In the flue gas dekaBEDE has the highest concentration level.

Concentration of dioxins in emissions to air (after cleaning)

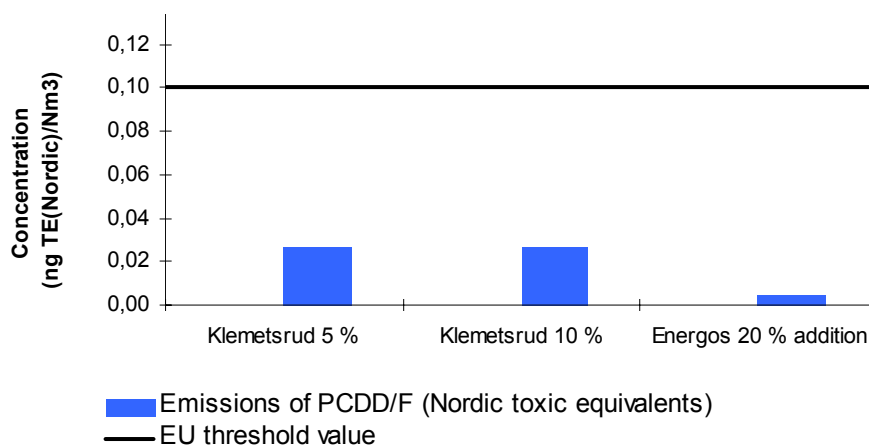
The figure below shows emissions of chlorinated, brominated and chlorinated/brominated dioxins without any addition of brominated waste, and with the addition of 5 % by weight, 10 % by weight and 20 % by weight bromine containing waste.

Emissions of chlorinated, brominated and chlorinated/brominated dioxins. The results are reported as actual emission, not toxic equivalents.



Emissions of chlorinated dioxins (PCDDs/Fs), in terms of Nordic toxic equivalents, resulting from the addition of brominated waste, are presented in the figure below.

Emissions of chlorinated dioxins (PCDDs/Fs), in terms of Nordic toxic equivalents, resulting from addition of brominated waste.



Uncertainty in sampling and analysis, variations in operating conditions and waste mixture, differences between laboratories with respect to methods of analysis (especially dioxins), makes comparison of results difficult. We may although draw the following main conclusions:

- Increasing the content of BFRs in the waste gave no significant increase in the emissions of chlorinated dioxins, or either brominated and chlorinated/brominated dioxins
- The emission level is highest for chlorinated dioxins, lower for chlorinated/brominated dioxins and lowest for brominated dioxins

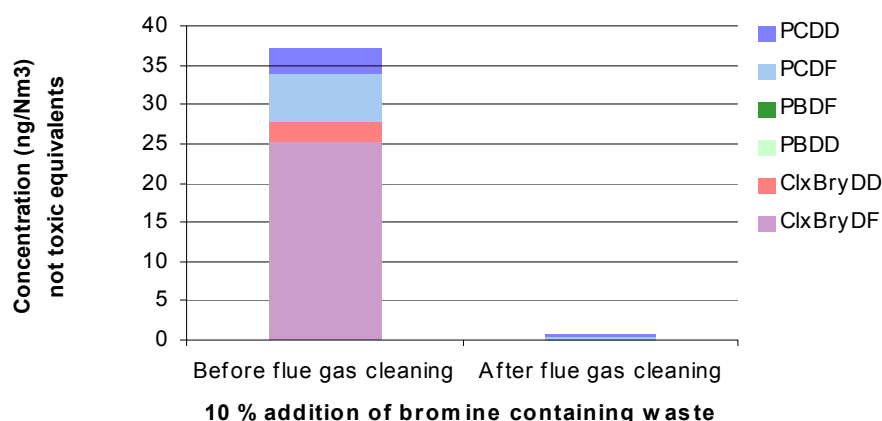
- The emission levels for chlorinated dioxins, reported as Nordic toxic equivalents, are low compared to emission threshold value in the EU-directive for incineration of waste. The reported emission levels were 0,03 ng/Nm³ and 0,006 ng/Nm³ respectively for the Klemetsrud Plant (Oslo) and Energos Plant (Ranheim), and the EU threshold value is 0,1 ng/Nm³.
- The emission measurement results indicate that the incineration efficiency and the operating conditions of the flue gas treatment systems are of greater importance to the resulting emission levels for dioxins, rather than the bromine content level.

Concentration of dioxins in emissions before and after cleaning

Measurements of dioxins in the flue gas before and after flue gas cleaning were carried out with addition of 10 % by weight bromine containing waste at the Klemetsrud Plant (Oslo)

The concentration of chlorinated/brominated dioxins before cleaning was approximately 28 ng/Nm³, which was three times the concentration of chlorinated dioxins. After cleaning the concentration was approximately 0,1 ng/Nm³. This gives a removal efficiency for chlorinated/brominated dioxins of >99% and for chlorinated dioxins approximately 93%. The removed dioxins end up in the fly ash from the fabric filter, which is treated as hazardous waste.

Concentration of chlorinated, brominated and chlorinated/brominated dioxins in flue gas before and after flue gas cleaning, Klemetsrud Plant (Oslo). The levels are given as actual measured levels, not corrected for toxicity.



1. Background and Objective

The most common use of BFRs is in building materials, textiles and electronic supplies, e.g. TVs, PCs and photocopiers. In incineration plants with good combustion BFRs will decompose and form other brominated compounds (Söderström, G. et al, 2000), mainly hydrogen bromide (HBr) (Vehlow, J. et al, 1998). Additionally, other brominated compounds will also be formed, in particular brominated organic compounds, such as dioxins where chlorine is fully or partly substituted by bromine (brominated and brominated/chlorinated dioxins).

The formation of brominated/chlorinated dioxins during incineration of waste with BFRs has been proven earlier, in the project “Co-incineration of brominated flame-retardants and MSW in small-scale reactor” in 2000 (financed by the Nordic PA-group and documented in TEMA-Nord Report No 2001:512). The tests were carried out at Umeå University, in at laboratory pilot plant with no flue gas treatment.

There have been few studies regarding incineration of plastics containing BFRs at full-scale incineration plants with a modern flue gas cleaning system.

The Norwegian Ministry of the Environment presented in the autumn of 2002 a working plan for reducing the emissions and discharges of BFRs. One action is to investigate the emissions from incineration of waste containing BFRs.

The objective of the project is to investigate the emissions of dioxin-compounds that may occur from incineration of plastic waste containing brominated flame-retardants (BFRs) together with waste from households and the commercial sector. The decomposition of BFRs will also be investigated.

The project results will serve as a basis for both the authorities and the owners of incineration plants, to make decisions about whether, and under what conditions, this type of waste may be incinerated.

This report is based on separate reports from incineration tests at Klemetsrudanlegget (Oslo) (Kjelforeningen-Norsk Energi, 2004), and at FREVAR (Kjelforeningen-Norsk Energi, 2004b), which also include detailed description of measurement methods and analysis results.

The incineration tests at Energos Ranheim are reported in a report from TÜV Nord Umweltschutz (2003).

2. Terms and Abbreviations

Brominated flame-retardants (BFRs)

Name specific compound	IUPAC-no.*	Abbreviation	Abbreviation groupname	Groupname
TBA		TBA	TBA	Tribromanisol
4,4'-DiBB	15	DiBB	PBB	Polybrominated Biphenyls
2,2',4,5'-TetBB	49	TetBB		
2,2',5,5'-TetBB	52			
2,2',4,4',5,5'-HexBB	153	HeksaBB		
2,4,4'-TriBDE	28	TriBDE	PBDE	Polybrominated diphenyl ethers
2,2',4,4'-TetBDE	47	TetBDE		
2,3',4',6-TetBDE	71			
3,3',4,4'-TetBDE	77			
2,2',4,4',5-PenBDE	99	PeBDE		
2,2',4,4',6-PenBDE	100			
2,3',4,4',6-PenBDE	119			
2,2',3,4,4',5'-HexBDE	138	HexBDE		
2,2',4,4',5,5'-HexBDE	153			
2,2',4,4',5,6'-HexBDE	154			
2,2',3,4,4',5',6-HepBDE	183	HepBDE		
DecaBDE	209	DecaBDE		
TBBPA		TBBPA	TBBPA	Tetrabrombisphenol A
alpha-HBCD		HBCD	HBCD	Hexabrom-cyklododecane
beta-HBCD				
gamma-HBCD				

* Indexes according to International Union of Pure and Applied Chemistry (IUPAC).

Chlorinated dioxins (PCDD+PCDF)

PCDD = polychlorinated dibenzo-p-dioxins

PCDF = polychlorinated dibenzofurans

Brominated dioxines (PBDD+PBDF)

PBDD = polybrominated dibenzo-p-dioxins

PBDF = polybrominated dibenzofurans

Brominated/chlorinated dioxins (ClxBryDD+ClxBryDF)

ClxBryDD, PXDD = polychlorinated/brominated dibenzo-p-dioxins

ClxBryDF, PXDF = polychlorinated/brominated dibenzofurans

3. Incineration of Plastics Containing Brominated Flame-Retardants

3.1 Plastics from EE-waste

Brominated flame-retardants are being found in i.e. electric and electronic (EE) products. In Norway and Sweden there is established extensive collection systems for discarded EE products. As a consequence of new EU regulations, similar systems will have to be established in all EU/EEA countries within the end of 2005.

Table 1 shows the amounts of plastics from EE-waste, based on the information from collection companies in Norway (Svendsen, T. C., 2003).

Table 1 Amounts of plastics from EE-waste, based on the information from collection companies (tons/år)

Collection company	Separated plastics (tons/år)	Plastics in shredderfluff (tons/år)
Elektronikkretur AS	1800	180
Hvitevareretur AS	150	4000
RENAS AS	45	239
Total	1995	4419

As will be seen from Table 1, approximately 2000 tons separated plastics is generated yearly from EE-waste. This is bigger plastic items with and without BFRs, which relatively easy may be sorted out manually, for example the cover of a data monitor, back-cover of a TV and soap container in a dishwasher. These plastic components will mainly be incinerated in advanced waste incinerators with adequate flue gas cleaning.

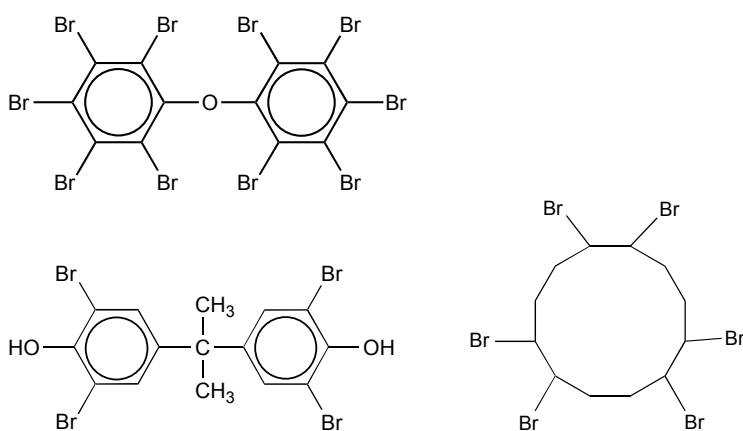
The largest amount of plastics will however be found in the so-called shredderfluff, with an amount of approximately 4400 tons/year. Shredderfluff is the waste fraction from wrecked car/scrap metal fragmenting plants, and it contains (among other things) a mix of plastics, rubber, wood, concrete, and small amounts of metals. In Norway, shredderfluff is normally deposited in landfills.

3.2 Emissions of brominated flame-retardants

The most applied brominated flame-retardants are the group polybrominated diphenylethers (PBDE) and the compounds tetrabromobisphenol A (TBBPA) og hexabromocyclododecane (HBCD).

Figure 1 shows an example of polybrominated diphenylethers (DeBDE), TBBPA and HBCD.

Figure 1 Polybrominated diphenylether (DeBDE), TBBPA og HBCD.



Decabromodiphenyl ether (DeBDE)
Hexabromocyclododecane (HBCD)

Tetrabromobisphenol A (TBBPA)

In incinerators with good combustion, the BFRs will decompose and form other brominated compounds (Söderström, G. et al, 2000), mainly hydrogenbromide (HBr) (Vehlow, J. et al, 1998).

3.3 Formation and emissions of chlorinated, brominated and brominated/chlorinated dioxins

Chlorinated dioxins is a collective term for organic compounds consisting of dibenzo-p-dioxins and dibenzofurans with 1-8 chlorine substituents in different positions. This gives a total 210 different polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Chlorinated dioxins and furans are often referred to as "dioxins".

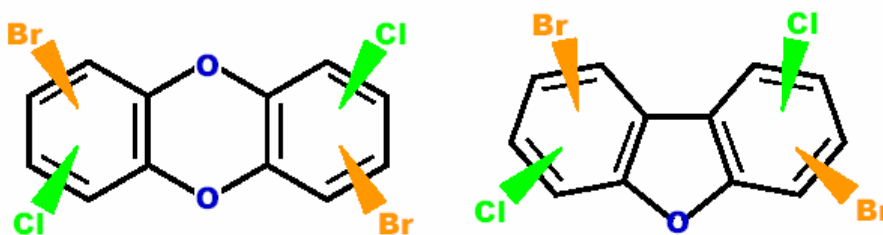
Brominated dioxines is a collective term for the corresponding 210 organic compounds substituted with bromine instead of chlorine. These are normally also referred to as PBDD og PBDF (polybrominated dibenzo-p-dioxins og polybrominated dibenzofurans).

Brominated/chlorinated dioxins includes dibenzo-p-dioxins and dibenzofurans with both bromine and chlorine substituents, in total 4600 different compounds. See figure 2.

Air emissions of chlorinated dioxins are regulated through the standard regulations for incineration, and the emissions are checked every 6 or 12 months. The emission limit value is given in terms of toxic equivalents, which is generated by weighted calculation, giving each compound a relative weight value between 0 and 1, depending on the toxicity. 2,3,7,8-tetrachlorine dibenzo-p-dioxin is known as the most toxic compound, and therefore has the relative weight value 1.

Toxic equivalents terms is however not established for compounds of brominated and brominated/chlorinated dioxins.

Figure 2 Brominated/chlorinated dibenzo-p-dioxins and dibenzofurans



Formation of dioxins

The formation of dioxins during incineration has been studied extensively for nearly 30 years.

Different formation mechanisms has been found:

- De Novo synthesis
- Precursor reactions
- Secondary halogenations in flue gas

In the de Novo synthesis, the formation takes place by chlorination of compounds in flue gas containing carbon. The chlorination step is assumed to occur as HCl combine to form Cl_2 (the Deacon-reaction), with subsequently chlorination of aromatics. The Deacon-reaction is catalysed by (among others) compounds of copper, and is favoured by oxygen excess.

Chlorinated dioxins may also be formed from precursors, for example chlor-phenols, which can condensate on particle surfaces, and also by halogenation of non-chlorinated dioxins and furans in flue gas. Studies have shown that the highest formation of dioxins takes place at temperatures between 200-600° C.

Emissions of dioxins may also occur if the incinerated waste or the added combustion air contains dioxins. To minimize the formation of chlorinated dioxins, one has found the following to be important:

- Short residence time at temperatures favouring dioxin formation
- Efficient combustion
- Minimize chlorine content in waste
- Minimize particle content in flue gas
- Increased sulphur/chlorine content ratio
- Minimize oxygen excess
- Minimize content of metals which can act as catalysers (especially copper)

Several studies have shown that there is no clear relation between the rate of dioxin formation and the chlorine content (SFT, 1994) (Wikström, E., 1999). However, some waste incineration tests indicate that dioxin formation increases with increasing chlorine content, when the chlorine content exceeds a certain value.

Several studies of waste incineration have shown that combustion efficiency is of greater importance for the dioxin formation, rather than the chlorine content.

Formation mechanisms for brominated and brominated/chlorinated dioxins are less investigated. It is however reasonable to assume that mechanism has similarities with the formation mechanism of chlorinated dioxins.

Incineration plants which comply with the regulations of the EU-directive for waste incineration, are all equipped with flue gas cleaning systems which reduce the concentration of chlorinated dioxins in the flue gas substantially. The similarities between chlorinated, brominated and brominated/chlorinated dioxins indicates strongly that the cleaning efficiency is also high for brominated and brominated/chlorinated dioxins.

4. Former Incineration Tests

Swedish, Danish and Finnish environmental authorities has been contacted to get data from incineration tests including measurements of brominated and brominated/chlorinated dioxins.

Information has also been gathered from universities and research communities in Sweden, Denmark and Germany, and also through search on the Internet. Articles from the last three Dioxin conferences (2001, 2002, 2003) are also examined.

The objective of this work has been to establish a detailed measurement program. The possibility to estimate input amounts of bromine from measurements/calculations of output bromine containing flows (bromine in bottom ash, fly ash, flue gas and scrubber water) is also investigated. The work should also form basis for comparison and evaluation of measurement results from the incineration test.

4.1 Brominated and brominated/chlorinated dioxins

4.1.1 Incineration tests in pilot plants

Emissions and formation of brominated dioxins is investigated in a pilot plant in Germany. The TAMARA Plant has a capacity of 250 kgs of waste per hour, and is equipped with textile filter, quenching and a wet scrubber. At this plant incineration tests of polystyrene- and polyurethane foam containing BFRs has been carried out, together with waste from households and smaller industries/businesses (Vehlow, J. et al, 1996).

The incineration temperature was ranging from 850 to 950 °C. The additional inputs of bromine during the tests were ranging up to 6 times the original bromine content in the household waste.

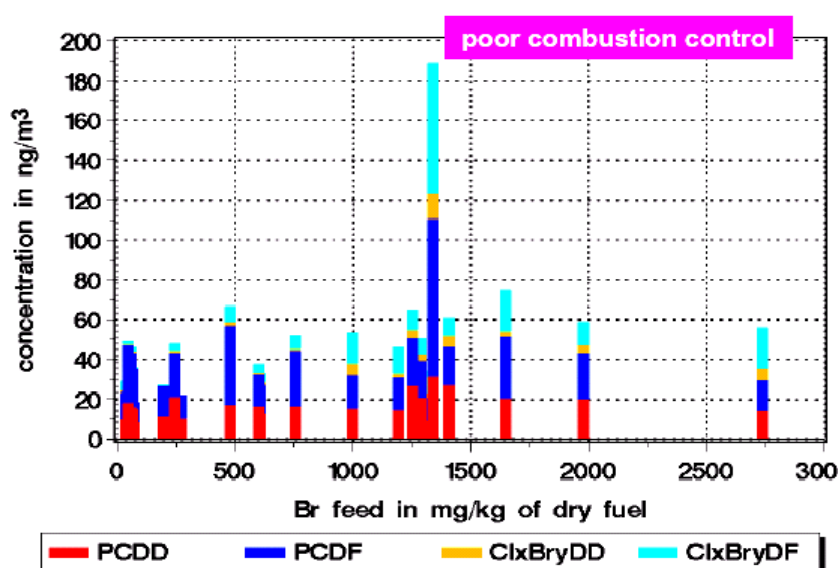
Measurement results showed low concentrations of brominated dioxins, and the study concluded that incineration of limited amounts of specific foams in efficient plants with “state of the art” flue gas cleaning, is environmentally acceptable.

Tests with incineration of plastics from EE-waste, together with waste from households and smaller industries/businesses, have also been carried out in the TAMARA Plant (Vehlow, J. et al, 1997). The tests included four different types of plastics, with different contents of bromine.

Measurements of brominated, chlorinated, and brominated/chlorinated dioxins in flue gas, both prior to and after cleaning, were carried out. The tests also included analysis of bromine content in the plastics, bromine-,

chlorine- and antimony-content in bottom ash, fly ash and flue gas before cleaning. Antimony is often added to enhance the effect of BFRs. It was concluded that EE-waste containing bromine and bromine and chlorine did not increase the total formation of dioxins. Figure 3 shows concentration levels of PCDDs/Fs and Cl_xBr_yDDs/Fs in flue gas before cleaning as a function of the bromine content in the waste.

Figure 3 Concentration levels of PCDDs/Fs and Cl_xBr_yDDs/Fs in flue gas before cleaning as a function of the bromine content in the waste, recorded from incineration tests with EE-waste at TAMARA Plant, Germany (Vehlow, J. et al, 1997).



The formation of brominated dioxins from co-incineration of household waste and brominated flame-retardants is investigated in a 5kW incineration reactor (fluidised bed) in pilot scale at the university of Umeå (Söderström, G. et al, 2000). Different types of flame-retardants were added in amounts corresponding to a "worst case scenario" for batch wise incineration of flame retarded products med BFRs. The incineration temperature was slightly above 800 °C.

The results from the studies in Umeå showed that the formation of halogenated dioxins were much higher when adding BFRs, than with only chlorine present. Additionally, the study showed that bromine caused significant higher formation of halogenated dioxins than the equal amount of chlorine, which is assumed to relate to the ratio between Br₂ and HBr, which again is substantially different from the ratio between Cl₂ and HCl. The conclusion from the study is that batch incineration of wastes containing BFRs should be avoided.

4.1.2 Measurements at full scale plants

In 2002 measurements of emissions of brominated dioxins were carried out at Energos Hurum Plant, Norway (Energos Hurum Energigjenvinning) with normal waste composition (wastes from households and small industries/businesses).

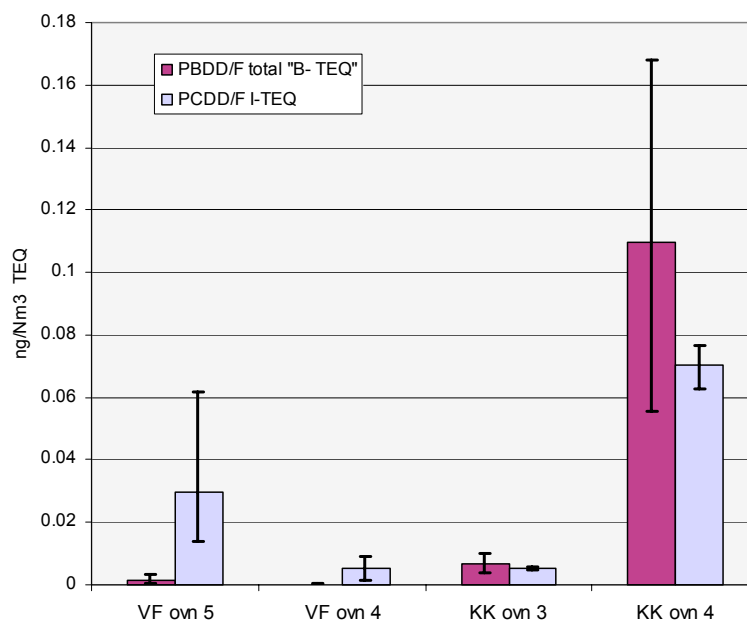
It was found 0,003 ng/Nm³ tetrabrominated dibenzo-p-dioxins. Concentrations of other single compounds were lower than the detection limit, i.e. than 0,0001-0,02 ng/Nm³. Note that the concentrations is given as actual measured values, not as toxic equivalents (Energos ASA, 2002).

In 1999 measurements of brominated dioxins were carried out at Uppsala Energi, Sweden and at Renova, Gothenburg, during incineration of ordinary municipal waste. Both plants are equipped with advanced flue gas cleaning systems, with low emissions of chlorinated dioxins (substantially lower than 0,1 ng/Nm³ in 1999). The emissions of brominated dioxins were lower than the detection limit for the measurements, i.e. < 0,05 ng/Nm³ for all measured dioxins (Westas, H., 2000).

Autumn 2002, Danmarks Miljøundersøgelser carried out a study regarding the content of brominated, chlorinated and brominated/chlorinated dioxins in flue gas and in remains from flue gas cleaning at Vestforbrænding (VF) (wastes from households and small industries/businesses) and Kommunekemi (KK) (hazardous waste) (Vikelsøe, J., 2000). Both plants were equipped with advanced flue gas cleaning systems.

Figure 4 shows comparison of PBDDs/Fs and PCDDs/Fs in flue gas from the plants after cleaning

Figur 4 Comparison of PBDDs/Fs and PCDDs/Fs in flue gas from Vestforbrænding and Kommunekemi (after cleaning). PBDDs/Fs total "B-TEQ" og PCDD/F I-TEQ, ng/Nm³. (Vikelsøe, J., 2000).



4.1.3 Comparison of test programs from earlier tests

Table 2 shows the added amount of bromine/brominecontaining plastics in earlier testprograms in small-scale pilot plants.

Table 2 Former test programs/measurements

Plant/test description	Share BFR-plastics [% by weight]	Bromine content in BFR-plastics	Bromine content in waste
		[% by weight]	[% by weight]
TAMARA			
Polystyrene- and polyurethane foam + waste from households and small industry/businesses	1-3	2,2-4,2	0,02-0,08
TAMARA			
Plastics from EE-waste + waste from households and small industry/businesses	3-12	0,4-1,5	0,01-0,18
Umeå University			
Waste from households and small industry/businesses added different BFRs	-	-	0,9-1,7

Table 3 shows the measurements included in incineration tests with brominated dioxins and/or chlorinated/brominated dioxins.

Table 3 Measurements included in incineration tests with brominated dioxins and/or chlorinated/brominated dioxins

	Analyzed parameters in waste	Analyzed parameters Raw flue gas	Analyzed parameters Clean flue gas	Additional analyzed parameters
TAMARA	Bromine, chlorine	PXDDs/Fs		Bromine in fly ash
PS- og PU- foam + waste from households and small industry/businesses				
TAMARA	Bromine, chlorine, antimony (Sb), PXDDs/Fs ⁰⁾ and flame-retardants ¹⁾	Bromine (HBr, Br ₂), chlorine, antimony (Sb), PXDDs/Fs	PCDDs/Fs Non-brominated dioxins	Bromine, chlorine, antimony (Sb) in bottom- and flyash
Umeå Universitet	Bromine, chlorine and flame-retardants ²⁾	Cl ₂ , HCl, Br ₂ , HBr, PXDDs/Fs ³⁾		
Waste from households and small businesses added different BFRs			PXDDs/Fs	
Uppsala Energi, Renova				
Waste from households and small industry/businesses				
Vestforbrænding			PXDDs/Fs	PXDDs/Fs in residue from flue gas cleaning
Waste from households and small industry/businesses				
Kommunekemi Hazardous waste			PXDDs/Fs	PXDDs/Fs in residue from flue gas cleaning

0) PXDDs/Fs: Dioxins containing bromine and/or chlorine
PBB, PBDE, TBBA
DeBDE, TBPP-A, HBCD
PCDD, PCDF, TeBCDD, TeBCDF, TeBDF, TeBDD

Relatively extensive incineration tests, with different input of bromine, have been carried out at pilot plants both in Sweden and Germany. In both tests analysis were carried out with respect to brominated and brominated/chlorinated dioxins on raw flue gas only (before cleaning).

Analysis of brominated dioxins in flue gas after cleaning is carried out on some Swedish and Danish waste incineration plants, with normal waste composition.

Our literature search and preliminary studies indicated clearly a need for more incineration tests and studies of brominated and brominated/chlorinated dioxins, especially in full scale plants. The scope of former studies indicates that the main goal with such tests should be to decide the concentrations in flue gas of brominated, chlorinated and brominated/chlorinated dioxins before and after cleaning, and at different levels of bromine content in the waste. To verify the input of bromine and chlorine, all output flows (bottom ash, fly ash, water from scrubbers and flue gas) should also be analyzed for bromine and chlorine.

4.2 Brominated flame-retardants

An article presented by Chen, Y. et al (Dioxin 2003) reports from sampling and analysis of emissions of BFRs and brominated dioxins carried out at an incineration plant burning wastes from households and small industry/businesses. The plant is not described in the article, nor the waste or the operating conditions of the plant. The method used to determine BFRs and dioxins is not the same as the methods used in the tests at Klemetsrud Plant, Oslo and Energos Plant, Ranheim. It is carried out five series of measurements of air emissions from a waste incinerator and 3 series from an electric smelter. Average results are quoted in Table 4. Seven congeners of PBDE (BDE-28, -47, -100, -99, -154, -153, -183) was detected in all the samples. The three most dominating congeners is BDE -47, -99 og -28 and both the tests shows equal distribution between the congeners.

Table 4 Emissions of BFRs and brominated dioxins from waste incinerator and electric smelter. (Chen, Y. et al, 2003).

	BFRs (ng/m ³)	Brominated dioxins (ng/m ³)
Waste incinerator	99±31	0,275-4,01
Electric smelter	68±25	0,079-0,485

An article presented by Tamade, Y. et al, Japan (Dioxin 2003) reports from measurements during incineration of plastic waste with BFRs. The measurements include analysis of brominated dioxins and furans, PBDE and TBBPA on the input waste, such as back covers from TVs, dust from

TVs, and also in mass flows from a recovery plant for plastics, and finally in mass flow from an incineration plant.

The incineration plant was equipped with an electric precipitator and a fabric filter. The incinerated waste was a mixture of residues from the plastic waste recovery plant (with BFRs) and waste from households and small industry/businesses. The waste was analysed with respect to content of PBDE, TBBPA and brominated dioxins. Total input amount of PBDE and TBBPA were 18-360 g/hr and 6,2-96 g/hr respectively. Analysis of brominated dioxins and furans in air emissions showed a total concentration of 0,014 ng/Nm³. Air emission of PBDE and TBBPA was 3,5 and 8 ng/Nm³ respectively. Bottom ash and filter dust showed a content of PBDE of 300 and 470 ng/g respectively. The content of TBBPA in bottom ash and filter dust was 20 and 1,3 ng/g respectively.

Due to few studies and lack of emission limit values for BFRs from waste incineration, we have also looked at reported concentration levels in other types of samples.

A study of indoor dust in common households in Germany includes analysis of 40 samples (taken from vacuum cleaners) with respect to 10 different PBDE congeners (BDE-28, -47, -49, -85, -99, -100, -153, -154, -183, -209) (Knoth, W. et al, 2003). The results show huge variations in concentrations between the different congeners, and also between the samples. BDE-209 was the dominating congener in 35 of the 40 samples, as BDE-99 dominated in 4 of the samples. The source for PBDE in the samples was reported unknown, with exception for some samples of dust from mattresses which showed high levels of dekaBDE. Average total concentration of the 10 PBDEs in the 40 samples was determined to 1404 ng/g.

The Norwegian Institute for Air Research (NILU) has taken samples of sediments for analysis of BFRs in the Drammen river, Norway (Fjeld et al, 2004).

Samples of sediment were taken at seven different spots in the river, four samples from the inner Drammensfjord and one sample in the marine environment of the fjord. The sum of PBDEs analysed showed a concentration level of 4-80 ng/g. The BDE-209 congener dominated in all samples.

NILU have also made studies of BFRs in leachate from landfills (Schlabach, M. et al, 2002).

Samples were taken from sediments in leachate from 6 larger landfills. PBBs were not detected in any of the samples. PBDE-209 was detected in all samples, with a concentration level in the range of 0,49-91 ng/g wet weight. The three HBCD-isomeres was detected in almost all samples, and the concentrations was in the range <0,1-84 ng/g wet weight for HBCD. TBBPA was detected in all sediment samples from the landfills, with a concentration level in the range of 01,9-44 ng/g wet weight.

PBDE-209 and HBCD are also detected in samples of moss, which implies that the compounds may be transported by air. NILU has estimated that maximum discharge from a larger landfill might rate up to 1-10 g/year per single compound of PBDE, HBCD and TBBPA. The concentrations found in the investigations are at the same levels as concentrations found in sewage sludge in Sweden.

Table 5 Results from different studies of BFRs

Type of study	BFR-compound	µg/g	ng/m ³
Air emissions from waste incineration	PBDE		99
Air emissions from electric smelter	PBDE		68
Dust from households	PBDE	1,4	
River sediments	PBDE	0,004-0,08	
Sediments from landfill leachate	PBDE	0,0005-0,09	
	HBCD	<0,0001-0,08	
	TBBPA	0,001-0,044	
Bottom ash from incinerator, Japan	PBDE	0,3	
	TBBPA	0,02	
Fly ash from incinerator, Japan	PBDE	0,47	
	TBBPA	0,0013	
Air emissions from incinerator, Japan	PBDE		3,5
	TBBPA		8

Our preliminary studies and literature search indicated clearly a need for more incineration tests and studies of emissions and decomposition of BFRs in connection with waste incineration.

4.3 Studies of other bromine compounds at Klemetsrud Plant, Norway

In 2002 measurements of brominated and brominated/chlorinated organic compounds were carried out at the Klemetsrud Plant in Norway. The measurements were performed by Kjelforeningen-Norsk Energi (Kjelforeningen-Norsk Energi, 2002).

In 1998 incineration tests with EE-waste were carried out at the same plant, and online measurements of a variety of brominated components in flue gas were performed (not dioxins). A portable GC was used for the measurements (Det Norske Veritas, 1998). In parallel measurements of emissions of chlorinated dioxins after flue gas cleaning was performed. The results indicated an increased level of dioxins during incineration of EE-waste. It should be noted that this was before active coal injection and fabric filtration were introduced at the plant.

5. Incineration Tests at Three Norwegian Waste Incineration Plants

Measurements of emissions of brominated and brominated/chlorinated dioxins, and brominated flame-retardants (BFRs) are carried out during incineration of waste with both normal and increased content of BFRs in the waste. For verification of input, analysis of bromine and chlorine in output flows were made. Decomposition of BFRs during incineration was also investigated by analysis of BFRs in output flows.

Tests and measurements were carried out at the following Norwegian plants:

- Klemetsrud Plant, Oslo : municipal waste incinerator, capacity 2 x 10 tons/hr
- Energos Plant, Ranheim : municipal waste incinerator*, capacity 1,5 tons/hr
- FREVAR Plant, Fredrikstad : municipal waste incinerator, capacity 2 x 5 tons/hr

* source separated and shredded waste

5.1 Measurement program

The program for measurements during tests at three Norwegian waste incineration plants are shown in Table 6 below.

Table 6 Program for measurements during tests at three Norwegian waste incineration plants

	Type of waste	Analysed parameters in flue gas <i>before</i> cleaning	Analysed parameters in flue gas <i>after</i> cleaning	Other analysed parameters
Klemetsrud-Plant	Waste from households and small industry/businesses	HCl, Cl ₂ , HBr, Br ₂	Chlorinated, brominated and chlorinated / brominated dioxins	-
	Waste from households and small industry/businesses + 5 % by weight brominated waste	HCl, Cl ₂ , HBr, Br ₂	Chlorinated, brominated and chlorinated / brominated dioxins	-
	Waste from households and small industry/businesses + 10 % by weight brominated waste	Chlorinated, brominated and chlorinated / brominated dioxins HCl, Cl ₂ , HBr, Br ₂	Chlorinated, brominated and chlorinated / brominated dioxins	Bromine, Chlorine and BFRs in bottom ash, fly ash, flue gas, scrubberwater
FREVAR Plant	Waste from households and small industry/businesses	HCl, Cl ₂ , HBr, Br ₂	BFRs Chlorinated, brominated and chlorinated / brominated dioxins	-
Energos Plant	Hospital waste		Chlorinated and brominated dioxins	-
	Industrial waste	HCl, Cl ₂ , HBr, Br ₂	Chlorinated, brominated and chlorinated / brominated dioxins	Bromine, Chlorine and BFRs in bottom ash
	Industrial waste + 20 % by weight brominated waste	HCl, Cl ₂ , HBr, Br ₂	HCl, Cl ₂ , HBr, Br ₂ BFRs	

Sampling and analysis of dioxins during tests with no addition of brominated waste at Klemetsrud Plant, and all sampling and analysis at Energos Plant, were performed by the German consultancy TÜV. Kjelforeningen-Norsk Energi did all other sampling at Klemetsrud Plant, and at FREVAR Plant. NILU laboratory made the analysis of dioxins and BFRs, Eurofins laboratory (Oslo) analysed the flue gas samples, and Analytica laboratory made the bottom ash, filter dust and scrubber water analysis.

5.2 Characterization of the brominated waste

Data from literature regarding bromine content in municipal waste from households and small businesses, indicates typical bromine content of 0,003-0,006 % by weight of bromine. One source (Söderström, G. et al, 2000) reports typical content of 0,004 % by weight from a study in 1992, but that the level has increased the last decade. In comparison is normal chlorine level in municipal waste approximately 0,75 % by weight (Söderström, G. et al, 2000).

The brominated waste added to the municipal waste was generated in a demolition plant for electric and electronic waste (Stena Miljø AS, Oslo). In total approximately 70 tons brominated waste were generated for the incineration tests.

Stena Miljø AS has calculated the level of bromine in the actual mixture (brominecontaining plastics) which were used in the tests at Kle-

metsrud and Energos Plants. The calculations gave the following levels : 27 % by weight brominated plastics, 16 % by weight wooden material, 57 % by weight plastics without bromine (Aass, F.E., 2003a). The bromine level in plastics is reported to be 3-4,5 % by weight, and the bromine level in the total mixture approximately 1 % by weight (Sjølin, S., 2003).

Approximately 80 % by weight of the brominated plastics is reported to contain PBDE (polybrominated diphenylethers).

Exact level of BFRs in the plastics is not known, but is earlier reported to be approximately 12 % by weight (SFT, 2003) (Aass, F.E., 2003b). This is determined mainly from PCs and monitors, and the level relatively uncertain.

A Danish report from 1999 reports the content of TBBPA and other BFRs separately in different electronic products (Miljøstyrelsen i Danmark, 1999). Reported levels are:

- Colour TVs :
 - a) TBBPA 12 % by weight
 - b) BFRs 12 % by weight
- PCs
 - a) TBBPA 12-14 % by weight
 - b) BFRs 12-14 % by weight

Levels in printers, photocopiers and fax-machines are reported to be lower.

As the brominated plastics used in the tests mainly origins from TV- and monitor-cabinets, it is assumed a BFR-level in the plastics of 12 % by weight.

Stena Miljø AS has also reported that the waste mix may contain approx. 1 % by weight PVC (Aass, F.E., 2004), from which on may derive that the chlorine level in the waste is significantly lower than in municipal waste from households and businesses.

The Norwegian State Pollution Control Authority (SFT) has done a preliminary analysis of BFRs in 60-100 kgs of plastic waste from the Stena Miljø AS demolition plant.

The total concentration level of BFRs was determined to be approximately 20 000 mg/kg, i.e. 2 % by weight.

The level of BFRs in the these plastics is therefore lower than the assumed levels for the plastics used in the tests. Still, the samples analysed by SFT may not necessarily be representative for the brominated waste used in the tests. Further, SFT showed that octaBDE and decaBDE was the dominating BFR-compounds, with a level of 8 000 - 9 000 mg/kg for each of the compounds.

Figure 5 shows brominated waste used in the incineration tests (before shredding).

Figur 5 Brominated waste used in the incineration tests (before shredding).



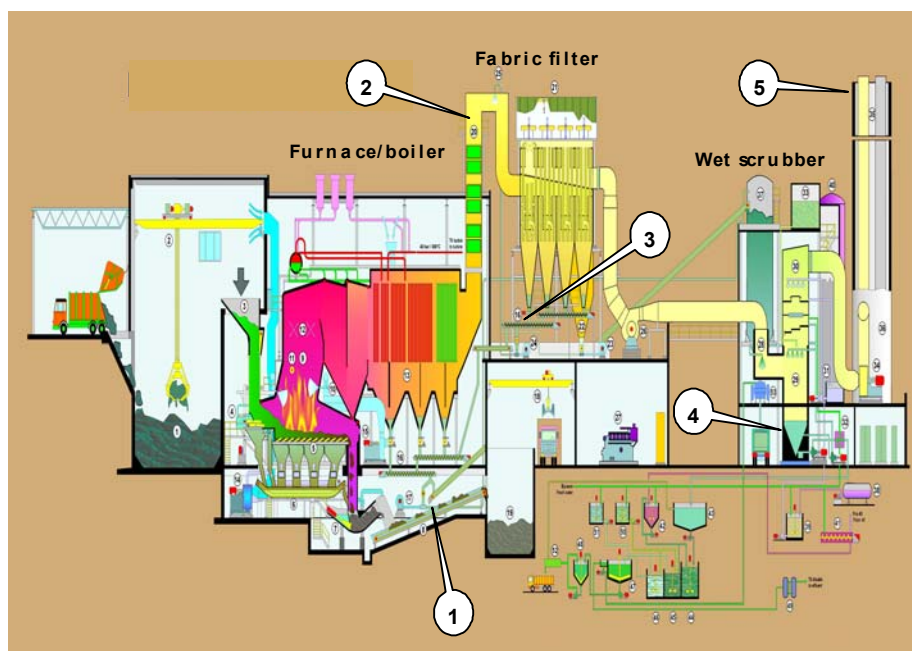
5.3 Description of plants and sampling points

5.3.1 Klemetsrud Plant

Measurements are carried out at Oslo Municipality's incineration plant at Klemetsrud in Oslo. The plant incinerates untreated municipal waste from households and businesses in 2 lines, each with a capacity of approx. 10 tons/hr. Each line is equipped with a flue gas cleaning system, consisting of active coal injection, a fabric filter and a wet scrubber.

A sketch of the plant, with marking of the sampling points, is shown in figure 6.

Figure 6 Sketch of Klemetsrud Plant, with marking of the sampling points.



- 1 **Bottom ash** Total bromine, total chlorine. Brominated flame-retardants.
 2 **Raw flue gas** Gaseous bromine and chlorine. Brominated, chlorinated, brominated/chlorinated dioxins
 3 **Filter dust** Total bromine, total chlorine. Brominated flame-retardants.
 4 **Scrubber water** Total bromine, total chlorine. Brominated flame-retardants.
 5 **Cleaned flue gas** Brominated, chlorinated, brominated/chlorinated dioxins. Brominated flame-retardants.

Measurements without addition of bromine containing waste

Measurements of brominated, chlorinated, brominated/chlorinated dioxins were done on line 1 by TÜV in parallel to the annual emission control measurements October 16th -17th 2003. Measurements of total bromine and chlorine in raw flue gas were done on line 2 December 18th 2003 by Kjelforeningen-Norsk Energi.

Measurements with addition of bromine containing waste

The measurements with addition of bromine containing waste were done October 28th and 30th 2003 by Kjelforeningen Norsk Energi.

Measurements were done with two different mixtures:

- Low addition: 5 % by weight addition of bromine containing waste. This mixture gives a feed rate for bromine containing waste of approx. 0,5 tons/hr, i.e. slightly above 5 % by weight. The resulting bromine feed rate was approx. 5 kg bromine/hr.
- High addition: 10 % by weight addition of bromine containing waste. It is possible to feed up to 2 tons/hr of bromine containing waste at line 2 at the Klemetsrud Plant. This is however an unrealistic high share, because it may significantly affect the incineration conditions. A realistic maximum addition is approx. 1 ton/hr (10 % by weight)

bromine containing waste). This mixture gives a feed rate of approx. 10 kg bromine/hr.

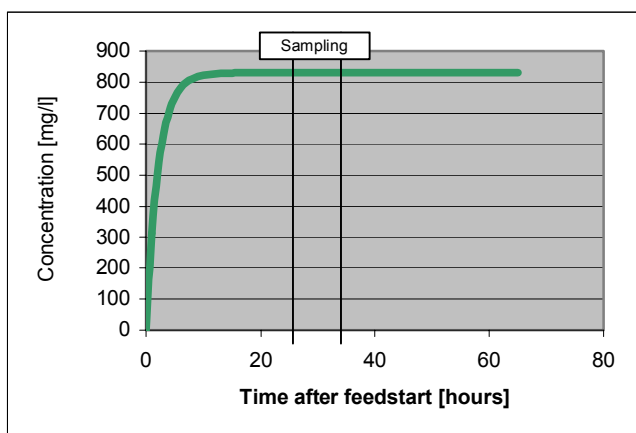
In order to maintain stable concentrations in output flows from the process, feeding of bromine containing waste to the incinerator has to start in due time before sampling.

Figure 7 shows the calculated theoretical change in concentration of bromine in filter dust, and in circulating fluids in scrubber (HCl-step). One can see from the figure that the concentration level in filter dust during sampling period is approx. 80-90 % by weight of maximum concentration level, and that the actual time of feed start, 24 hours before sampling, was sufficient to maintain a stable concentration level in circulating fluids in scrubber.

Figure 7 Calculated change in concentrations of bromine in filter dust and circulating fluids in scrubber (HCl-step).



Concentration change in filter dust



Concentration change in circulating fluids in scrubber

5.3.2 Energos Plant

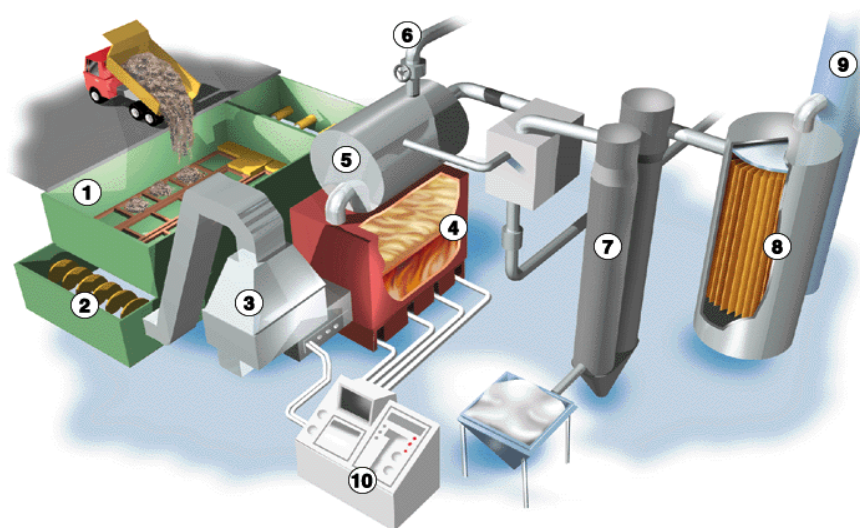
The Energos Plant at Ranheim incinerates annually approx. 10 000 tons of waste. The plant has approx. 4 MW thermal output, and a steamproduction of approx. 25 GWh/year, supplied to a neighbouring industrial plant, Peterson Linerboard Ranheim (PLR). The waste is a mixture of waste from PLR and other industries.

The flue gas is treated in a fabric filter after injection of coal and lime. Output flows are bottom ash/slag, fly ash and emissions to air from stack.

A flow sheet for the plant is shown in Figure 8. The waste is fed from the storage silo (1) with the conveyor (2) into the 2nd storage (3). From this storage the waste is fed in portions onto the fire grate in the primary chamber of the furnace (4). On the fire grate the waste is dried, gasified and burned-out at sub-stoichiometric conditions. A conveyor brings the waste through the primary chamber, and to the output shaft, where the burned waste falls down as slag. The flue gases are led through the boiler (convection unit) (5) and are cleaned in the fabric filter (8) after addition of activated carbon and lime.

Measurements with and without addition of 20 % by weight of bromine containing waste were carried out November 11th-13th 2003 by TÜV. The sampling points are positioned right into the inlet to the filter (8), and in the vertical outlet of the filter/inlet to stack (9).

Figure 8 Flow sheet for the Energos Plant at Ranheim



- | | |
|-----------------|----------------------------------|
| 1. Storage silo | 2. Conveyor |
| 3. 2nd storage | 4. Furnace |
| 5. Boiler | 6. Steam system |
| 7. Reactor | 8. Filter system |
| 9. Chimney | 10. Control- / monitoring system |

5.3.3 FREVAR Plant

FREVAR Incineration Plant is owned by Fredrikstad municipality. The plant incinerates approximately

78 000 tons waste annually, using two incineration furnaces. The plant produces 185 GWh steam per year, and has 99 % utilization of the produced energy (FREVAR, 2004).

The waste is fed into the feedershaft with a crane. From the shaft, the waste is fed in portions onto the fire grate. On the grate, the waste is dried, combusted and burned out. The movable grate takes the waste through the furnace to the outgoing shaft, into which the burned waste drops down as slag.

The flue gases are burned in a secondary combustion zone over the grate. The flue gas is cleaned in an electric precipitator, wet scrubber and a fabric filter. Active coal is added prior to the wet scrubber, and activated carbon and lime prior to the fabric filter.

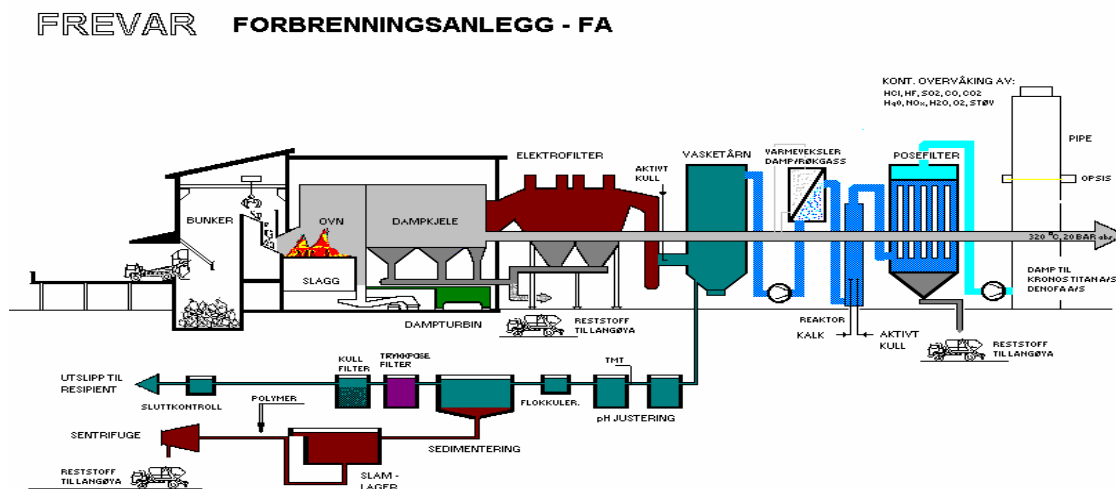
The flue gases from the two furnaces are led in to the same duct before the scrubber, and let out through a joint stack.

FREVAR also has a incinerator for hospital waste. The flue gas from this furnace is quenched and treated through a separate wet scrubber, before it is led in to one of the other furnaces for further combustion and cleaning. Annual control measurements at FREVAR are normally done with the hospital waste incinerator running.

Measurements of gaseous bromine and chlorine, and brominated, chlorinated and brominated/chlorinated dioxins were carried out parallel to the annual control measurements on November 5th 2003, by Kjelforeningen Norsk Energi.

A flow sheet of the plant is shown in Figure 9.

Figure 9 Sketch of the FREVAR incineration plant for household waste (FREVAR, 2004), with sampling points.



6. Results

6.1 Operating conditions

The combustion conditions were normal during sampling and measurement at the Klemetsrud plant, with CO-levels of approximately 20-30 mg/Nm³. CO-levels during sampling at FREVAR Plant were approx. 50 mg/Nm³. At the Energos Plant, CO was not detected during measurements, which indicates a very effective combustion.

Some problems were experienced with the fabric filter at FREVAR Plant during the sampling period.

6.2 Measurements of gaseous bromine in flue gas before cleaning

Results of measurements of gaseous bromine in flue gas before cleaning are shown in Table 7.

Table 7 Results from measurements in uncleaned flue gas with different addition of bromine containing waste

Plant	Addition of bromine containing waste	Gaseous bromine			
		HBr		Br ₂	
		mg/Nm ³	kg/hour	mg/Nm ³	kg/hour
Klemetsrud Plant	No addition	3,6	0,2	0,1	0,007
	5 % by weight addition	6	0,4	0,3	0,02
	10 % by weight addition	40	2,5	2,3	0,1
FREVAR Plant	No addition	1,2	0,08	<0,5	<0,03
Energos Plant	No addition	< 2,15	< 0,014	< 2,15	< 0,014
	20 % by weight addition	97-200 ¹⁾	0,95-1,97	< 2,15	< 0,014

1) During the approx. 12 hour sampling period, the HBr-concentration in raw flue gas varied from approx. 97 to 200 mg/Nm³, with the highest level during the last sample.

The measurement results for gaseous bromine in uncleaned flue gas, with a normal waste composition, indicates a bromine level equal to, or slightly lower than what is normal for waste from households and small businesses (0,003-0,006 % bromine by weight).

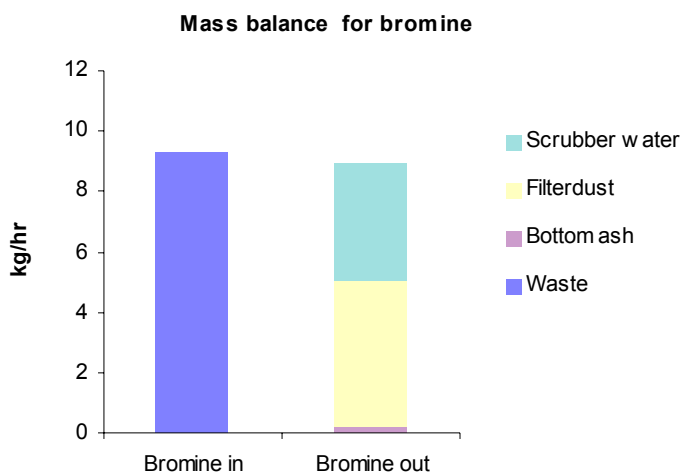
Results from measurements during addition of bromine containing waste, shows a clear increase in the HBr-concentration in uncleaned flue gas, compared to results from measurements with no brominated waste.

At the Energos Plant, gaseous bromine was also measured after the filter. The concentration was $< 2,2 \text{ mg/Nm}^3$, which leads to a removal efficiency of $>97 \%$ for the filter.

6.3 Mass balance for bromine

Figure 10 shows a mass balance for bromine after addition of 10 % by weight bromine containing waste at Klemetsrud Plant.

Figure 10 Mass balance for bromine after addition of 10 % by weight bromine containing waste at Klemetsrud Plant.



From Figure 10, we can see that the mass balance of bromine from Klemetsrud Plant shows good correspondence between input and output flows in the plant.

At the Energos Plant, 20 % by weight of bromine containing waste was fed into the furnace.

Table 8 shows resulting bromine levels in input and output mass flows.

Table 8 Bromine in input and output mass flows, Energos Plant

Mass flow	Amount (kg/hour)
Bromine in input waste (total input)	2,1
Bottom ash	0,045
Flue gas before filter	0,95-1,97
Flue gas after filter	0,014
Total output (excl. bromine in filterdust)	1,0-2,0

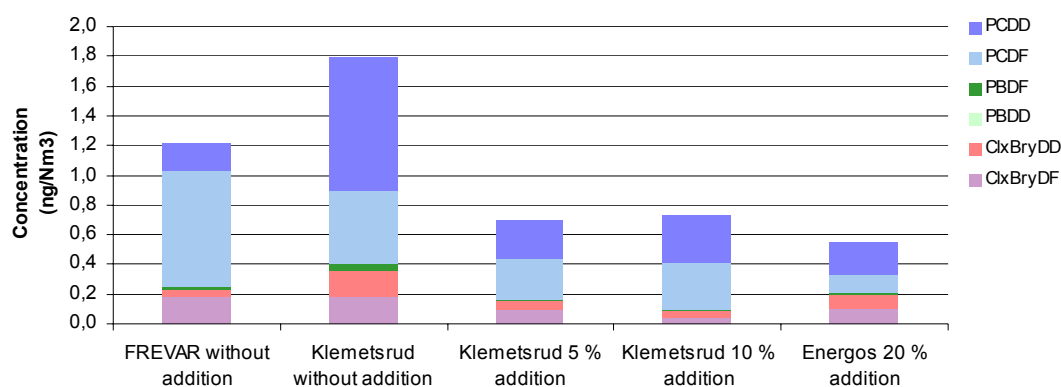
During the approximately 12 hours of sampling and measurement, the bromine content in flue gas before filter varied between approximately 1-2 kgs/hr, with the highest level during the last measurement. According to Energos, it is very likely that the adsorption-/desorption-processes in the boiler system leads to a slow increase of HBr-level in flue gas. Bromine in filterdust is not measured.

6.4 Brominated, chlorinated and brominated/chlorinated dioxins

Concentrations in emissions to air (flue gas after cleaning)

Figure 11 shows resulting emissions of brominated, chlorinated and brominated/chlorinated dioxins with no addition of brominated waste, and with the addition of 5 %, 10 % and 20 % by weight of brominated waste respectively. The results are reported as the actual concentration levels, not as toxic equivalents.

Figure 11 Total emissions of the brominated, chlorinated and brominated/chlorinated dioxins analysed.



From Figure 11 one can see that the emissions of *chlorinated dioxins* (PCDDs+PCDFs, as actual concentrations, not toxic equivalents) from Klemetsrud Plant were approx. 1,5 ng/Nm³ with no addition of brominated waste, and approx. 0,5 ng/Nm³ with 5 % and 10 % by weight of bromine containing waste. At the FREVAR Plant, the emissions of chlorinated dioxins were approx. 1 ng/Nm³ (with no addition of bromine containing waste). The Energos Plant had an emission concentration of approx. 0,3 ng/Nm³ with the addition of 20 % bromine containing waste.

Further, one can see that the emission of *brominated dioxins* (PBDDs+PBDFs) was very low, both with and with no addition of bromine containing waste.

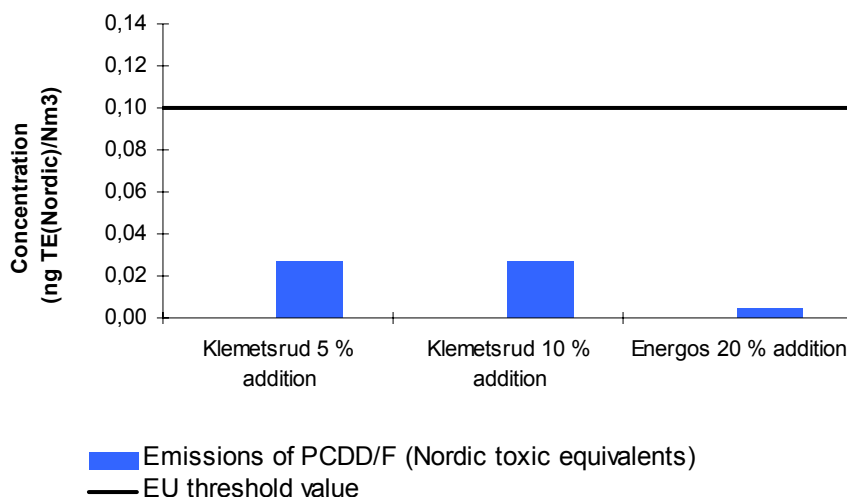
The emissions of *brominated/chlorinated dioxins* (ClxBryDDs+ClxBryDFs) with no addition of brominated waste (Klemetsrud and FRE-

VAR plants) were apparently higher than with addition of brominated waste (Klemetsrud and Energos plants).

Resulting concentrations of brominated/chlorinated dioxins (ClxBryDDs+ClxBryDFs) during measurements with addition of brominated waste, were less than half of the concentrations of chlorinated dioxins (PCDDs+PCDFs).

The emissions of *chlorinated dioxins (PCDDs/Fs)*, presented as *nordic toxic equivalents*, resulting from addition of brominated waste, is shown in Figure 12.

Figure 12 Emissions of chlorinated dioxins (PCDDs/Fs), presented as Nordic Toxic Equivalents, resulting from addition of brominated waste



From Figure 12, one can see that the emissions of chlorinated dioxins, presented as Nordic Toxic Equivalents, were approx. 0,03 ng/Nm³ from the Klemetsrud Plant, both with addition of 5 % and 10 % by weight of bromine containing waste. From the Energos Plant, the concentration level was 0,006 ng/Nm³ with addition of 20 % by weight of bromine containing waste.

The corresponding emission limit value in the EU-directive for waste incineration is 0,1 ng/Nm³.

Uncertainty in sampling and analysis, variations in operating conditions and waste mixture, differences between laboratories with respect to methods of analysis (especially dioxins), makes comparison of results difficult. We may however draw the following main conclusions:

- Increasing the content of BFRs in the waste gave no significant increase in the emissions of chlorinated dioxins, or either brominated and chlorinated/brominated dioxins
- The emission level is highest for chlorinated dioxins, lower for chlorinated/brominated dioxins and lowest for brominated dioxins
- The emission levels for chlorinated dioxins, reported as Nordic toxic equivalents, are low compared to the emission threshold value in the

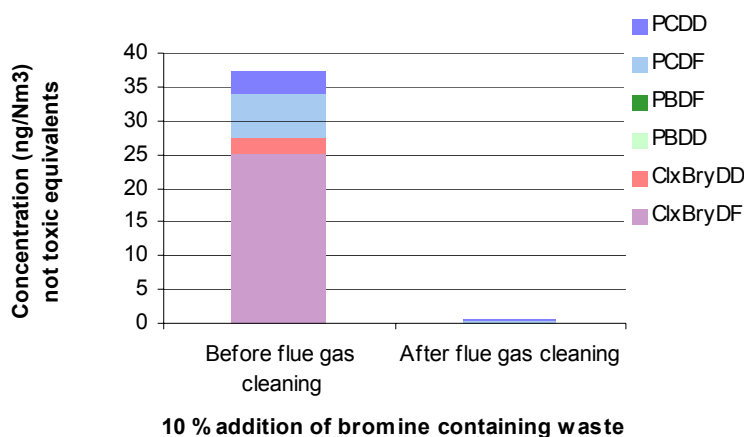
EU-directive for incineration of waste. The reported emission levels were 0,03 ng/Nm³ and 0,006 ng/Nm³ respectively for the Klemetsrud Plant (Oslo) and Energos Plant (Ranheim), and the EU threshold value is 0,1 ng/Nm³.

The emission measurement results indicate that the incineration efficiency and the operating conditions of the flue gas treatment systems are of greater importance to the resulting emission levels for dioxins, rather than the bromine content level.

Flue gas concentrations before and after cleaning

Measurements of dioxins in flue gas before and after cleaning were carried out with addition of a high proportion (10 % by weight) bromine containing waste, see Figure 13.

Figure 13 Concentrations of brominated, chlorinated and brominated/chlorinated dioxins analysed in raw flue gas/emission outlet from Klemetsrud Plant, resulting from addition of 10 % by weight of bromine containing waste.



Concentration of brominated/chlorinated dioxins before cleaning is significantly higher than the corresponding concentration of chlorinated dioxins. After cleaning, the brominated/chlorinated dioxins amounts to only 10-20 % of the total emissions of dioxin compounds. Dioxins removed from flue gas are found in the filter dust. The filter dust from incineration plants is treated as hazardous waste.

6.5 Brominated flame-retardants (BFRs)

Table 9 shows concentrations of BFRs in bottom ash, filter dust, water from the scrubber and in emissions to air from tests with addition of bromine containing plastics at Klemetsrud and Energos Plants.

Table 9 Concentrations of BFRs from incineration tests with addition of bromine containing plastics at Klemetsrud and Energos Plants.

	Unit	Level of BFRs	
		Klemetsrud Plant	Energos Plant
Bottom ash	mg/kg	0,034-0,1	<0,016
Filter dust	mg/kg	0,04	-
Scrubber water (untreated)	ng/l	0,01	-
Emissions to air (after cleaning)	ng/Nm ³	14-22	< 5

From table 9, one can see that the concentration of BFRs in flue gas from Klemetsrud Plant was 14-22 ng/Nm³. This equals 0,9-1,4 mg/hour and approximately 0,01 kg/year, assuming 8000 running hours/year at the same emission level. A Danish study (Miljøstyrelsen, 1999) estimates the total annual Danish emissions of BFRs from incineration to be < 0,04 tons. A report from the Norwegian National State Pollution Control Authority (SFT), estimates the national emissions from combustion in Norway to be < 0,01 tons/year (1998), i.e. < 10 kg/year.

At the Energos Plant (Ranheim) the reported concentration of BFRs in the flue gas was <5 ng/Nm³.

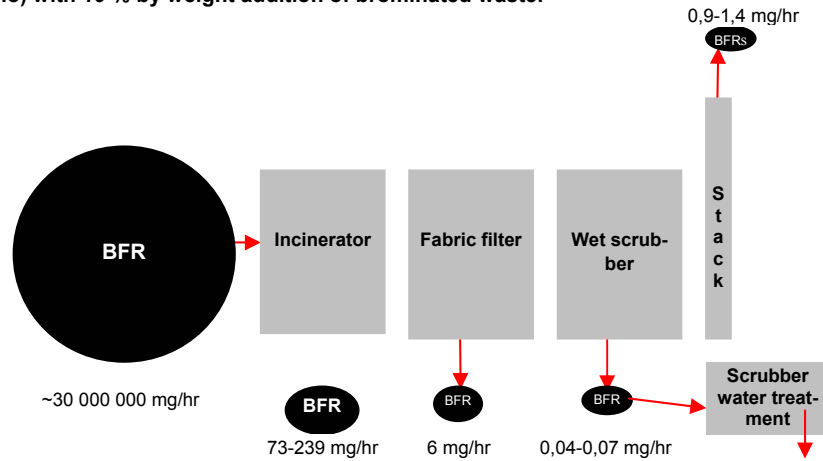
The concentration of BFRs in bottom ash from the tests at Klemetsrud Plant (Oslo) shows levels far below the emission limit value of 0,25 % by weight stated in the Hazardous Waste Directive.

DekaBDE and TBBPA (Tetrabrombisphenol A) are the dominating compounds of BFRs in the bottom ash from Klemetsrud Plant. In water from the scrubber and in the flue gas, dekaBEDE has the highest concentration level.

The amount of BFRs in the waste mixture used in the tests at Klemetsrud Plant was not analysed, but calculated/estimated to be approximately 30 kg/hr, based on a share of bromine containing plastics of 27 % by weight, and an assumed content of BFRs in the plastics of 12 % by weight.

Figure 14 shows input and output flows of brominated flame-retardants at Klemetsrud Plant (Oslo) with 10 % by weight addition of brominated waste.

Figure 14 Input and output flows of brominated flame-retardants at Klemetsrud Plant (Oslo) with 10 % by weight addition of brominated waste.



The results indicates that the BFR-level in output flows amounts to less than 0,001 % by weight of the total BFRs in the waste mixture

14 October 2016

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RE: Ozone Limiting Method Study for Upset Conditions at TNG Energy for Waste Facility

1 INTRODUCTION

The following document provides supplementary information for the Human Health Risk Assessment (HHRA) being completed by AECOM for the TNG Energy from Waste (EfW Facility).

As presented within the Air Quality Assessment for the EfW facility (**Pacific Environment, 2016**), under 'Upset Conditions', there are predicted to be exceedances of the NSW EPA assessment criteria for NO₂ (**NSW DEC, 2005**) when conservatively assuming that all NO_x is converted to NO₂.

This predicted exceedance is only anticipated to occur under a worst case emission scenario (i.e. plant upset) combined with worst-case dispersion meteorology. It should thus be regarded as 'worst-worst case', with the probability of occurrence of these two combined events extremely unlikely.

Notwithstanding the above, the authors of the HHRA have requested that the inherent conservatism within the dispersion modelling be evaluated, and a more accurate prediction of impacts be presented, if possible.

To realistically estimate NO₂ concentrations at ground level using modelled NO_x concentrations, it is necessary to incorporate the effects of atmospheric chemistry. The amount of primary nitrogen dioxide (NO₂) in a combustion process exhaust stream is typically in the order of 5-10% of total NO_x (expressed as NO₂ equivalents). This can be higher for some combustion sources, such as modern diesel vehicles equipped with catalytically regenerating particle filters.

Following release, the NO₂ proportion also changes through complex photochemical reactions of atmospheric ozone and NO_x.

Several approaches are available for estimating the transformation of NO to NO₂ that occurs after the exhaust gases are discharged. For the current evaluation, the 'ozone limiting method' (OLM) was used. The OLM is an approved method document in Section 8.1.2 of the Approved Methods (**NSW DEC, 2005**).

The OLM is based on the assumption that approximately 10% of the NO_x emissions are generated as NO₂ (**Alberta Environment, 2003**). The majority of the NO_x emission is in the form of nitric oxide (NO), which readily reacts with ambient levels of ozone to form additional NO₂.

If the ambient ozone concentration is greater than 90% of the predicted NO_x concentration, all the NO_x is assumed to be converted to NO₂, otherwise NO₂ concentrations are calculated using the equation below, which assumes total conversion of the ozone and adds the 10% of the NO_x that was emitted as NO₂:

$$[\text{NO}_2]_{\text{total}} = \{0.1 \times [\text{NO}_x]\} + \text{MIN} \{ (0.9) \times [\text{NO}_x] \text{ or } (46/48) \times [\text{O}_3] \text{ background} \} + [\text{NO}_2] \text{ background}$$

To apply the OLM, hourly background concentrations of ozone and NO₂ for the calendar year 2013 were obtained for the NSW EPA monitoring station at St Marys.

The NO₂ concentration at each receptor (maximum residential, commercial and grid) was calculated using the above equation for each hour of the year, and then added to the corresponding hourly background value from the St Marys site. The maximum hourly NO₂ concentration were then determined from the results.

2 OLM ASSESSMENT

The results of the OLM assessment are presented in **Table 1**. As shown, there are not anticipated to be any exceedances of the assessment for the NSW EPA 1-hour NO₂ assessment criterion (246 µg/m³).

The ground level concentrations differ from those presented in **Pacific Environment, 2016** since, as noted above, in this assessment it was conservatively assumed that 100% conversion of NO_x to NO₂ would occur.

Note that the cumulative results have accounted for the respective background 1-hour NO₂ concentrations from the St Marys site during the 2013 year.

Table 1: Summary of 1-hour NO₂ concentrations under 'Upset Conditions' using the Ozone Limiting Method

Receptor Type	x	y	Max. Incremental NO ₂ (µg/m ³)	Max. Cumulative NO ₂ (µg/m ³)
Residential	299412	6258847	123.2	137.6
Commercial	299251	6258615	159.6	167.8
Grid Maximum	299400	6256900	166.8	179.1

3 CONCLUSION

Pacific Environment has re-evaluated the predicted ground level concentrations of NO₂ under 'Upset Conditions' at the Energy for Waste facility. Using the Ozone Limiting Method (per the Approved Methods), the results indicate that there are not anticipated to be any exceedances of the NSW EPA assessment criterion at the most impacted residential and commercial receptor, or the grid maximum.

4 REFERENCES

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NSW DEC (2005). "Approved Methods for the Modelling and Assessment of Air Pollutants in NSW", published August 2005

Pacific Environment (2016). "Energy from Waste Facility – Air Quality and Greenhouse Gas Assessment".

MEMO

Job TNG Energy from Waste Facility, Eastern Creek,
Treated Wood Waste (TWW)
Date 2016-10-25
From Martin Brunner, Ahmet Erol

Treated wood waste (TWW)

Treated wood waste (TWW) represents a large proportion of wood waste arising. A WRAP study ¹ on waste composition found that (including laminated and veneered wood) an average of 85% of the wood from the observed Civic Amenity sites and 23% of the wood from the observed construction and demolition sites was treated.

TWW is defined as wood that has been treated with one or more of the following:

- Copper Chromium Arsenic (CCA)
- Copper Organics
- Creosote
- Light Organic Solvent Preservatives (LOSP)
- Micro-emulsion
- Paint / stain
- Varnish

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EfW plants must incinerate waste aligning with the relevant requirements of Australian and NSW Regulatory Framework.

According to NSW Energy from Waste Policy Statement (chapter 4 Energy recovery facilities, technical criteria) the gas resulting from the process should be raised to a minimum temperature of 850 °C for two seconds after the last injection of combustion air. If waste has a content of more than 1% of halogenated organic substances, expressed as chlorine, the temperature should be raised to 1,100 °C for at least 2 seconds after the last injection of air.

¹ Options and Risk Assessment for Treated Wood Waste, The Waste & Resources Action Programme
http://www2.wrap.org.uk/downloads/Options_and_Risk_Assessment_for_Treated_Wood_Waste.6ac4f667.2237.pdf

Certain wood wastes are treated with preservatives or coatings like listed above.

One of the main sources for organic chlorine is varnish containing Polychlorinated biphenyl (PCB).

To get an idea of what the maximum chlorine content in treated wood might be, a brief calculation with following assumptions is made:

Wood size:	0.0254 m x 1 m x 1 m (1 inch thickness)
Varnish thickness on wood:	100 μm , coated both sides
Specific weight wood	700 kg/m^3
Specific weight varnish	900 kg/m^3
Calculated weight wood	17.8 kg
Calculated weight varnish on treated wood	90 g
Percentage of varnish on wood	0.5%

The chlorine content of PCB varies from 19% to 71% depending on PCB configuration². In building materials up to 33 g/kg of PCB's have been found³ (e.g. in caulking materials). Assuming the unrealistic case of 71% chlorine and 33 g/kg of PCB in varnish this would result in a chlorine content of 2.3% in the varnish.

The wood content in the different waste streams of the TNG design fuel varies from 0% to 58.20%. The waste stream with the highest wood content is CRW.

Assuming that all wood waste in CRW is treated with a varnish containing 33 g/kg PCB, the contribution of this PCB to the chlorine concentration of CRW would be less than 0.01% ($58.2\% \times 0.5\% \times 2.3\%$).

Conclusion

Even in a worst case scenario the chlorine contribution of PCB's from TWW to the overall chlorine concentration of the waste is negligible. As a result there is no need to raise the combustion temperature to 1,100°C because of processing TWW.

² Polychlorinated biphenyl (PCB) is an organic chlorine compound with the formula $\text{C}_{12}\text{H}_{10-x}\text{Cl}_x$. There are 209 configurations with 1 to 10 chlorine atoms.

³ CHARACTERIZATION OF POLYCHLORINATED BIPHENYLS IN BUILDING MATERIALS AND EXPOSURES IN THE INDOOR ENVIRONMENT; KM Coghlan, MP Chang, et. al.; Environmental Health and Engineering, Inc., Newton, MA, USA

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THE NEXT GENERATION NSW PTY LTD

PROJECT DEFINITION BRIEF



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1. INTRODUCTION

The purpose of this document is to define the key design parameters which are to be used in the documents for the new Waste-to-Energy plant owned by The Next Generation (hereafter TNG).

The Next Generation NSW Pty Ltd, a stand-alone company, has been formed by Dial a Dump Industries and Genesis Xero Waste Facility to develop a low carbon electricity generating plant that will be fuelled by waste derived fuels.

The project can be divided into the following primary systems, which will be described below in this order:

- Delivery, tipping and feeding
- Furnace/boiler
- Flue gas treatment (APC)
- Turbine/Condensers
- Ancillary equipment
- Control and monitoring system
- Electrical systems
- Civil works and layout
- Operation

2. KEY FACTS OF THE PLANT

2.1 General

The proposed Development involves the construction and operation of an Electricity Generation Plant (the proposed Facility). The proposed Facility will generate electrical power from unsalvageable and uneconomic residue waste which would otherwise be land filled. It will be a 'green' electricity generation facility, and NSW's first (and Australia's largest) Energy from Waste Facility. The proposed Facility will be compliant with NSW Emissions Requirements and in line with the NSW EfW Policy.

The design fuel has been calculated based on the expected waste fractions and has a Net Calorific Value (NCV) of 12.3 MJ/kg (equivalent to 12,300 kJ/kg). Based on the design fuel NCV the Facility will have capacity to treat 1,105,000 tpa (34.53 t/h, 4 streams, 8,000 h) of fuel.

Composition and NCV will vary for each individual fuel fraction. The Facility is designed to operate efficiently within an NCV range to maximise operational flexibility and high efficiency. The combustion diagram is based on an NCV range from minimum 8.5 MJ/kg to maximum 16.5 MJ/kg.

To maintain the planned generating capacity with the proposed NCV range the fuel requirement can vary from approximately 810,000 tpa (25.31 t/h, 4 streams, 8,000 h) to 1,350,000 tpa (42.19 t/h, 4 streams, 8,000 h).

The proposed Facility has a capacity to generate net 137.3 Mega Watts of electrical energy (MWe). The Fuel will be sourced from the neighbouring Genesis MPC, which will enter the proposed Facility via conveyor and the private under pass culvert, as well as from third parties via the public road system.

Construction and operation will take place in two phases, as follows:

- **Phase 1** will include the complete construction of the Tipping Hall and Waste Bunker and combustion Lines 1 and 2 comprising of two independent Boilers, Flue Gas Treatment (FGT) systems, Stack as well as one Turbine and one Air Cooled Condenser (ACC) and all other auxiliary equipment.
- **Phase 2** will comprise the installation of combustion lines 3 and 4 with again two independent Boilers, Flue Gas Treatment (FGT) systems, Stack as well as one Turbine and one Air Cooled Condenser (ACC) and all other auxiliary equipment.

This two Phase approach has been adopted after receiving feedback from the various government agencies. Lines 3 and 4 will be constructed once the Department of Planning and Environment is satisfied that the required amount of eligible residual waste fuel is available to the TNG facility.

The technology proposed for the Facility is a moving grate system with water and air cooled grate bars. This system offers the most flexible and cost effective solution for the fuel mix being considered. The proposed turbine exhaust cooling system for the Facility is an Air Cooled Condenser (ACC). ACCs are considered to be the preferred option as they not require water and do not generate an effluent discharge. Furthermore there is no visual plume impact through the ACC, as there would be for an evaporative cooling tower.

The flue gas treatment system is designed to achieve the emission limits as required by the Industrial Emissions Directive. The flue gas treatment system will consist of a Selective Non-Catalytic Reduction (SNCR) of NO_x, activated carbon injection, dry lime scrubbing and fabric filters.

Without any changes to the main process, the Facility will be configured so that it will be possible to export heat to nearby consumers.

Operation of the Facility will generate three types of solid waste by-products:

- bottom ash;
- boiler ash; and
- flue gas treatment residues (APC residues).

The facility will produce no excess effluent during operation.

2.2 Fuels

A moving grate system offers TNG the greatest flexibility in the range of waste fuels that may be processed at the Facility. The following fuel types have been identified as the main sources of fuel for the Facility;

- Chute Residual Waste (CRW) from the Genesis MPC;
- Commercial and Industrial (C&I);
- Construction and Demolition(C&D);
- Floc waste from car and metal shredding;
- Paper pulp;
- Glass Recovery;
- Garden Organics (GO);
- Alternative Waste Treatment (AWT); and
- Material Recovery Facility waste (MRF waste) residual

As the NCV of waste fuels vary depending on type, the facility will operate within a range of NCVs to support operational flexibility.

2.2.1 Design Fuel

Based upon the fuel types listed above, a design fuel composition has been developed. This is based on typical values for each of the proposed fuels and an estimated fuel mix. Input fuel will always be mixed as part of the normal operational process to produce as homogenous an input as possible.

	Units	CRW	C&D	C&I	Floc waste	Paper Pulp	Glass Recovery	GO Residual	AWT Residual	MRF Residual	Design Fuel Mix
Fuel Mix	%	23.37%	28.69%	16.84%	14.43%	4.81%	1.72%	2.06%	6.87%	1.20%	100
Compositional Analysis											
Paper/Card	%	4.30	14.05	22.44	3.93	78.40	62.00	30.00	21.05	38.54	16.75
Plastic Film	%	10.20	6.37	10.90	10.90	21.60	3.80	2.50	20.00	26.94	10.47
Dense Plastic	%	0.00	6.37	10.90	10.90	0.00	34.20	2.50	21.05	0.00	7.32
Textiles	%	5.30	0.00	12.89	0.18	0.00	0.00	0.00	10.53	0.00	4.16
Glass	%	0.00	0.00	1.81	0.00	0.00	0.00	4.00	0.00	8.50	0.49
Vegetation	%	8.30	0.00	1.70	0.00	0.00	0.00	35.00	3.16	0.00	3.16
Other combustibles	%	0.00	0.00	0.00	70.40	0.00	0.00	0.00	0.00	0.00	10.16
Metal	%	1.80	1.12	0.37	0.00	0.00	0.00	5.00	0.00	7.59	1.00
Fines	%	0.00	0.94	0.18	0.00	0.00	0.00	0.00	11.58	0.00	1.10
Wood	%	58.20	43.90	21.53	0.85	0.00	0.00	0.00	4.21	0.00	30.24
Combustibles	%	0.00	0.00	2.84	2.84	0.00	0.00	0.00	2.11	0.00	1.03
Non-Combustibles	%	4.50	0.00	0.00	0.00	0.00	0.00	21.00	1.05	0.03	1.56
Hazardous	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gyprock	%	2.40	6.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.42
Other	%	5.00	20.75	14.44	0.00	0.00	0.00	0.00	5.26	18.40	10.14
Total	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Units	CRW	C&D	C&I	Floc waste	Paper Pulp	Glass Recovery	GO Residual	AWT Residual	MRF Residual	Design Fuel Mix
Chemical Analysis											
Carbon (C)	%	31.34	27.02	35.00	29.65	42.90	41.01	16.98	38.96	32.63	31.44
Hydrogen (H)	%	4.21	3.51	4.29	3.80	5.84	4.63	2.12	4.98	4.84	4.07
Nitrogen (N)	%	0.34	0.06	0.59	0.18	0.00	0.00	0.12	0.47	0.00	0.26
Sulphur(S)	%	0.42	1.04	0.05	0.11	0.12	0.09	0.06	0.04	0.06	0.43
Chloride (Cl)	%	0.09	0.66	1.15	1.78	0.19	3.27	0.26	2.18	0.23	0.88
Oxygen (O)	%	21.11	21.50	17.50	7.04	24.64	26.69	12.58	13.77	12.11	18.06
Water (H ₂ O)	%	28.47	21.51	21.68	22.62	22.58	20.81	36.20	18.40	15.20	23.38
Ash	%	14.03	24.70	19.74	34.82	3.73	3.50	31.68	21.20	34.93	21.49
Total	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
NCV	MJ/kg	11.95	9.97	13.84	12.59	17.22	15.24	5.67	16.33	14.23	12.30

Table 1 Proposed design fuel analysis, as received basis

The analysis above defines the design fuel of the Facility. Suitable ranges for various key components such as the moisture, ash and energy content of the fuel are discussed in section 2.2.2. Based on the above design compositions, NCV of the nominal design fuel mix is calculated to be 12.30 MJ/kg.

2.2.2 Fuel Range

Despite the identification of a design fuel mix and the homogenisation process of mixing fuels prior to incineration the facility operates within a fuel range to allow for operational flexibility.

The minimum and maximum fuel ranges as basis for calculation and design of the plant are shown in Table 2 . Within this range the facility will still operate efficiently.

		Minimum	Maximum
Nitrogen(N)		0.19%	0.34%
Sulphur(S)		0.31%	0.57%
Chloride (Cl)		0.64%	0.96%
Ash		13%	26%
Water(H ₂ O)		14%	34%
NCV	MJ/kg	8.5	16.5

Table 2 Fuel range

2.3 Special waste fractions and contaminants

2.3.1 Chlorine

In view of the APC design the chlorine content of the waste is relevant. The main contribution to the chlorine content of the waste is PVC. PVC (C₂H₃Cl) itself contains approx. 57% of chlorine. In municipal waste typically approximately 50 % of the chlorine comes from PVC, in C&I waste the contribution of PVC to the overall chlorine content is expected to be even higher.

In the EU regulation the following is stated: “If **hazardous waste** with a content of more than 1 % of halogenated organic substances,” . We are aware that the EFW policy from NSW only states: “If **a waste** has a content of more than 1% of halogenated organic substances, ..” . Nevertheless PVC is **not** considered a hazardous material.

During combustion PVC is fully decomposed to CO₂, HCl and water vapour. The HCl will be eliminated by the Air Pollution Control (APC) system which is designed, controlled and operated to capture such substances even when occurring as a spike. The chosen APC technology for this facility is standard in modern WTE plants with comparable feedstock and with continuously very low emissions.

The waste composition of the Facility is well within the range of other facilities operating in Europe. Many facilities have average chlorine concentrations of above 1% (some even 1.7%) and all categorised as facilities with a necessary furnace temperature of 850°C according to EU regulation.

The effect of waste mixing

The fuel of TNG has some fractions containing PVC and their chlorine content will be slightly above 1%, nevertheless the waste in total and as an average will not contain more than 1% chlorine. Main reason for this is the extensive mixing of waste before feeding it to the combustion process.

The mixing and homogenisation of the different waste streams is a very important aspect of the operation of a waste-to-energy plant and therefore it is given a very high importance. When the waste is tipped in to the bunker it has to be picked up by the crane grab so to keep the delivery area free and allow further waste deliveries. During times with low delivery it is the duty of the crane driver (or in the case of an automatic crane of the automation system) to thoroughly mix the waste by picking it up and dropping it in a different place of the storage area in the bunker. This ensures a thorough mixing of the different waste fractions. To be fed to the combustion system the waste is again picked up by the crane grab.

As a result any waste is picked and offloaded at least 2 to 3 times before being fed into the combustion process and therefore is well mixed. As a conclusion it is reasonable to assume that the contaminant concentrations of the different waste streams will be well homogenised when being fed to the combustion process.

2.3.2 Waste wood

Treated wood waste (TWW) represents a large proportion of the arising waste wood. TWW can be defined as wood that has been treated with at least one of the following:

- Copper, Chromium, Arsenic (CCA)
- Copper Organics
- Creosote
- Light Organic Solvent Preservatives (LOSP)
- Micro-emulsion
- Paint / stain
- Varnish

Several studies are available on the impact of processing TWW in an EfW plant. The most important results are summarized below:

- Thermal treatment is suitable for all types of TWW as there is in any case there is an effective control of the emissions.
- Co-incinerating of impregnated wood along with the basic waste brings an increase of the average arsenic content in the waste, whereas the concentrations of copper and chromium do not differ significantly from the basic waste. The increased arsenic content will primarily end up in the residues from the flue gas cleaning process, and to some extent the concentration in the bottom ash is also increased. It is, however, probable that the concentration of arsenic in leachate will not increase.
- Full-scale tests with co-incineration of impregnated wood, has not shown significant increase of arsenic emissions to air. Air emissions of arsenic (and trace metals in general) are mainly dependent on the APC technology and only to a small degree on the input concentration.

2.3.3 Shredder residue (floc waste/shredder floc)

Processing floc waste in EfW facilities is widespread and a preferred recovery option in Europe. The European End-of-Life Directive requires a reuse and recovery rate for end-of-life vehicles of at least 85% by 1.1.2006 and 95% by 1.1.2015 at the latest. In Germany the recovery rate was 99.1% in 2012 compared to the European average for reuse and recovery of 89% in 2012. Metals contribute approximately 75% to this number, the rest is achieved by recovery of shredder residues. In 2012 45% of the German floc waste went to energy recovery (mainly EfW).

According to the Australian Federal Chamber of Automotive Industries the reuse and recovery rate of end-of-life vehicles in Australia is 75% (data published 2011) which obviously represents the metals.

In Australia the current recycling practice for the end-of-life vehicles is to drain fluids and to dismantle for saleable parts (wheels, batteries, engines, alternators, body panels, etc.). Approximately 65-75% of the rest of the vehicle are ferrous and nonferrous metals.

Macroscopic composition of European floc waste

The following graph shows the average composition of European floc waste.

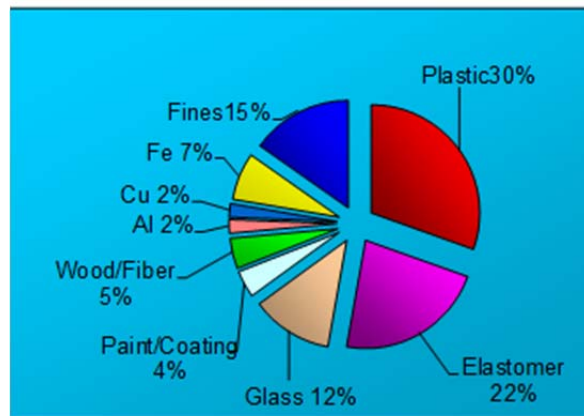


Figure 1 Average Composition of Floc Waste Europe

Macroscopic analysis of Australian floc waste

The average Australian floc waste composition range is shown below.

Material type	Average composition range (% weight)
Plastics	35 – 55%
Rubber	10 – 20%
Metals	6 – 13%
Textiles	7 – 15%
Fines (paint, glass, sand)	10 – 20%

Figure 2 Range of Composition of Floc Waste Australia

Chemical analysis of European floc waste

The composition of floc waste can vary widely depending on the input to the shredder, on the shredder process, the floc removal (wet or dry) as well as the amount of water-spray used for dust abatement. The following table shows the variation of the composition of European floc waste.

Parameter		Average	Range
Moisture	%-Weight	6.7	0.1 - 18
Ash	%-Weight	52.7	25 - 80
NCV	MJ/kg	13	7 - 20
C	%-Weight	32.6	20 - 47
H	%-Weight	4.1	2 - 6
N	%-Weight	0.9	0.2 – 1.8
O	%-Weight	7	3 - 11
S	%-Weight	0.6	0.1 – 1.4
Cl	%-Weight	1.8	0.5 - 3

Table 3 Range and average chemical composition of Floc Waste Europe

As the above table shows, the variation in composition is significant. The main factors contributing to the variation are the water and the ash content. The water content depends on the process (as described above) or the transport conditions (open containers, rain). The measured ash depends on two factors: the sampling and the material fed to the shredder. The feed material often contains sand/dirt or is very rusty. As a result the ash of floc waste always has a very high SiO₂ (quartz sand) and Fe₂O₃ (rust) content. More important however is the sampling. Depending on how the sample is taken (bottom or top of heap, one small or several partial samples, etc.) the result from one single floc waste can vary widely. Further rust and sand (often mixed with rests of liquids) stick to plastic sheets and affect the final result.

Nevertheless one can say that typical European floc waste has a composition similar to the values given as "Average" in Table 3.

Analysis of floc waste to be processed at TNG

To have a clear picture of the expected composition of the floc waste to be processed at TNG (referred to as "floc waste TNG"), 17 samples of nearby floc waste producers were collected. These samples were then individually analysed to determine the macroscopic composition, the chemical components and the calorific value. ¹

The following results refer to dry basis (db): The majority (58%) of shredder floc is inert material. There are also substantial amounts of non-polystyrene plastics (21%) and textiles (11%). These three materials make 90% of shredder floc. The rest is rubber/leather (5%), wood waste (3%), metal (1%), polystyrene (1%) and paper/cardboard (0.4%).

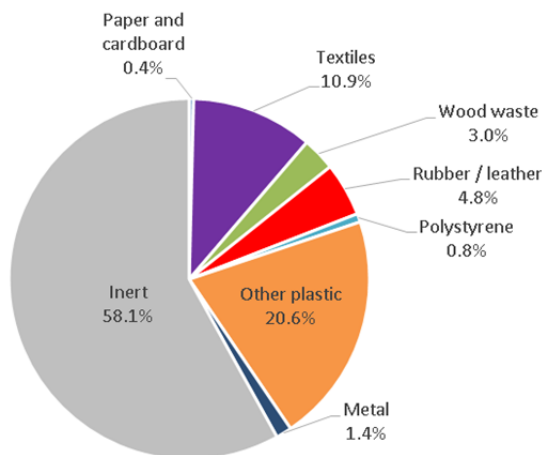


Figure 3 Average macroscopic composition of "floc waste TNG" (dry basis)

The analysed net calorific value (NCV) of the 17 samples varies from 7.8 to 15.7 MJ/kg (as received). The average value is 11.6 MJ.

¹ Reference Audit of potential feedstock for The Next Generation energy-from-waste facility for Dial A Dump Industries, by apc waste consults, dated August 2016

Comparison of "floc waste TNG" with European values

The chemical profile of "floc waste TNG" is summarised in Table 4 and compared with the European values.

	unit	TNG	Europe
Carbon (C)	% (db)	27.0*	32.6
Hydrogen (H)	% (db)	4.8	4.1
Nitrogen (N)	% (db)	1.1	0.9
Sulphur (S)	% (db)	0.3	0.6
Chloride (Cl)	% (db)	0.6	1.8
Bromine (Br)	% (db)	0.01	0.02
Oxygen (O)	% (db)	9.2	7.0
Ash	% (db)	57.0	52.7
Water (H ₂ O)	% (ar)	13.2	6.7
Total PAH	mg/kg (db)	20	-
Total PCB	mg/kg (db)	14	120
NCV	MJ/kg	11.6	13.4

Table 4 Comparison of "floc waste TNG" and average European values

*Note: Value corrected to allow for uncertainties of the chosen analytical method

In general the chemical profile of the "floc waste TNG" and European values is considered to be comparable. In "floc waste TNG" the ash content is higher and as a result the carbon content and NCV is lower. The chlorine and sulphur contents are lower, Bromine is comparable. The average PCB value for TNG is substantially lower than in Europe, however the European value is based on only one source in the 1990ies.

A major difference is the higher moisture content in the "floc waste TNG". As described earlier, the water content depends on the shredder technology and the methods used for dust abatement. The higher moisture content also contributes to the lower NCV of "floc waste TNG"

²The effects of co-processing floc waste with other waste streams/sources have been evaluated in several European studies. These studies have concluded the following benefits:

- By incinerating 10% shredder residue along with the basic waste, there is an increase of metals in bottom ash when compared to incinerating basic waste only. The primary increase can be assigned to the elevated metal content in the incoming waste, which, to a large degree, can be extracted and recycled. There is a slight increase of trace metal content, even after the sorting process, but actual full scale tests show no indication of increased concentration of trace metals in leachate.
- The concentration of trace metals in flue gas cleaning residues is increased when co-combusting shredder residue. But full scale tests show, that there is no increase of trace metal in the emissions compared to incinerating basic waste only.

² Ministry of Environment and Food of Denmark, Environmental Project No. 1654, 2015

"Vurdering af metalholdigt affald til forbrænding" (Abstract in English)

<http://mst.dk/service/publikationer/publikationsarkiv/2015/mar/vurdering-af-metalholdigt-affald-til-forbraending/>

Conclusion

The results of the analysis of 17 samples of floc waste which could be considered to be processed in the TNG facility (referred to as "floc waste TNG") show, that "floc waste TNG" is comparable to European floc waste. The concentration of chlorine and sulphur of "floc waste TNG" is substantially lower. The chlorine content is below 1% and even lower than assumed in the design fuel.

There is a long-term positive experience in processing floc waste in Europe in EfW plants. Having a comparable composition of this waste in Australia supports the utilization in the TNG facility.

References

Figures 1 and 3 Table 3	http://rcswww.urz.tu-dresden.de/~deut/Homepage_IAA_ab_De2006/L&D/SS2009/Uebung_Grundl_Abfw09/Stoffliche_und_brennstofftechnische_Charaktng_SLF.pptx
Figure 2	www.sustainability.vic.gov.au
Figure 3 and Table 4	Reference Audit of potential feedstock for The Next Generation energy-from-waste facility for Dial A Dump Industries, by apc waste consults, dated August 2016

2.4 Performance

The Facility is designed to have a thermal input of 471.9 MW (117.98 MW for each combustion line) at the design point. The Facility has an assumed net average annual electrical efficiency of 29.1%. The Facility is designed to export 137.3 MWe (29.1% x 471.9 MW). High net electrical efficiency is a priority for TNG and there are a number of options which have been incorporated to maximize the efficiency.

The export voltage will be set to match the requirements of the local high voltage electricity grid.

Items	Units	Phase 1		Phase 2		Overall facility
		Total	Per stream (based on 2 streams)	Total	Per stream (based on 2 streams)	
Gross Power	MW _e	76.0		76.0		152.0
Auxiliary load	MW _e	7.3		7.3		14.6
Power Export	MW _e	68.7		68.7		137.3
Net Efficiency	%	29.1%		29.1%		29.1%
Fuel NCV	MJ/kg	12.30		12.30		12.30
Thermal load	MW _{th}	235.96	117.98	235.96	117.98	471.9
Availability	%	91.3%		91.3%		91.3%
Waste Throughput (based on assumed availability)	t/h	69.06	34.53	69.06	34.53	138.1
	tpa	552,500	276,250	552,500	276,250	1,105,000

Table 5 Overall Facility Performance (LPN, Design point)

2.5 Combustion Diagram

A combustion diagram is used to show the correlation of throughput in tons/hour, the calorific value in kJ/kg and the thermal output in MW for the plant. Combustion diagrams are a useful tool to identify the operational area where all guarantees, environmental and functional requirements are fulfilled.

Continuous operation shall preferably be at loading points near the nominal loading point to have an efficiently operating plant. Continuous operation outside the limits of the diagram is not possible.

Figure 4 shows the combustion diagram for one line of the proposed TNG facility.

As shown in the diagram the nominal design point (Load Point, LPN) is 34.53 tons per hour at a NCV of 12,300 kJ/kg (which is equivalent to 117.98 MW).

The line (LP6) – (LP1) represents 100% thermal load and the plant will mostly be operating along this line, in practice done by operating the boiler on a fixed steam flow rate set point (MCR: 144.7 t/h steam flow at boiler outlet). This implies that the amount of waste is reduced if the calorific value exceeds 12,300 kJ/kg and similarly increased if the calorific value decreases.

The diagram allows a range for the calorific value between 8,500 kJ/kg (line between (LP2) and (LP3)) and 16,500 kJ/kg (line between (LP5) and (LP6)). This allows variations between +34% and -31% of the nominal value of 12,300 kJ/kg.

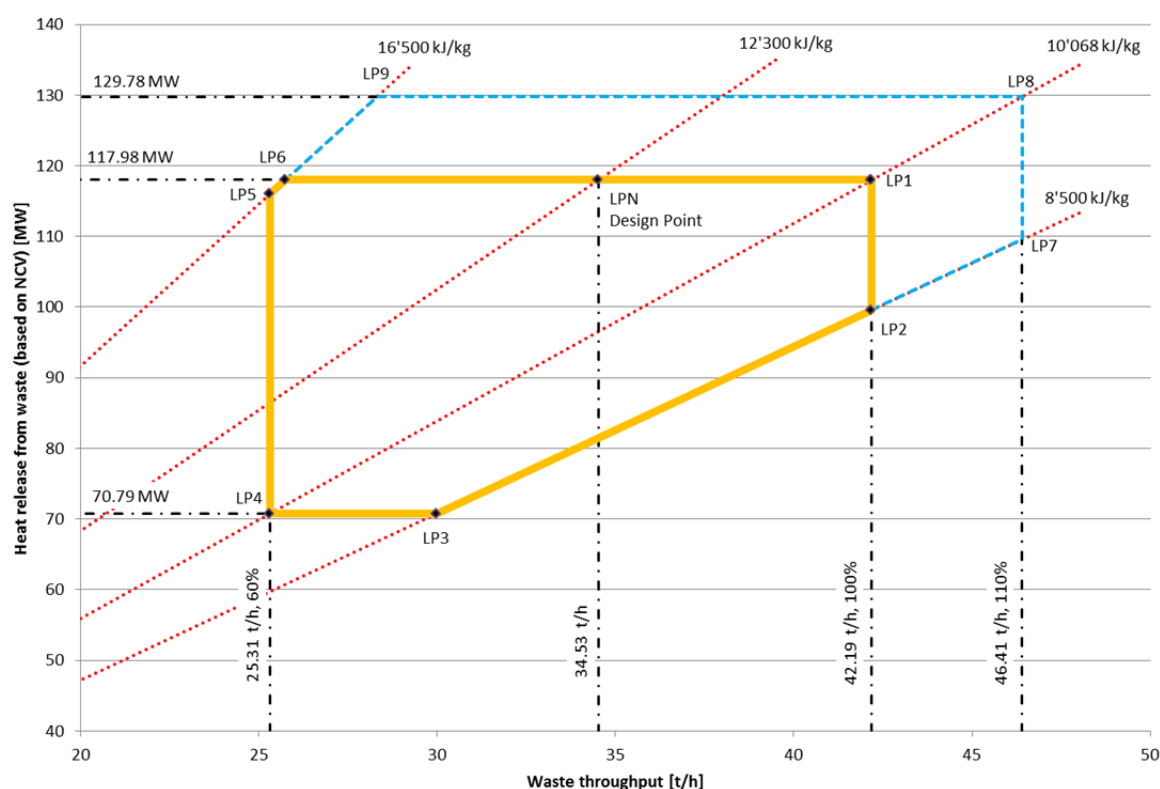


Figure 4 Combustion diagram

For short time overload (during less than one hour) a throughput of 46.41 tons per hour, corresponding to 110% of the nominal throughput is allowed.

The minimum amount of waste throughput is 25.31 tons per hour represented by the line (LP4) – (LP6), corresponding to 60% of the nominal throughput (mechanical load).

To maintain the planned generating capacity with the proposed NCV range the fuel requirement could vary from approximately 810,000 tpa ((LP4), (LP6): 4 streams, availability 8,000 h) to 1,350,000 tpa ((LP1), (LP2): 4 streams, availability 8,000 h).

However, it must be noted that operation on either the maximum or the minimum amount of waste is only possible during a very short period of time in order to absorb variations in the amount of waste and the calorific value of the waste. Continuous operation outside the limits of the diagram is not possible.

Inside the area made up by the lines (LP1), (LP2), (LP3), (LP4), (LP5) and (LP6) the plant shall be able to be in continuous operation (Table 6).

The line (LP8) – (LP9) is the maximum short time thermal overload (129.78 MW), which is 110 % of the nominal thermal load. The area constituted by the lines (LP1), (LP8), (LP9) and (LP6) represents a thermal load of 100–110 % of the nominal load, is designed to manage inevitable fluctuations from the preferred operational line (LP1) – (LP6). Continuous operation at thermal overload is not possible.

The line (LP3) – (LP4) is the minimum allowable thermal input (fuel firing) where all guarantee values have to be fulfilled without use of the auxiliary gas burners. The line is representing 60 % of the nominal thermal load (70.79 MW).

Load Point	Capacity	Capacity	CV	Energy input (burnt fuel)
	[tonnes/h]	[tonnes/a/line]	[kJ/kg]	[MW]
LPN	34.53	276,240	12,300	117.98
LP1	42.19	337,520	10,068	117.98
LP2	42.19	337,520	8,500	99.62
LP3	29.98	239,840	8,500	70.79
LP4	25.31	202,480	10,068	70.79
LP5	25.31	202,480	16,500	116.09
LP6	25.74	205,920	16,500	117.98

Table 6 Load Point table, normal operation

2.6 Availability Requirement

The plant is designed to ensure operation minimum availability of 8,000 h/a. 8,000 h/a is a usual availability standard within the EfW industry and a Standard guarantee required in EfW contracts. This allows for 760 hours a year of operational management that may include inspection stops, a maintenance period and some hours of unplanned stop of main components. The total number of hours per year is divided as follows:

Plant availability:	8,000 h
Scheduled plant stop, 14 days:	336 h
Scheduled inspection, 2 days:	48 h
<u>Unplanned stops:</u>	<u>376 h</u>
Total:	8,760 h

To meet the overall availability of 8,000 h/a, each system/component in the plant will have a significantly higher availability or redundancy.

The operator will ensure that fully redundant solutions are developed and implemented for all relevant equipment/components, in particular the components that lead to plant shut-down, in case of failure of the particular component. This also includes appropriate consideration of redundancy in relation to electrical and control and monitoring system. To a high extent all parts will be able to be maintained without stopping the plant / boilers, this is achieved by applying process bypass options (for example turbine bypass), and/or duplicate components (for example feed water pumps or multiple fabric filter chambers).

3. ENVIRONMENTAL STANDARDS

3.1 Background

The Facility design has been developed to align with the relevant environmental, operational and safety requirements of Australian and NSW Regulatory Framework. Key performance requirements have been used to inform the development of the design and operation of the TNG Facility.

The main statutory instruments are summarised in Table 7:

FRAMEWORK LEVEL	PLANNING INSTRUMENT
Legislation and Regulations	<ul style="list-style-type: none"> Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) <i>Environmental Planning and Assessment Act 1979</i> Environmental Planning and Assessment Regulation 2000 <i>Protection of the Environment Operations Act 1997</i> Protection of the Environment Operations (Waste) Regulation 2014 Protection of the Environment Operations (Clean Air) Regulation 2010 Waste Avoidance and Resource Recovery (WARR) Act 2001 Water Management Act 2000
Environmental Planning Instruments – State	<ul style="list-style-type: none"> State Environmental Planning Policy (State and Regional Development) 2011 State Environmental Planning Policy (Infrastructure) 2007 State Environmental Planning Policy (Western Sydney Employment Area) 2009 State Environmental Planning Policy No. 33 – Hazardous and Offensive Development State Environmental Planning Policy No. 55 – Remediation of Land State Environmental Planning Policy No. 64 – Advertising and Signage.
Environmental Planning Instruments – Local	<ul style="list-style-type: none"> Blacktown LEP 2015
Local Planning Policies	<ul style="list-style-type: none"> Blacktown DCP 2006

Policies and Guidelines – State	<ul style="list-style-type: none"> ▪ NSW State Rivers and Estuary Policy (1993); ▪ NSW State Groundwater Policy Framework Document (1997); ▪ NSW State Groundwater Quality Protection Policy (1998); ▪ NSW State Groundwater Dependent Ecosystems Policy (2002); ▪ NSW Energy from Waste Policy Statement 2015 ▪ Waste Avoidance and Resource Recovery Strategy (WARR) 2014 – 2021 ▪ Aquifer Interference Policy (2012); ▪ Department of Primary Industries Risk Assessment Guidelines for Groundwater Dependent Ecosystems (2012); and ▪ Guidelines for Controlled Activities (2012). ▪ Waste Classification Guidelines (EPA, 2014) ▪ Environmental guidelines: Composting and Related Organics Processing Facilities (DEC) (2004) ▪ Environmental guidelines: Use and Disposal of Biosolid Products (NSW EPA)
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Table 7 Legislative Framework

The implementation of the relevant legislative and policy framework is achieved through the following key processes:

- Environmental Impact Statement (and supporting documents) and the associated Development Approval (granted under the *Environmental Planning and Assessment Act 1979*).
- Environment Protection Licence (issued under the *Protection of the Environment Operations Act 1997*)

The granting of Environment Protection Licences (EPL) for Waste-to-Energy plants would be carried out by the Environment Protection Authority (EPA). The EPL requirements effectively drive key performance design decisions, and the EPL itself sets out operational requirements in respect of the environmental performance of the process, including the process emissions.

The starting point for the environmental performance of the Facility has been the compliance with legislative standards which are required of Waste-to-Energy plants in Europe. The European Industrial Emissions Directive IED 2010/75 EC has also been used as the basis for the development of the NSW Energy from Waste Policy, which is the legislative framework for the proposed Facility.

Furthermore the environmental permits sets out which waste types can be treated and gives directions to the reception, handling and storage of waste.

3.2 Proposed basic design parameters

In NSW EfW policy states "The process and air emissions from the facility must satisfy at a minimum the requirements of the Group 6 emission standards within the Protection of the Environment Operations (Clean Air) Regulations 2010. The EU regulations for EfW plants (part of the Industrial Emission Directive IED) are generally considered to be the most stringent requirements for EfW plants worldwide. Therefore the IED standards, including emissions, process performance and design and emissions monitoring will form the starting point for the process design along with the current Best Available Technology (BAT) reference note.

3.2.1 Process guarantees

In accordance with the decision to commence design on the basis of achieving compliance with the IED (above), process guarantees will be set to ensure compliance with the IED, as a minimum.

3.2.2 Emissions monitoring requirements

The Facility will be designed to meet the emission limits contained within the Chapter IV and Annex VI of the Industrial Emissions Directive (IED) (Directive 2010/75/EU) for waste incineration and waste co-incineration plants.

3.2.3 Continuous emission monitoring

Emissions from the stack will be monitored continuously by an automatic computerised system and reported in accordance with NSW EPA protocols. Sampling and analysis of all pollutants will be carried out to NSW Approved Methods, European Committee for Standardization (CEN) or equivalent standards (e.g. International Organization for Standardization (ISO), national, or international standards). This ensures the provision of data of an equivalent scientific quality.

This monitoring has three main objectives;

1. to provide the information necessary for the facilities automatic control system to ensure safe and efficient facility operation;
2. to warn the operator if any emissions deviate from predefined ranges; and
3. to provide records of emissions and events for the purposes of demonstrating regulatory compliance.

The following parameters will be monitored and recorded continuously at each stack using a Continuous Emissions Monitoring System (CEMS);

- (1) oxygen;
- (2) carbon monoxide;
- (3) hydrogen chloride;
- (4) sulphur dioxide;
- (5) nitrogen oxides;
- (6) ammonia;
- (7) VOCs (volatile organic compounds);
- (8) Particulates; and
- (9) Flue gas volume

In addition, the water vapour content, temperature and pressure of the flue gases will be monitored so that the emission concentrations can be reported at the reference conditions required by the IED or as required by the NSW EPA.

The continuously monitored emissions concentrations will also be checked by an independent auditor at regular interval or as required by NSW EPA.

The following parameters will be monitored by means of spot sampling at frequencies agreed with the relevant regulator.

- (1) dioxins and furans;
- (2) mercury;
- (3) cadmium and thallium; and
- (4) heavy metals.

The methods and standards used for emissions monitoring will be in consistent with the IED or as directed by with NSW EPA.

There will be duty CEMS (one per line) and one hot stand-by CEMS per two lines. This will ensure that there is continuous monitoring data available even if there is a problem with one of the duty CEMS systems.

3.2.4 Noise

There will be a general sound pressure level requirement of max. 85 dB(A) for noise emissions inside the plant.

Most equipment within the plant will fulfil the 85 dB(A) requirement without further measures, except for the turbine during bypass operation, some larger pumps and fans and possibly conveyers for bottom ash transport, air coolers and steam condensers.

Where possible such equipment shall be place in dedicated noise areas (rooms) or be acoustically insulated/covered by noise hoods.

Item No.	Noise Source	Assumed Noise Level SWL dB(A)
1	Stacks (2 – 1 per block)	91
2	Turbine Hall (2)	88
3	Tipping Hall	85
4	Air Cooled Condensers (ACC's) (2)	102 (per section of 6 units)
5	Transformers (2)	102
6	Compressors (2)	97
7	Boiler Area (2)	85
8	Flue Gas Treatment (4)	98
9	ID Fans (4)	100
10	Silo's & Bag Storage (2)	85
11	Bottom Ash Handling (2)	93

Table 8 Noise requirements in various areas and development zones

4. WASTE AND RESIDUE LOGISTIC

4.1 Reception Hall and Bunker Storage Capacity

The EfW facility will operate continuously, 24 hours a day and 7 days a week. Fuel will only be delivered to the site at the operators' specified times, where it will be unloaded and stored inside the bunker. Sufficient storage for 5-7 days at full load will be provided to provide a buffer to cater for disruptions in fuel supply or with unplanned outages of the Facility. The fuel will be mixed in the bunker using the overhead cranes to try and ensure homogeneity in the fuel.

Checking and auditing the various fuels forms are an important first step in the control process. Upon arrival at the Facility, all fuels will be weighed, visually checked with CCTV and if necessary sampled. Any deviation from the fuel specification will be noted, and if significant, fuel loads will be rejected. During unloading, facility operators will carry out further visual checks of the fuel.

The bunker is an important component of any Waste-to Energy plant as it functions as the recipient and storage of the waste supply. The waste will be delivered by trucks (rear tipping). However, there is normally considerable diurnal variation in the supply of waste.

For this reason the tipping hall, as well as access and queuing areas shall be able to accommodate this variation in flow of vehicles, also during periods with adverse weather, around public holidays etc.

The bunker and tipping hall are significant civil works items and therefore the volume of the bunker and the area of the reception hall and number of unloading bays need to be balanced against costs and with due attention to the need to minimise queuing and waiting time for vehicles.

The tipping hall will be of sufficient width to ensure easy access for all types of trucks.

There will be a one bunker with two compartments, each compartment serving two incineration lines. The bunker will have a maximum capacity of approximately 68,950 m³. The bunker will have an approximate footprint of 30 m x 94 m, with a stacking height up to 30 m. Even at the maximum throughput the bunker size described in Table 9 is sufficient to provide 5.9 days storage. Fill and removal of material will be via the waste cranes.

Facility & Fuel parameters			
		LP1	LPN
Fuel flow (4 combustion lines)	t/day	4,061	3,315
Assumed Fuel Density	t/m ³	0.35	
Volumetric fuel flow	m ³ /day	11,602	9,471
Bunker parameters			
Length	m	30	
Width	m	2 x 47 = 94	
Height	m	30	
Maximum fuel stacking height	m	30	
Bunker capacity (with stacking), waste volume	m ³	68,950	
Maximum number of days storage	days	5.9	7.3

Table 9 Bunker Design Data (Parameter for the 2 bunkers together)

4.2 Number of unloading bays

It is assumed that all trucks will be walking floor type, although it may be possible to take tipping bulkers if required. It is assumed that the average unloading time for a 22 tonne load is 12 minutes, which is the total time occupying a bay, including reversing and leaving.

Table 10 indicates that in case of the maximum fuel throughput NCV (10 MJ/kg) and accounting for variability and peak flows, there would be a short term maximum of 17 deliveries per hour, requiring a minimum of 4 delivery bays.

Parameter	Unit	Design fuel, average flow	Maximum fuel throughput peak flow
Fuel NCV	MJ/kg	12.3	10
Peak hourly fuel	t/h	132	374
Delivery capacity	t/h	22	22
Peak deliveries	Deliveries /h	6	17
Unloading time per bay	minutes	12	12
Minimum bays required	(rounded up)	2	4

Table 10 Unloading bays requirement

To provide flexibility in operations (i.e. bunker management) the design layout has allowed for 16 delivery bays.

4.3 Trucks (size and frequency)

The waste will be transported to the plant in predominately Semi-trailers, Trucks and Dog trailers. Likewise, the bottom ash and the residual products from the flue gas cleaning will be picked up in semi-trailer trucks.

Trucks are anticipated to carry an average load of 22 tonnes. The plant will operate 24 hours a day, seven days a week. The proposed plant is to have a maximum total capacity of 1,350,000 tonnes per annum. As such, the plant will receive a maximum of up to 168 truck deliveries per day associated with input waste material. However, the planned nominal operational input of 1,105,000 tonnes per annum will result in only 138 trucks per day.

Tonnes p.a.	Weeks per Year	Days per Week	Truck Capacity (t/veh)	No. of Trucks (per day)	Truck Movements (per day)	Hours per Day (hrs)	Truck Movements per Hour (veh/hrs)
1'350'000	52	7	22	168	336	24	14
1'105'000	52	7	22	138	276	24	11.5

An additional 20 truck movements per week are expected for miscellaneous deliveries such as hydrated lime, activated carbon and other materials required for the various processes involved in the power generation. Assuming these will be trucks with an average load of 22 tonnes, delivered over a standard 5 day week, results in a demand for up to 4 additional trucks per day.

Tonnes p.a.	Weeks per Year	Days per Week	Truck Capacity (t/veh)	No. of Trucks (per day)	Truck Movements (per day)	Hours per Day (hrs)	Truck Movements per Hour (veh/hrs)
24'300	52	5	22	4	8	24	0.3

The total ash residue waste (APC Residues and Bottom ash) for worst case fuel will be in the order of 451,700 tonnes per annum (please refer to Chapter 6.8.5, table ash production). As a worst case, it is assumed that this waste is to be carried on trucks with an 18 tonne capacity, removed over a 12 hour period, 6 days a week. On this basis, the removal of ash residue equates to an additional 80 ash truck per day, as outlined in Table below.

Tonnes p.a.	Weeks per Year	Days per Week	Truck Capacity (t/veh)	No. of Trucks (per day)	Truck Movements (per day)	Hours per Day (hrs)	Truck Movements per Hour (veh/hrs)
451'700	52	6	18	80	160	12	14

Table 11: shows the estimated average and peak road deliveries by type, assuming the worst case scenario that all fuel and consumable deliveries, and residue removal from site takes place by road.

		Fuel (NCV 10MJ/kg)	Consumables	APC Residues	Bottom Ash	Total
Average mass flows	t / a	1,350,000	24,300	51,700	400'000	1,826,000
	t / week	25,960	467	994	7,690	35,115
	t / d (Mon-Sun)	3,710	78	166	1,282	5,233
	per h	155	3.3	7	53	218
Average deliveries	per a	61,360	1,105	2,870	22,220	87,555
	per week	1,180	21	55	427	1,683
	per day	168	4	9	71	252

Table 11 Total Traffic Flows on worst case fuel

4.4 Effluent discharge

Under normal operating conditions, no effluent is disposed of to the sewer or stormwater systems but returned to the Facility for re-use. In this way, the liquid effluent produced on site will either be evaporated or absorbed into the bottom ash discharger via the process water system.

Liquid effluent will consist of boiler blow down, boiler water treatment, swilling down water, occasional maintenance discharges and drain water from contaminated areas.

The re-use of the different water streams within the process results in a liquid effluent free EfW Facility during normal operation.

5. BOILER/FURNACE

5.1 EfW grate technology

The EfW plant is based on advanced moveable grate mass burn technology.

A moving grate EfW incineration facility has been preferred due to the robustness and its proven ability to treat a very wide range of wastes. EfW grates show little technical processing sensitivity to the vast majority of variations normally seen in wastes e.g. physical dimensions and chemical composition.

5.2 "Vertical" and Horizontal "Tail-End" Boiler

An important consideration is the fundamental boiler concept. The Facility will use of a 5-pass horizontal boiler incl. vertical economiser pass as shown in Figure 5.

Below the most important topics with regard to the design of the boiler/furnace are discussed.

In principle, the boiler is either designed as a so-called "vertical boiler", i.e. a boiler with vertical passes in both the radiation and the convection parts (incl. the economiser), or as a so-called horizontal, "tail-end" boiler where the boiler has one or more vertical radiation passes followed by a horizontal convection pass with pre-evaporator, superheater, evaporator and economiser sections, see Figure 5.

The horizontal boiler type (the "tail-end") is characterised by the radiation pass being followed by a horizontal convection pass and economiser.

The "vertical" boiler is characterised by the radiation pass being followed by one or two vertical convection passes and an economiser.

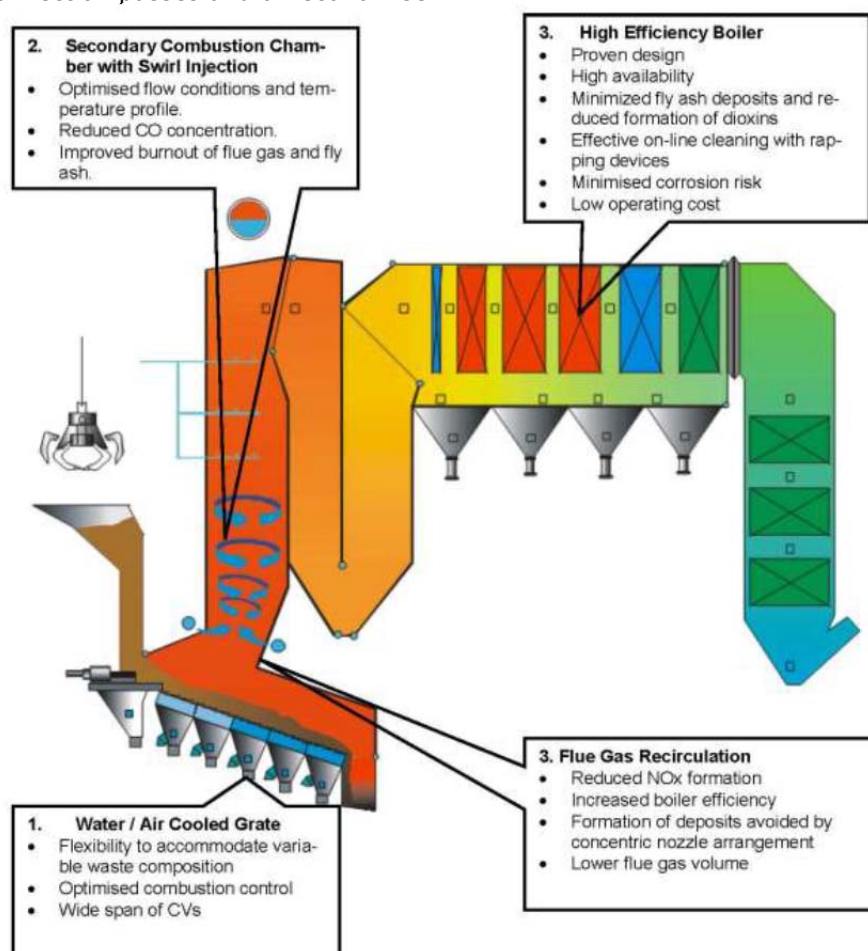


Figure 5 5-pass boiler configuration

Cleaning, Operation and Maintenance

The horizontal convection pass is equipped with a mechanical rapping device, which at a pre-set frequency (typically 4-6 cleaning sequences of 2-5 minutes per day) raps the tubes in the convection pass and thereby removes dust and ash from the tube bundles which fall into the collection hoppers.

A water spray cleaning system is installed in the vertical radiation parts. The radiation part is without baffle walls as it ensure a more conservative or spacious design of the boiler. The boiler is dimensioned for moderate flue gas velocities (3.5 – 5.5 m/s, lowest in the first pass).

The temperature in the cross section at the inlet to the convection part is an important factor and should not exceed 625°C at the beginning of the operation time after manual boiler cleaning.

The convection part consists of superheater sections, the evaporator and the economiser. In between the superheater sections water injections are used to control the temperature of the live steam.

The economiser, evaporator and superheater sections is designed as fully de-mountable tube bundles dedicating special attention to easy replacement of the super heater section subject to the highest thermal load.

The following maintenance and operating conditions speak in favour of selecting a horizontal convection pass:

- A smaller extent of fouling due to more effective cleaning. Soot blowing and shot ball cleaning generally do not result in a uniform cleaning of entire tube sections.
- With the horizontal "tail-end" boiler very long operating intervals between manual boiler cleanings can be achieved. Thus, a guaranteed, continuous operating time of up to 8,000 hours for horizontal boilers against 4,500 hours for vertical boilers leads to less downtime.
- Mechanical cleaning with rapping devices is a considerably gentler and effective and also simpler method compared to steam or compressed air soot blowing. Maintenance of the rapping devices is primarily limited to replacement of parts, which are accessible from the outside of the boiler.
- The horizontal boiler will have a better working environment at the manual cleaning process of the pipe bundles. In a horizontal boiler, the manual cleaning can be performed in an up-right position, whilst in a vertical boiler; the cleaning must be made lying down, thereby exposing the worker to dust and ashes.
- There is no steam consumption for the cleaning and hence no reductions in the power production or operational problems with the turbine due to momentary relatively large steam consumption for soot blowing.
- Generally, fewer corrosion and erosion problems can be expected of a mechanically cleaned horizontal convection pass, mainly because of a smaller extent of fouling and ash deposition and because the protective oxide coating of the tubes is not damaged when using this cleaning method.
- Future replacement of tube bundles in the superheater is easier.

Thermal Conditions

A higher thermal efficiency (0.5-1 %) can be expected of the horizontal boiler as the smaller extent of fouling leads to a better heat transfer of the super-heater tubes of the boiler.

Construction and Operating Costs

A boiler with a horizontal convection pass is more expensive than a boiler with a vertical convection pass.

As, however, the average annual operating and maintenance costs during the life time of the facility are normally expected to be lower for the horizontal boiler the full life cost of the horizontal is generally expected to be lower than the vertical boiler.

Summary

From the above it can be concluded that the horizontal boiler is technically and also from environmental/efficiency point of view the best solution. It requires, however, a bigger up-front investment than a vertical boiler solution

As a result of these considerations the Facility will use of a 5-pass horizontal boiler incl. vertical economiser Figure 5.

5.3 Combustion control system

Given the thermal output increases with greater waste throughout (see Figure combustion control system), a cooling system is used to condense the steam from the turbine exhaust for re-use. Large variations of the calorific value (CV) may require an adaptation of the parameters of the different control loops. The adaptation of all control parameters is executed manually by the adjustment of one single input value. This is the so called 'CV- correction'; a feature that is fully integrated in the control system. The CV-correction effects an automatic adjustment of up to ten parameters of the combustion control system.

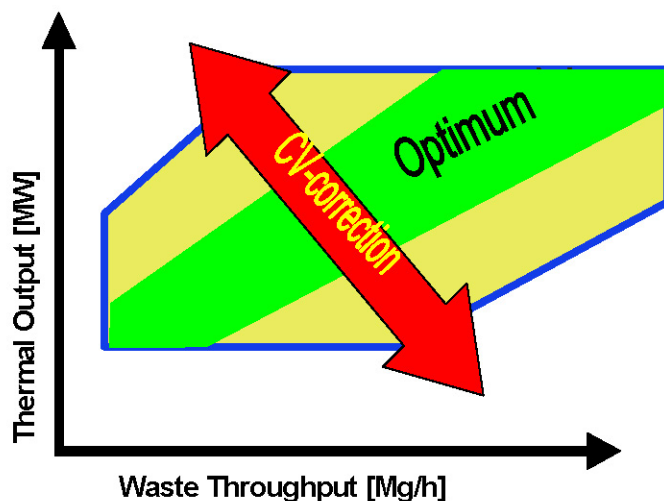


Figure 6 Combustion control system

5.4 Furnace and Secondary Combustion Chamber

The furnace and secondary combustion chamber shall comply with the 2 s retention time and 850°C temperature requirements of the IED and be equipped with auxiliary burners.

5.5 Steam Parameters and Corrosion

Steam parameters have been fixed at 70 bar/430°C, as this allows for high energy efficiency and at the same time keeping the risk of corrosion at an acceptable level.

Corrosion is a significant issue in waste fired boilers. Corrosion increases with higher temperatures. Steam parameters for boilers are therefore determined to achieve the optimal balance between boiler corrosion and plant efficiency.

In addition to the risk of high temperature corrosion in the superheaters, experience has shown that there is a risk of corrosion in the evaporator part of the boiler, particularly where the unprotected membrane tube walls in the first and second passes of the boiler are exposed. Therefore Inconel³ cladding are foreseen at some parts of membrane walls furnace, membrane walls top of pass 1 and 2 and some tubes of superheater 3.2

5.6 Combustion Air Excess (λ)

All systems are designed for all load situations according to the combustion diagram, Figure 4. The combustion air systems are designed to ensure a correct amount of excess air in the flue gas, both in order to ensure high combustion efficiency and to avoid a reducing (corrosive) atmosphere, incomplete burnout of the flue gases etc.

5.7 Primary Air Intake

Maintaining a negative air pressure in the tipping hall is critically important to avoid odour problems from the waste bunker. Therefore, all primary air required for the combustion process are drawn from the bunker. During stand still negative air pressure is maintained and air goes directly to stack.

5.8 Secondary Air Intake

Secondary air shall be drawn from the top of the furnace/boiler hall, and will be injected into the furnace and at the inlet to the first boiler pass through 2 rows of nozzles.

5.9 Flue Gas Recirculation

To increase the overall efficiency of the boiler and reduce NO_x formation (by reducing the amount of excess air) it is beneficial to recirculate the flue gas. Further by flue gas recirculation the flue gas treatment plant will have to treat less flue gas increasing the removal efficiency.

5.10 Feed Water Pumps

The feed water pump is a critical component that secures operation and needs redundancy in case of failure. It is especially important to avoid boiling off all water in the water-steam system, thus avoiding damaging the pressure part in worst case conditions. The Facility will have 2 x 100 % feed water pumps for each line (one pump in operation, one in stand-by mode).

5.11 Make-up Water System

A water treatment plant, producing the make-up water for all combustion lines, is able to fill the tank in 72 hours with all combustion lines in operation whilst maintaining Plant supply at MCR. The capacity of the make-up water tank shall be 125% of the volume required to completely fill one respectively two boilers including superheaters (depending on 2 or 4 combustion lines).

³ Inconel alloys are oxidation and corrosion resistant materials well suited for service in extreme environments subjected to pressure and heat.

5.12 Proposed Design Data

For proposed overall design data refer to table below.

Waste-to-Energy with waste utilization Preliminary Process and Design Data Boiler/Furnace			
Plant Component / Parameter		Value / Description	
Input and Output			
Gross Heat Release		117.98 MWth	
Throughput nominal		34.53 t/h	
Calorific Value nominal		12.30 MJ/kg	
Steam flow 100 %, at 70 bara, 430 °C		144.7 t/h	
Steam pressure nominal		70 bara	
Steam temperature nominal		430 °C	
Flue gas Temperature			
Flue gas temperature exit boiler		Nom 170 °C	
Bottom ash Handling System			
Water content bottom ash nominal		19 %	
Max. Ignition loss bottom ash		5 %	
Max. TOC bottom ash dry		3%	
Bottom ash Bunker parameters (per phase)			
Length		m	13
Width		m	47
Height		m	9 (included 7m below ground level)
Maximum ash stacking height		m	9
Ash bunker capacity		m³	5,499
Bottom ash flow (4 combustion lines)		t/day	1,282 (see Table 11)
Assumed Bottom ash Density		t/m³	1.8
Volumetric Bottom ash flow		m³/day	712
Maximum number of days storage (at LP1)		days	7.7

6. FLUE GAS TREATMENT

6.1 Flue Gas Cleaning System

The flue gas will be cleaned in the Flue Gas Treatment plant to control emissions of acid gases, particulates, dioxins and furans and heavy metals.

The semi-dry flue gas cleaning process is designed to remove acidic gaseous contaminants by chemical absorption with hydrated lime. Heavy metals and organic contaminant compounds (i.e. dioxins and furans) are reduced by adsorption on activated carbon. Features of this system are illustrated in Figure 7.

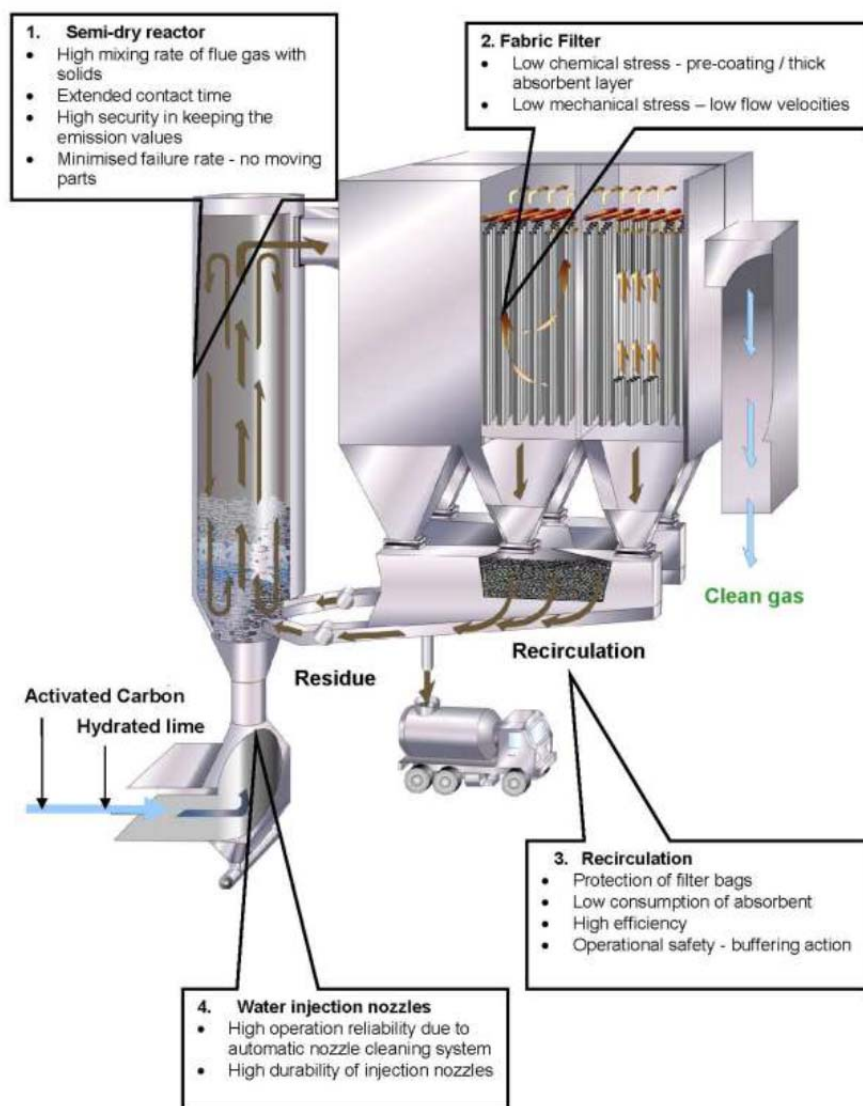


Figure 7 Semi-dry Flue Gas System

In this process the flue gas and solids move turbulently through the semi-dry reactor with partial inversion of the solid flow. The pollutants react with the injected hydrated lime and the activated carbon at a temperature of approximately 145 °C.

The separation of solids from the flue gas takes place in the fabric filter downstream of the reactor. Precautions are considered for water contacted parts, generally water-proof insulation is applied. All maintenance and inspection areas are encased in order to protect against rain during maintenance work.

The flue gas cleaning process is characterised by the following features:

- Flexible to load changes and changes in gas contaminant concentrations;
- Efficient use of adsorbent and minimised residue quantities;
- Designed for high Hydrogen Chloride (HCl) and Sulphur Dioxide (SO₂) inlet concentrations;
- Dry injection of Calcium Hydroxide (CaOH₂) and Powdered Activated Carbon (PAC);
- Separate injection of water for conditioning and reactivation of recycled lime particles;
- Compact design; and
- Low manpower requirement.

6.2 Nitrogen Oxide (NO_x) Removal System

The NO_x Removal system is a selective non-catalytic reduction, SNCR.

With an SNCR system, ammonia water is injected into the first pass of the boiler at a temperature level of approximately 900°C. Here the chemical reaction takes place, converting NO_x to harmless N₂ and water. The system requires 2-3 levels of injection nozzles in the first pass of the boiler and a system based on water or air to atomize ammonia water into the boiler. With a SNCR system the requirement of 200 mg/Nm³ NO_x can be comfortably reached.

The SNCR technology can be optimised to reach 120 mg/Nm³ for a sophisticated SNCR (as daily average). The increased efficiency comes with a modest increase of CAPEX and additional consumption of ammonia.

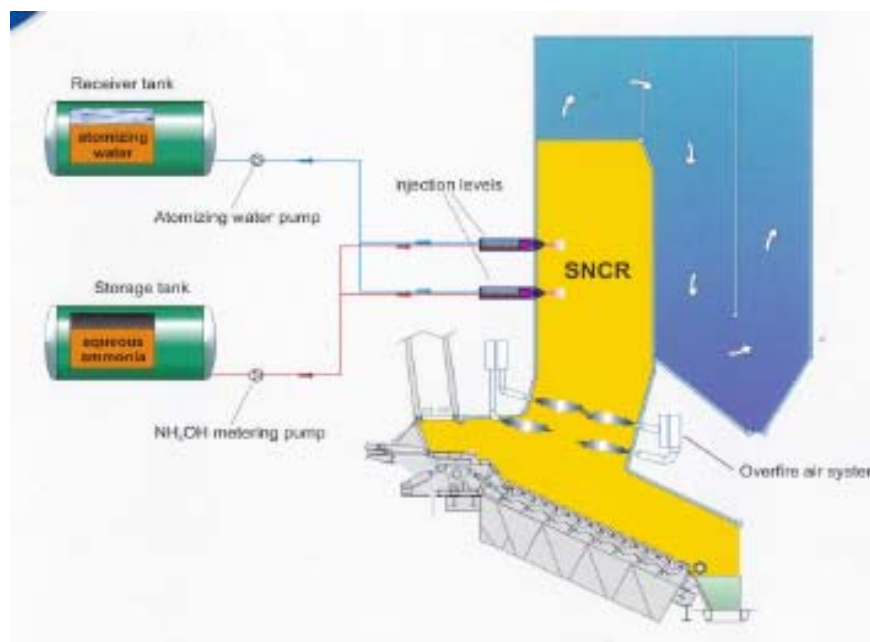


Figure 8 Schematics, SNCR system.

6.3 ID-fan

The ID-fan is designed for boiler operating at 110 % MCR in a fouled condition after 8,000 hours of operation. In order to keep the wear and noise level down the air fan speed shall be below 80% of the maximum speed for which the fan is designed for sustained operation. The ID-fan is electrically driven.

Spare capacity of air and flue gas systems with respect to flow rate is necessary for several reasons. The ID-fan shall always have sufficient capacity to ensure negative pressure in the furnace, also during short term variations. During the life time of the plant the waste composition, quality and quantity might change, leading to different requirements of air and flue gas flows.

6.4 Stack

Flue gases will be emitted to atmosphere via a stand-alone stack for each phase. The final stack height was selected based on a combination of compliance of ground level concentrations and reference to the US EPA document "Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations)" (US EPA Good Engineering Guideline).

Treated flue gases will be emitted to the atmosphere via two separate twin-flues within the standalone stacks, located to the south of the Flue Gas Treatment Areas.

Each stack will be built to the minimum height necessary to ensure adequate dispersion of the emissions and excessive concentrations of any air pollutant in the immediate vicinity of the stack (as defined through air quality dispersion modelling). The US EPA Good Engineering Guideline states the general rule of thumb for good engineering practice stack height is 'Height of building + 1.5 times the lesser of building height or projected width'.

With height being the less of these two dimensions; a stack height of 125 m was initially identified. Dispersion modelling was then used to refine and identify a project specific stack height, based on achieving compliance with ground level concentrations. Dispersion modelling found that a stack height of between 80m and 100m would be suitable. A final stack height of 100m was selected due to consistency with the good engineering practice guide and modelled emissions concentrations at ground level.

6.5 Chosen Emission Standard

Under the EfW Policy Statement the stack emissions from the facility are required, as a minimum, to meet the Group 6 standards of concentration set out in the *Protection of the Environment Operations (Clean Air) Regulation 2010* ("the Clean Air Regulation"). The Clean Air Regulation sets emission standards for various industrial activities and those that are applicable to an EfW facility are outlined in Table 12.

Pollutant	Standard (mg/Nm ³)	Source	Activity
Solid Particles (Total)	50	Electricity generation	Any activity of plant using liquid or solid standard fuel or non-standard fuel
HCl	100	General standards	Any activity or plant
HF	50	Electricity generation	Any activity of plant using liquid or solid standard fuel or non-standard fuel
SO ₂	No applicable standard		
NO ₂	500	Electricity generation	Any boiler operating on a fuel other than gas, including a boiler used in connection with an electricity generator that forms part of an electricity generating system with a capacity of 30 MW or more
Type 1 & 2 substances (in aggregate)	1	Electricity generation	Any activity of plant using non-standard fuel
Cd or Hg (individually)	0.2	Electricity generation	Any activity of plant using non-standard fuel
Dioxins or furans	1x10 ⁻⁷ (0.1 ng/m ³)	Electricity generation	Any activity of plant using non-standard fuel that contains precursors of dioxin or furan formation
VOC	40 (VOC) or 125 (CO)	Electricity generation	Any activity of plant using non-standard fuel
Cl ₂	200	General standards	Any activity or plant
H ₂ S	5	General standards	Any activity or plant

Reference conditions defined as dry, 273.15 K, 101.3 kPa and 7% O₂ for all air impurities when burning a solid fuel, with the exception of dioxins and furans where the required O₂ concentration is 11% for waste incineration.

Table 12: POEO Clean Air Regulation Standards of Concentration

However, the proposed flue gas treatment will be designed to employ Best Available Technology (BAT) and achieve the emission limits specified by the European *Industrial Emission Directive IED 2010/75/EU* (IED). The IED emissions limits (refer Table 13) are generally more stringent than the Clean Air Regulation limits. The proposed technology is based on existing facilities operated throughout Europe, which are designed to meet the IED limits.

The European limit values for emissions in waste incineration plants are defined within the IED. The specific emission limits for WtE are found in Annex VI, part 3 of the Directive.

Parameter	Daily Average	Half Hour Average	Units
Continuous measuring			
Total Dust	10	30	mg/Nm ³
Total Carbon (TOC)	10	20	mg/Nm ³
Inorganic chlorine compounds (HCl)	10	60	mg/Nm ³
Inorganic fluorine compounds (HF)	1	4	mg/Nm ³
Sulphur dioxide (SO ₂)	50	200	mg/Nm ³
Oxides of nitrogen (expressed as NO ₂)	200	400	mg/Nm ³
Carbon monoxide (CO)	50	100	mg/Nm ³
Discontinuous measuring			
Dioxines and furanes	0.1	ng/Nm ³	average of 6-8hours
Hg	0.05	mg/Nm ³	average of 0.5-8hours
Cd+Tl	0.05	mg/m ³	average of 0.5-8hours
Total of heavy metals	0.5	mg/m ³	average of 0.5-8hours

All emissions are dry basis, 11% O₂ and at normal temperature and pressure.

Table 13 IED Emission Limits for an Incineration

6.5.1 Continuous Emission Monitoring System (CEMS)

Consistent with the requirements of the EfW Policy Statement, there will be continuous measurements of NO_x, CO, particles (total), total organic compounds, HCl, HF and SO₂. This data will be made available to the EPA in real-time graphical publication and a weekly summary of continuous monitoring data and compliance with emissions limits will be published on the internet. Further, the emission monitoring shall comply with the requirements of European Industrial Emissions Directive. Continuous monitoring is therefore installed for the pollutants CO, HCl, SO₂, NO_x, NH₃, VOC and particulates. Auxiliary parameters are also measured: Flue gas flow rate, temperature, pressure, moisture content and oxygen.

6.6 Plume Visibility

For the proposed semi-dry flue gas treatment, a stack exit temperature of around 120 °C and moisture of the flue gas of 15-18% is expected. Calculations show that that plume formation will not occur at ambient temperatures above 12 °C and a relative humidity of 75%.

The mean relative humidity (9am) is between 65 and 75% all year. In the months May to October the mean maximum temperature is 17-23 °C, which is well above the 12 °C threshold. The mean minimum temperatures of May-Oct are 7-11 °C, indicating that there will be a number of hours where plume visibility is possible.

It can be concluded that the plume will not be visible the vast majority of the time, and even under adverse conditions, the plume will be light (not dense) and it will disappear quickly. The plume will most likely occur only at night and in early morning hours in the coldest 6 months of the year and have very limited height.

6.7 Consumables Handling

The Facility will use various raw materials during operation. Primarily, these include hydrated lime, ammonium hydroxide, activated carbon, Low Sulphur gas oil and water. These will be delivered to the Facility in bulk transportation vehicles (except for water, Low Sulphur gas oil and oil). The minimum on site storage capacity will be set to reflect the process requirements and local delivery capability. Table 15 shows the approximate consumable requirements.

Various smaller amounts of materials are used for the operation and maintenance of the Facility. These are:

- hydraulic oils and silicone based oils;
- Low Sulphur gas oil emptying and filling equipment;
- boiler water dosing chemicals.

All liquid chemicals stored on site will be kept in bunded controlled areas with a volume of 110% of stored capacity.

6.8 Residue Handling

The facility will generate the following residues:

- bottom ash
- boiler ash
- APC residue;
- Ferrous material residue;
- Staff waste;

6.8.1 Bottom ash

Bottom ash is the burnt-out residue from the combustion process. Bottom ash from the grate is quenched with water and moved by conveyor to the enclosed ash storage bunker where it is stored prior to being transported off-site. The conveyor passes under a magnetic separator to remove ferrous materials.

6.8.2 Boiler ash

The characterisation of boiler ash is dependent upon in which boiler pass it is accumulated in. Boiler ash of the horizontal pass will be conservatively disposed of with the APC residues. The composition of the ash from the first vertical passes is similar as the bottom ash and can be disposed of with the latter.

6.8.3 Air pollution control (APC) residue

Flue Gas Treatment (FGT) residues, also known as APC residues, comprise fine particles of ash and residues from the FGT process. APC residue is collected in bag filters and will contain fly ash and reaction products from the hydrated lime scrubber and spent activated carbon. Due to the heavy metals involved in FGT, this material is classified as restricted solid waste. It will be stored in dedicated enclosed silos located adjacent to the flue gas area before being transported via a sealed tanker to an appropriate offsite disposal facility.

6.8.4 Ferrous material residue

Ferrous metals will be removed from the bottom ash by means of magnetic separators and discharged to into bins which are then transported offsite to metal recycler.

6.8.5 Mass Balance

The residue production from the Facility has been estimated and presented within Table 14:

Parameter	Units	Design fuel	Worst case fuel
Fuel NCV	MJ/kg	12.30	10
Ash content	%	21.49	20
Fuel Flow	tpa	1,105,000	1,350,000
Bottom ash (dry)	tpa	237,465	324,000
Bottom ash (wet)	tpa	293,166	400,000
FGT/APC residue	tpa	43,800	51,700
Combined ash and residue	tpa	336,966	451,700

Table 14 Residue production

Raw material	Process	Typical usage (tpa)
Hydrated Lime	Flue gas treatment – acid gases	19,800
Ammonium hydroxide (25% solution)	Flue gas treatment – NOx reduction	2,200
Activated carbon	Flue gas treatment – dioxins/ heavy metal	420
Low Sulphur gas oil ⁴	System firing	1,900

Table 15 Consumable requirements

6.9 Water Balance

Based on the water balance from a typical EfW facility, the average process water requirement is likely to be 23.25 m³ per hour for the overall plant. Based on 8,000 operating hours a year this equates to approximately 186,000 m³ per year for the overall plant. The primary requirement for water is to provide make-up for the boiler and steam cycle (to replace that which is blown down) and the FGT plant.

⁴ Based on 10 starts per year per boiler (assuming 4 boilers), each start using 43 t gasoil. 10% has been added to the total figure to account for other uses e.g. maintaining the temperature above 850°C. Delivery size is nominal.

6.10 Proposed design data

For proposed overall design data please refer to table below.

Waste-to-Energy with waste utilization Preliminary Process and Design Data Flue Gas Treatment	
Plant Component / Parameter	Value / Description
Raw Flue Gas	
Referring to flue gas downstream the boiler.	
Nominal data ¹⁾	
Flue gas flow rate, dry flue gas at 11% O ₂	279,900 Nm ³ /h
Temperature	170 °C
Pressure	– 1,000 Pa
H ₂ O	14.5 % vol.
O ₂	7.4 % vol., dry
Dust	1,850 mg/Nm ³ , 11% O ₂ , dry
Σ Cd + Tl	3 mg/Nm ³ , 11% O ₂ , dry
Σ Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	70 mg/Nm ³ , 11% O ₂ , dry
HCl	900 mg/Nm ³ , 11% O ₂ , dry
SO ₂ and SO ₃ (as SO ₂)	530 mg/Nm ³ , 11% O ₂ , dry
HF	20 mg/Nm ³ , 11% O ₂ , dry
NO _x as NO ₂ ³⁾	200 mg/Nm ³ , 11% O ₂ , dry
NH ₃ ³⁾	3 mg/Nm ³ , 11% O ₂ , dry
N ₂ O	~ 0 mg/Nm ³ , 11% O ₂ , dry
Hg	0.7 mg/Nm ³ , 11% O ₂ , dry
Dioxins and furans (tox. equivalent 2,3,7,8 TCDD) ³⁾	5 ng/Nm ³ , 11% O ₂ , dry
¹⁾ Nominal values to be used as reference for guarantee values (at nominal) of consumables, residues, and energy production and consumption etc. Values apply at boiler exit ²⁾ Wet flue gas at actual O ₂ content ³⁾ after SNCR-deNOx	
Emission limits, Outlet stack	
Emission limits	Clean Air Regulation Group 6, and where more stringent, IED 2010/75/EU (Please refer to Chapter 0)
Absorbents/adsorbents silos	
Minimum capacity, lime	7 days' consumption + 30 tonnes
Minimum capacity, activated carbon	20 days' consumption + 30 tonnes
Silo for Flue gas Treatment residue	
Minimum capacity	5 days' production at nominal conditions

7. TURBINE/CONDENSERS

7.1 Energy recovery, water steam cycle

The Facility will be capable of exporting approximately 137.3 MW of electricity, amounting to about 1,040,000 MWh per annum of electricity. For the export of electricity there will a separate connection to the electricity distributed network.

The/A Substation will be designed for both phases by taking into account two connection points for each turbine generator and also ability to make a new connection for the second turbine generator at phase 2 without shutting down the phase 1 facility.

The Facility will have one turbine for each phase which will serve two streams each. The principle of water steam cycle is shown below in Figure 9.

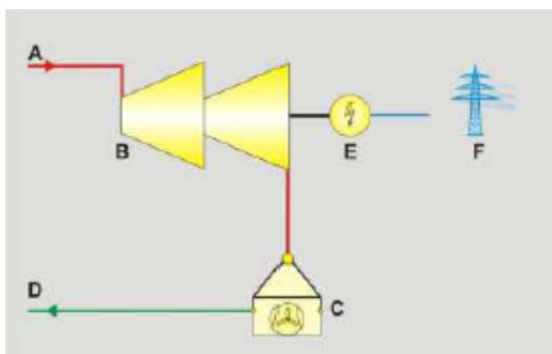


Figure 9 Steam Turbine set generating electricity

By means of a pressure controlled steam extraction, low pressure steam is taken for internal consumers in the plant. The expanded steam is then led to an air-cooled condenser to completely condensate the steam. Also part of this cycle are general steam and condensate systems, water treatment and feed water preparation systems as well as a closed-loop cooling system for all general cooling purposes of the plant.

7.2 Condensing System

The EfW plant will require a cooling system to condense the steam from the turbine exhaust for re-use. A Best Available Technology (BAT) assessment has concluded that the use of ACC represents BAT for this installation based on its geographical location.

ACCs condense steam from the turbine exhaust by transferring heat to the air. The steam travels down the inside of finned metal tubes whilst air is blown by fans across the outside of the tubes. As the steam loses heat it cools and then condenses. The condensate is collected in a condensate tank below the ACC unit and then pumped to a feed water tank ready for recirculation back to the boilers.

7.3 Power Generation

As previously mentioned the steam parameters are 70 bar at 430°C. With these parameters processing of 34.53 tonnes/hour with at a calorific value of 12,300 kJ/kg the plant has a thermal power of 117.98 MW per combustion line.

The estimated nominal steam turbine power output is 76 MW (gross power). The net power output is estimated at 68.7 MW.

The power generation from the Facility is presented within Table 5. The Facility will be designed to export 68.7 MWe in phase 1 and a further 68.7 MWe in phase 2 a total of 137.3 at full operation to the grid.

7.4 Turbine

The steam turbine shall be designed to swallow 110% of the maximum boiler steam production. This allows for sufficient turbine capacity for slight overshoots and variations in steam flow, as well as gives margin if the boiler is performing better than expected.

In order to achieve a flexible operation of the plant and for safety reasons and for start-up/shutdown it is necessary to provide the plant with a possibility of operation without passing the steam through the turbine: This is done with a turbine bypass system.

The turbine bypass system function is designed to allow operation of the combustion during maintenance on the turbine without having to shut down the complete Facility.

Bypass operation is used, when the turbine cannot receive the steam due to internal malfunction (turbine trip) and maintenance works or at start-ups and shut-downs, where the condition of the steam is outside the operational range.

The bypass is able to swallow steam corresponding to 20-110% boiler load. During bypass operation (that is, operation without the steam turbine), a live steam reduction valve shall provide the necessary steam for deaerator and air preheating.

The bypass station produces slightly superheated steam of such conditions, that the condenser works properly in the whole load range.

Typical load point of bypass operation could be: steam turbine producing only house load (~2 MW) or steam turbine completely out of operation.

7.5 Export of heat

Without any changes to the main plant design, the Facility is configured so that it is possible to export heat to nearby consumers for space heating or cooling or hot water. The turbine is constructed to export up to 20MW heat per turbine.

TNG is very interested to use this technical possibility and is actively exploring potential heat export possibilities.

7.6 Proposed design data

The proposed overall design data is summarised in the table below.

Waste-to-Energy with waste utilization Preliminary Process and Design Data Turbine/generator/condensers	
Plant Component / Parameter	Value / Description
Turbine design steam data	
Nominal (100%) Steam flow	Maximum continuous flowrate (MCR) in boiler combustion diagram
Steam flow nominal	144.7 tonnes/h
Steam flow rates possible	Island mode – 110% of boiler MCR
Steam pressure (inlet of Emergency shut-off valve, controlled by turbine inlet nozzle group)	70 bara
Steam temperature nominal at boiler exit	430 °C
Swallowing capacity for turbine	Corresponding to operation at 110% MCR
Swallowing capacity for bypass system	Corresponding to operation at 110% MCR
Island mode	
Electricity demand, Island Mode (preliminary for tendering)	3,0 – 6,0 MW (final value to be given during detailed engineering)
Turbine bleeds (design)	
	Approx. 5 bara to supply steam to: - air preheater - de-aerator Further bleeds foreseen for heat export if later required.
Turbine bypass station	
Steam downstream turbine bypass station Temperature	[Saturation + 5-10 °C]
Air cooled condenser	
Operation pressure	0.1 bara at 22°C ambient temperature and turbine operating at 100% MCR
Temperature inlet / outlet	46/46°C

8. ANCILLARY EQUIPMENT

8.1 Waste Cranes

Two duty and one standby waste crane with integrated weighing cells will be installed capable of operating in automatic as well as manual mode.

Full redundancy will be secured via two identical waste cranes that each alone is sufficient for feeding the hopper. The cranes shall be able to operate in automatic mode, feeding/mixing/moving, thus programmed for random homogenisation and mixing of waste when feeding is not required. The cranes shall be fitted with automatic weighing cells that feed data on the amount of waste placed in the hopper to the CMS system. A spare grab shall be present to ensure a high degree of reliability.

The waste crane grabs size and the speed of operation shall be appropriately sized to service two process lines with the duty cranes operated in semi-automatic mode, the regime being:

- The Contractor will define the unproductive time in the bunker management procedure;
- Maximum 30 minutes per hour to remove mixed waste from the bunker and feed the waste hoppers to enable the plant to operate at 100% MCR at the maximum fuel throughput as defined on the firing diagram (waste CV of 10 MJ/kg).;
- During the lorry and conveyor delivery time period the remaining time shall be sufficient to allow clearing of the tipping area and stacking, such that waste deliveries are not disrupted.
- Outside the main delivery time period the remaining time shall be sufficient to allow sufficient mixing and stacking and clearing of the tipping area.

8.2 Bottom Ash Cranes

Three bottom ash cranes will be installed with integrated weighing cells for run and standby operation, with the facility to operate both cranes simultaneously in either manual or automatic modes.

8.3 Component Cooling System

The component cooling system will supply the necessary amount of cooling water (water/propylene glycol mixture) at a specified pressure- and temperature level to the cooling water consumers connected to the system, for example the turbine.

The cooling system and its components are dimensioned for the maximum cooling need in the entire system at the most critical supply conditions.

8.4 Cranes and Ancillary Hoisting Equipment

To ensure efficient lifting of main equipment during operation and maintenance, two permanent cranes are installed:

- Workshop Crane, load capacity 5 tonnes
- Turbine Hall Crane; load capacity 72 tonnes
- Lifting hoists in boiler hall

Ancillary hoists will be installed in such a way that all major pieces of equipment and plant can be serviced and replaced efficiently throughout the plant where major equipment and components are installed.

It is important that maintenance and repair can be carried out efficiently at any given time to maintain the high plant availability. For this reason, cranes as well as galleries etc. are planned and established throughout the facility to ensure that all components can be serviced and replaced quickly and safely.

8.5 Proposed design data

For proposed overall design data please refer to table below.

Waste-to-Energy with waste utilization Preliminary Process and Design Data Ancillary Equipment	
Plant Component / Parameter	Value / Description
Waste	
Waste density within closed grab to be used for crane cycle calculations.	500 kg/m ³
Average density of the waste in the bunker before compression to be used for calculation of capacity	350 kg/m ³
Crane construction for waste cranes (both phases)	
Number of cranes	3 semi-automatic waste cranes
Crane capacity (per crane in semi-automatic mode)	
Charging waste hopper (nominal)	34.53 t/h
Compressed Air (per phase)	
General	
Total installed compressor capacity for process and instrument air	4x37% <u>or</u> 5x28% of total demand of one phase
Process and Instrument air	
Maximum size of particles:	0.1 µm
Maximum concentration of particles:	0.1 mg/m ³
Dew point:	-40 °C
Maximum oil content:	0.01 mg/m ³

9. CONTROL AND MONITORING SYSTEM

In order to control and monitor all the processes and components and to support automatic operation of the EfW Plant, a Control and Monitoring System (CMS) is required.

The CMS is an automated system used to operate the plant and ensure the safety of personnel and equipment. The CMS operates the Facility processes, machinery, and drives. It also covers information management, quality control, and mechanical and field device condition monitoring.

The CMS replaces the following equipment:

- Operator Level
- Server stations
- Process stations
- System network (redundant Ethernet network)
- Bus systems to Remote I/O stations
- Communication to HV system
- Link to Turbine package unit

The CMS consists of the following levels:

- Plant level: Process equipment, sensors, actuators, probes and analysis devices
- Automation level: Process control, automated devices and autonomous systems, safety systems (SIL = Safety Integrated Level)
- Process control level: Monitoring and controlling of process, data acquisition, programming tools
- Plant control level: Management, maintenance and supervision
- Interface to management systems and the office network.
- Interface for remote access
 - o CEMS (Continuous Emission Measuring System)
 - o Remote maintenance
 - o Data and trends

The CMS will perform the dedicated control and monitoring tasks for specific equipment in the plant and support operator control of the said equipment, and support full-automatic and semi-automatic operation and control of the various process sections of the plant, and support plant operation staff in operation, control and monitoring of the entire plant. Furthermore, the CMS shall support plant operation staff in reporting to internal as well as external parties (e.g. supervising authorities) and support plant maintenance staff in planning, organisation and performance of maintenance of the plant. The CMS shall also enable automatic generation of environmental reports and provide maintenance schedules in accordance with license requirements.

The CMS overall configuration is illustrated in the topology drawing, Figure 10.

The CMS-system will be constructed with a number of operator stations from where operation and monitoring of all the facilities are performed. The operator stations shall mainly be located in the control room. If a specific process demands a local operation, it should be possible to place local operator screens at the process. The operator stations shall communicate with the process control stations through a safe redundant process network.

The process control stations will be established as autonomous processor-based units, which independently of any fault in the overall process network or operator stations shall be able to control, monitor and protect the facility equipment.

An engineering station will be established for configuration, programming, analysing, etc. the system. Furthermore, a common report server for operational and environmental reporting shall be established. Printing facilities, including colour laser printer, shall be available in the control room, to be used for printing of reports and documentation. A connection to the operation and maintenance system (O&M system) will be established, to update the O&M system with plant information, information from electrical components of the facility, for scheduling of preventive maintenance work. Access to the O&M system shall be provided from the control room and administration areas.

All electronic equipment, except monitors, keyboards and printers, will be installed in a dust-free and temperature-controlled environment. It is common to have an air conditioned server room close to the control room, where all the electrical equipment can be located safely.

A redundant control network for communication between all process stations will be established. It must be possible to access all information from each operator station. This process network will also be the interface to the network of the administrative system. The network must be constructed with intelligent firewalls, routers and switches to separate the process network with the administrative network. The network must be constructed with optical cable or cobber cable. Wireless network is not allowed, except for maintenance purpose (Service Laptops). The routers and the components on the network shall be based on the technology Simple Network Management Protocol (SNMP), which entails that diagnosis and operational information from the individual (SNMP) components can be transferred to further processing in the O&M system.

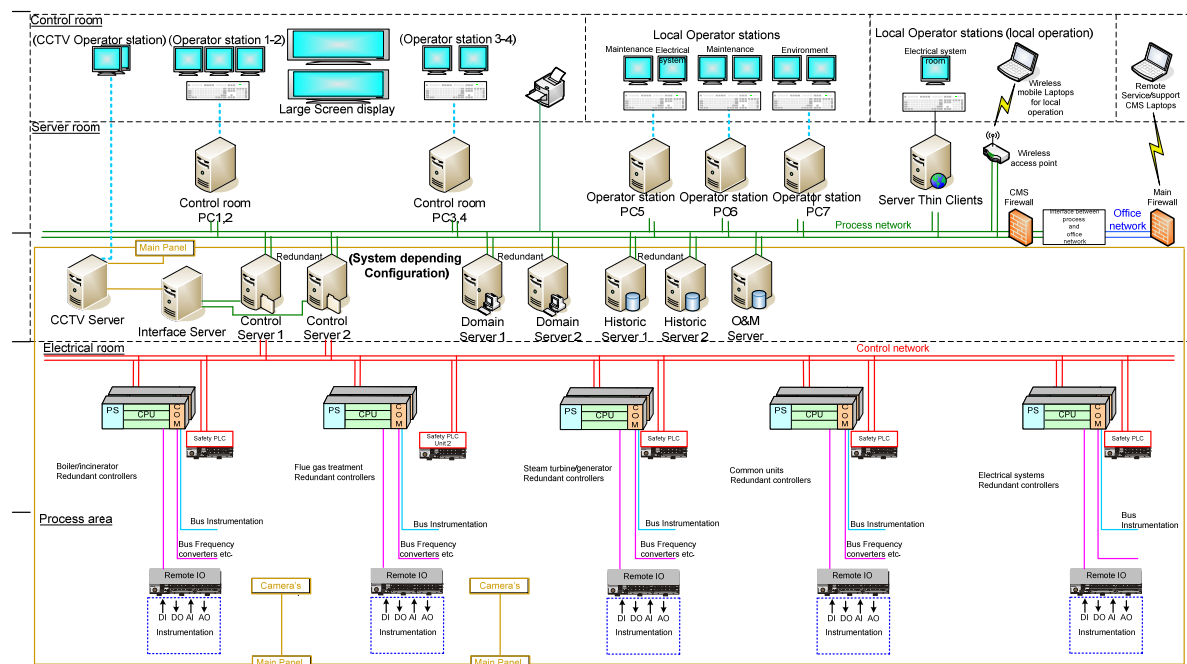


Figure 10 CMS configuration

9.1 Overall CMS Operation Philosophy

The following requirements regarding operation philosophy shall be observed:

- The total plant will be controlled and monitored from the operator stations in the control room. It shall be possible to carry out all control and monitoring functions by means of the operator stations. Under normal conditions it shall be possible for one operator to control and monitor the entire plant from the operator stations in the control room.
- Independent of the chosen level of operation and control, the CMS will ensure that the total plant can be controlled and operated in a secure and satisfactory manner. This includes personnel safety, plant safety and operational reliability. All operator actions shall be subordinate to the safety systems of the CMS. In case of faults in the plant, or in the CMS itself, partially or totally, the CMS shall ensure that the faulty part of the plant is brought into a controlled and secure condition.
- The operator will have full information from the entire plant available in the CMS, to help with decision making and issuing commands through the CMS. The operator is the person in charge and it is the obligation of the system to provide adequate and correct information, presented in an easily understandable manner. To do this, the CMS must be able to produce the following lists:
 - Presentation of the plant processes and object status
 - Indication of historical trends
 - Event and Alarm handling
 - Reporting system, for different reports.

Access shall be limited. It shall be possible to limit access to all or part of the system through the use of password protection.

9.2 CCTV

A common camera surveillance system (CCTV) with monitors in the control room, to which all cameras for the plant area are connected, shall be installed in the server room. It shall be possible to operate and select cameras from a position close to each operator stations in the control room.

10. ELECTRICAL SYSTEM

10.1 Electrical Installation

The following voltage levels shall be in use in the Facility:

Rated operating voltage	Maximum voltage of equipment	Neutral treatment	Purpose
11 kV AC	12 kV	Insulated high resistance earthing	Generator voltage and high voltage distribution.
710/415/240 V AC	+10%,-6%	Solidly earthed	Mains power distribution.
110 V DC	110 V	Isolated	Control voltage only where 24 V cannot be used and only available with the written approval of the Company's Representative.
24 V DC	24 V	Earthed negative	Control voltage, fire alarms.
24 V AC	24 V	Safety insulation	Safety voltage for lighting.

Table 16 Plant voltage levels

The steam turbine generator is expected to generate electrical power at 11 kV and will be connected on to the Facility 11 kV power distribution system and to the distribution network operator's network through a step-up transformer.

Each turbine generator will provide the electricity to operate the rest of the Facility. Electricity will normally be exported to the grid, but the grid connection will also allow for import of electricity back to the turbine halls for start-up of the whole Facility.

In addition, it shall be possible to supply power from one Power Island to the other via appropriate switching, including all necessary synchronisation and automatic controls. This should enable either power island to supply the other, whether operating in island mode, in the event of an emergency, or as desired during normal operation. An appropriate power management system shall be provided enabling all the necessary functionality.

All switchgear, control gear and fuse gear will be located indoors, in metal-clad sheet steel cubicles with front access doors. The equipment will be selected from manufacturers' standard product range and be fully type tested in accordance with relevant Australian, European and International Standards.

The equipment will be rated to withstand the mechanical forces and thermal effects of the maximum prospective fault current at the point of application.

In normal operating conditions, the power requirements of the Facility will be supplied by the steam turbine generator with the balance exported to the grid.

In the event of a breakdown of the steam turbine generator, the power for the site parasitic load will be supplied from the grid.

It is anticipated that the steam turbine will be capable of operating in island mode. In the event of a loss of grid connection, this would allow the Facility to continue processing fuel with the auxiliary load supplied from the turbine generator.

Emergency diesel generators will also be available for safe shut down of the Facility in the event of a loss of grid connection and failure of the steam turbine to transfer to island mode operation.

10.2 Transformers

Following transformers are used in the facility:

- Power transformers – 132/11 kV;
- Auxiliary transformers – 11/0.415 kV or 11/0.71kV;
- Unit transformers – 11/11 kV

10.3 Protection

The protection system will be designed that in the event of faults occurring, the faulty plant is safely disconnected, whilst continuity of supply consistent with system stability is maintained. The selection and setting of protection devices for the auxiliary system will be based upon the following major requirements:

- Faults on facility items will be disconnected as quickly as possible to minimise damage;
- Faults external to major power sources, e.g. unit transformers, will only open the circuit breaker controlling these power sources after all other protection nearer the fault has failed;
- Faults internal to major power sources shall cause their circuit breakers to open as fast as possible to ensure that the transmission system can restore itself within the limits of stability;
- The protection will be designed to be stable in transient conditions such as motor starting and will not operate for current surges caused by faults external to the auxiliary system, for which the main generator would recover and the item of plant protected would not be damaged; and
- Protection of plant is designed to match the plant operating characteristics and provide discrimination with other plant.

All circuits will have lockable isolating facilities so that they can be disconnected and worked upon in complete safety.

10.4 Electrical Works

The Facility will include standard electrical equipment, selected based upon safety, reliability and quality.

No single failure of a major part of the auxiliary plant should result in the total shutdown of the main generating plant.

Essential supplies systems will be provided to maintain unit output and to protect plant from damage, due to a loss of supply. The systems will be sized to enable the station to be shut down in a safe manner on loss of transmission supplies and afterwards to allow normal supplies to be re-instated following reconnection.

Suitable earthing and lightning protection will be provided.

10.5 Emergency Power/UPS

It is critically important that failure of the grid or other power failure does not result in either damage to the plant or in excessive emissions to the atmosphere. Therefore, uninterrupted power supply (shall be supplied in order to maintain control of the plant at power supply failure) and emergency diesel generator (the UPS can only supply power for smaller components - primarily the CMS) are installed in order to slowly run-down the plant at failure of the grid. The diesel generator will require suitable housing / positioning to limit the risk of noise impacts.

The main emergency power supply shall be from the emergency generators and shall be sufficient to permit the re-start of all necessary Plant control systems and equipment following a full Plant trip to permit the safe shut-down of the Facility. The emergency diesel generators are specified in chapter 10.5.1.

In addition battery back-up emergency systems (DC, UPS), as required for the safe shut-down of Plant components, shall be supplied.

10.5.1 Emergency Power

The two emergency diesel generators shall supply Emergency power to the selected items of Plant as required by TNG for the four incineration lines. They will not be used for shutting down and starting up the plant in the case of planned (scheduled) outages, or forced (unscheduled) outages.

The emergency generators shall be designed for continuous operation. In addition to providing emergency power supplies to essential users, the generators shall be designed for operation when:

1. synchronised to the grid;

2. synchronisation of the diesel generation set with the Site distribution system for testing purposes; and
3. automatic switching of the diesel generation set to the Site electrical connection so that the Site supply can be restored without disruption of the essential services.
4. Black start of one incineration line

In case of a complete breakdown of the normal auxiliary power supply, the emergency generators shall be sufficient to meet the electrical demand of at least the following consumers:

1. essential air conditioning, including boiler house/turbine hall chiller equipment and air conditions units for all main LV/HV switchgear/distribution rooms, Plant control room, relay rooms, and the CEMS rooms;
2. all drives and electrical devices necessary for the safe control and shut-down of the entire Facility and its associated systems;
3. 110 V DC and 240/415 V UPS systems;
4. Plant control room lighting and air conditioning systems;
5. radiator fan, diesel oil transfer pump and all other drives required for diesel generator operation;
6. ventilation fan of diesel engine room;
7. oil pump and turning devices for turbine shut down;
8. generator shut down heaters;
9. emergency lighting system, including in all main LV/HV switchgear/distribution rooms, central control/relay rooms, escape routes, exits, etc;
10. essential task and access lighting systems;
11. HV and LV switch-gear and switch-gear rooms;
12. weighing systems in weigh-bridge area;
13. Site access barriers;
14. passenger lifts, goods lifts;
15. Site fire pumps and fire detection, protection and alarm systems;
16. all other essential services/equipment/areas.

10.5.2 UPS

Supplies for protection, tripping, alarm, control, instrumentation, emergency drives, emergency lighting, communication equipment etc. as defined, shall be maintained by means of batteries for a period of not less than 1 hour in the event of loss of all normal means of supply.

Each DC system shall be supplied by one 100% battery and one associated 100% charger. Each charger shall be capable of simultaneously float charging the battery and supplying the total load.

The UPS requirements are:

	Parameter	Requirement
i	Output voltage	As required by the particular application
	Static tolerance	+ 1
	Dynamic tolerance	+ 4% for 100% load change
ii	Output frequency	50 Hz
	Tolerance	+0.2 to + 0.3% adjustable, synchronised to mains
iii	Harmonic distortion	<2% for linear load
		<5% for non-linear load
iv	Overload capability	150% for 1 min, 125% for 10 min
v	Short circuit current	2 x rated current for 10 seconds
vi	Ambient temperature range	0-40°C
vii	Cooling	Forced ventilation (redundant)
viii	Noise level	60dB (A) max

Table 17 UPS requirements

11. CIVIL WORKS AND LAYOUT

11.1 Background

The capacity of the Facility cannot be treated in a single combustion system. As single combustion system of the required size cannot be supplied. Therefore, the Facility will be configured as a four combustion line system.

The Facility will be built in two phases. Lines 1 & 2 being built in Phase 1 and Lines 3 & 4 being built in Phase 2 when the applicant can demonstrate the required quantity of Fuel is available to the Facility.

Each phase will comprise of two combustion grates and two boiler systems housed in one building and each boiler has its own independent Flue Gas Treatment system and connecting to one turbine enclosed in the adjacent Turbine Hall, connecting to one air cooling system and one emission Stack and the other auxiliary elements connecting the process.

In Phase 1 the entire Tipping Hall, Waste bunker Administration and workshop will be constructed as well as full sized underground infrastructure, substation, detention basins and back-up systems, to ensure no synergies or efficiencies of the facility are lost with the two phase approach and the external appearance is not altered between the construction of the two phases.

The Development will include the following elements:

- Four combustion lines and associated boilers;
- Cooling systems comprising air cooled condenser (ACC) units;
- Flue gas treatment systems, including residue and reagent storage silos and tanks;
- Emissions stacks and associated emissions monitoring systems;
- Steam turbines and generator housed within a turbine hall;
- Two auxiliary diesel generators.
- Buildings:
 - o tipping hall and fuel storage (common to both phases);
 - o boiler hall x2 ;
 - o turbine hall x2;
 - o substation;
 - o bottom ash collection bay x2;
 - o workshop (common to both phases);
 - o stack x2; and
 - o control room, offices and amenities (common to both phases).
- Control room, offices and worker amenities;
- Hard-standing, internal vehicular access roads, vehicle turning and waiting areas;
- Fuel reception and storage facilities, consisting of a tipping hall and vehicle ramps,
- Fuel storage bunker and cranes;
- Consumable Materials Handling and Storage area for raw materials including hydrated lime,
- ammonium hydroxide, activated carbon, Low Sulphur gas oil , oil, and water, bottom ash handling systems, compressed air systems;
- Process effluent storage tanks;
- Demineralised water treatment plants;
- Fire water and fire protection facilities;
- Administration and control buildings; and substation.

Associated and supporting components of the development will include:

- Subdivision of the land;
- Pedestrian footpaths and routes;
- Internal roadways and weighbridges (x 2);
- Direct underpass connection (Precast Arch and Conveyor Culvert) between the proposed Facility and the Genesis MPC;
- Staff car parking for 40 vehicles (including 3 visitor parking spaces);

- Water detention and treatment basin; and
- Services (Sewerage, Water Supply, Communications, Power Supply);
- Signage;
- CCTV and other security measures;
- External lighting; and
- Hard and soft landscaping and biodiversity measures.

The proposed buildings have varying footprints and heights, with the maximum height reaching 52 metres above ground level, and the stacks reaching 100m. The indicative dimensions of the buildings and various components of the facility are outlined within the table below. Various components of the facility are outlined within the Table 18.

Building	WIDTH (W)	LENGTH (L)	HEIGHT (H)
Tipping Hall	109	50	20.5
Waste Bunker	94	30	50 (included 7m below ground level)
Boiler House (per phase)	50	60	52
Flue Gas treatment (per phase)	45	47	37
Stack with two inner flues (per phase)	Outer diameter 3		100
Turbine Hall (per phase)	34	46	26
ACC (per phase)	50	50	23
Bottom Ash collection area (per phase)	47	13	19
Sub Station (4000m ²) common	63	63	20
Office Block	15	31	11
Workshop	32	35	16.5
Control Room	10	38	38
Weighbridge (in)	40	16	10
Weighbridge (out)	38	15	10
Fire water Tank	14.7	13.7	9
East Amenities	30.5	7	4.5
West Amenities	19	6	4.5

Table 18 Main Building Dimensions for the Facility (meters)

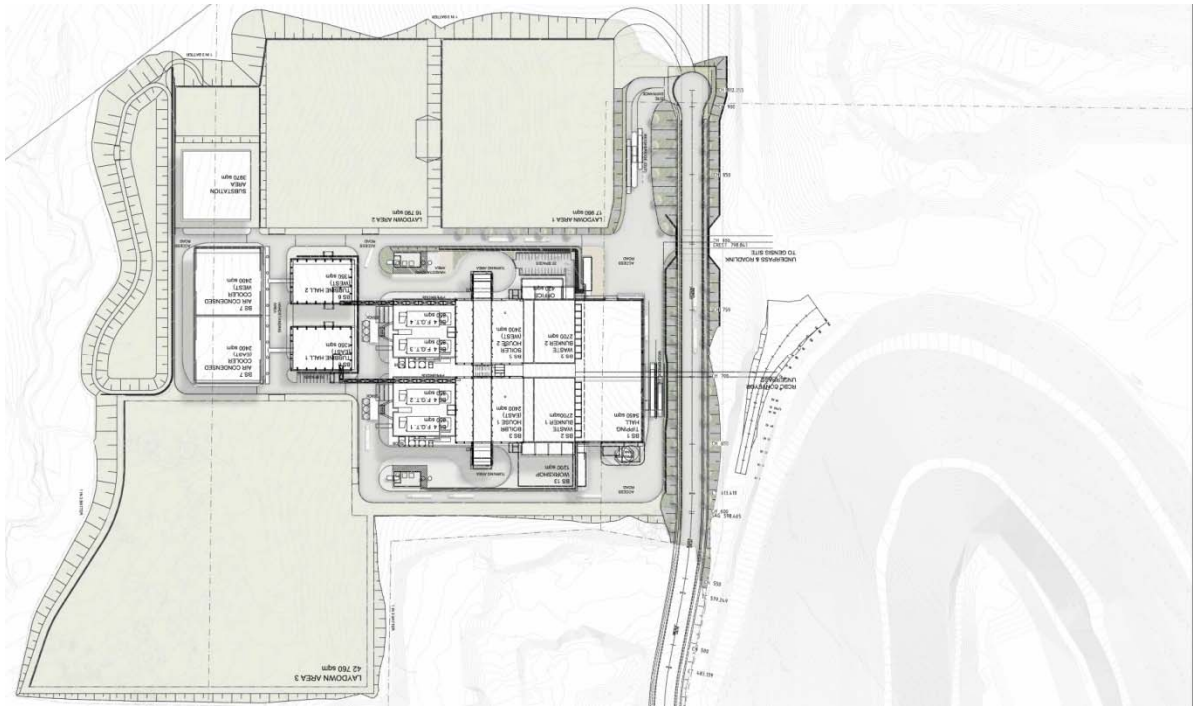


Figure 11 Site Layout

The above dimensions have been developed based in consultation with the technology provider (HZI) and the appointed construction company (Brookfield Multiplex) to ensure optimal functionality of the Proposed Development taking into consideration the unique site topography.

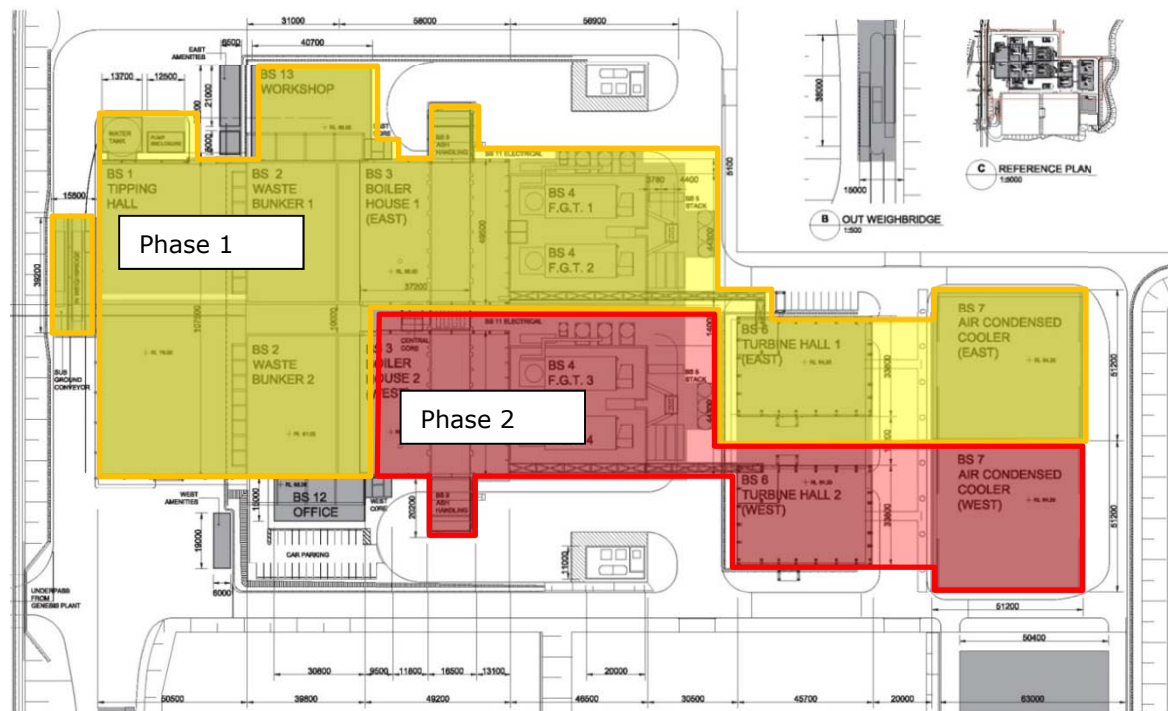


Figure 12 Building layout

11.1.1 Site Layout

Traffic areas are designed in accordance with the national regulations. The design takes into account the peak vehicle movements and any associated queuing or standing time in order to avoid trucks/cars cueing onto the public road. Furthermore, the design will separate the heavy traffic from the light traffic for safety reasons.

11.1.2 Entrance/Weighbridge

The proposed Facility will provide two new weighbridges to be constructed within the boundary of the Site on Precinct Road (one on entry and one on exit).

Fuels from external transfer stations and recycling facilities will be delivered via road vehicle. These vehicles will enter the Site through the main entrance off Precinct Road which is being constructed as part of this proposal.

Once vehicles have entered the site they will proceed to the weighbridge where the quantity of incoming fuel is checked and electronically recorded. Vehicle loads will be inspected at the weighbridge to confirm the nature of incoming fuel and only authorised fuel will proceed to the fuel reception area.

Loads will be nominally 22 tonnes for all fuel types. Fuel can be sampled from the vehicle at the weighbridge. The weight of the outgoing vehicles will be recorded on a separate weighbridge as they leave the Site.

Fuel from the Genesis MPC will arrive at the proposed Facility in two ways as described below. The incoming fuel will be pre-weighed and its details recorded at the Genesis Xero Waste Facility before transported to the Facility:

- By a conveyor transport system which will carry the residual waste output of the Genesis MPC. It will travel via the culvert under Precinct Road and will eject directly into the storage bunker.
- Some vehicle transport from Genesis MPC will be required and when this occurs it will be via the archway under the Precinct Road (to be constructed as part of the DA consent). Vehicle transport via the culvert under Precinct Road will also be used in the event the conveyor is out of service.

Out bound movements along the road may include unrecyclable wastes that are extracted from mixed waste stream at the pre-sort stage prior to be feed into the recycling plant

11.1.3 Process Building

The layout of the facility has been informed by a range of operational requirements of key components including the furnace boiler and flue gas treatment that are required to have a linear arrangement.

Below a number of issues which have impact on the layout of the facility and which are reflected in the proposed layout of the plant:

Tipping Hall:

- Full enclosed tipping hall through individual tipping gates
- Number of tipping bays (please refer to Chapter 4.2)
- Width and geometry to allow for efficient use and safe traffic manoeuvring
- Inspection area

Waste Bunker:

- Volume (please refer to Chapter 4.1)
- Depth (ground conditions/foundation/required tipping height)
- Diversion (sorting)
- Direct view from control room into waste bunker
- Waste crane maintenance area

Boiler Hall:

- Boiler configuration (horizontal/vertical)
- Boiler support integrated in primary building structure
- Bottom ash storage below the horizontal part of the boiler
- Combustion equipment arrangement and accessibility

FGT area:

- Flue gas treatment equipment arrangement
- Consumables silos
- Residue silos

Turbine Hall:

- Arrangement of turbine and water-steam cycle equipment
- Crane accessibility
- Area needed for maintenance and laydown area for turbine casing/rotor etc.

Bottom Ash Handling:

- On-site storage
- Storage capacity
- Crane accessibility
- Safe loading

Workshops:

- Maintenance philosophy (own staff/external)
- Separate mechanical and electrical workshop
- Needed area (closely linked to philosophy)

General:

- Crane accessibility
- Area for operation and maintenance
- Escape routes

Control Room/Offices/Staff Rooms

- Reception area
- Toilet/welfare facilities
- Employee mess room and kitchenette area
- Lift and stair access to all floors of the plant
- Office areas and meeting rooms
- Control Room

12. OPERATION

12.1 Start-Up and Shut-Down

The Facility will be started and stopped automatically, but under the supervision of trained operators. This means that the control system will start the Facility in a controlled and safe manner, but the operator will have various "hold" points where checks are made before proceeding to the next stage. The Facility will be started using fuel oil to reach safe combustion temperatures before any solid fuels are added. The flue gas cleaning system and emissions monitoring will be in operation before any solid fuel is added.

If the operator wishes to turn the Facility off, this is carried out in a controlled manner by reversing the start-up process. Solid fuel feeding is stopped, but the Facility continues to operate to ensure that all material is burnt and any flue gases are cleaned out of the system. Air flows are left on to allow the boiler to cool down before the Facility is fully shut off.

If any emergency condition is reached, or if a rapid facility shut down is required, the Facility will stop automatically in a rapid manner. Fuel flows and air flows are stopped instantly which causes combustion to stop very quickly. The boiler can be depressurised via safety valves if required. This system is fully interlocked to prevent manual intervention unless it is safe to do so.

The Facility is also protected in case of a complete loss of power, a "black plant" trip. In this case, the Facility will stop as under an emergency stop. The Facility will be provided with a secure electrical supply to provide power to essential consumers such as oil pumps, feedwater pumps, instrument air, fire pumps and emergency lighting. Control systems are supplied from a UPS system (Uninterruptable Power Supply) to ensure the operators are aware of what is happening.

12.2 Staff

The Facility will be operated and managed by suitably qualified and trained personnel. It is anticipated that a total of 55 staff will be employed of which 4 will be managers and 3 will be supervisors.

The shift teams will be led by experienced engineers who will have the responsibility for managing the operation of the Facility outside of office hours.

.As detailed in section 9 there will be a high degree of automation in the facility with the plant and key processes controlled from a central control room using a state of the art control system based on programmable logic controllers.

A fully automatic waste grab crane is to be installed which removes the need to man the grab crane except during peak waste delivery times. The weighbridge will also be fully automated with a vehicle recognition system and traffic barrier control system. Table 19 outlines the anticipated staff members required.

Role	Number of staff (Indicative)
	Overall Facility
Facility Manager	1
Operations Manager	1
Engineering Manager	1
Supervisor/Engineer – Mechanical	2
Supervisor/Engineer – Controls;	2
Supervisor/Engineer – Electrical;	2
Shift Engineers	6
Process Operatives	15
Day Team Supervisor	1
Weighbridge Operatives	2
Multi Skilled Labourers	9
Maintenance Technicians	10
Administrators	2
Compliance Manager	1
Total	55

Table 19 Staff required

13. R1 CALCULATION

The NSW Energy from Waste Policy Statement of Environment Protection Authority (EPA) states that:

"This Policy Statement is restricted in its scope to facilities that are designed to thermally treat waste for the recovery of energy rather than as a means of disposal. The net energy produced from thermally treating that waste, including the energy used in applying best practice techniques, must therefore be positive.

The R1 energy efficiency formula from the European Waste Framework Directive has been adopted with R1 to be ≥ 0.65 as the minimum total system efficiency threshold that must be met for a facility to qualify as an energy recovery facility.

Where these criteria are met, the facility will be licensed as 'Energy Recovery' under Schedule 1 of the Protection of the Environment Operations Act 1997, and therefore the waste and environment levy will not apply to waste received at the facility."

European Commission has produced a revised Directive on waste, which has replaced the old Waste Framework Directive (WFD) as of 20th October 2008. In this revised Directive, incineration facilities for municipal waste can be regarded as "Recovery" operations if the energy efficiency of the plant is greater than 0.65 for plants permitted after Jan 2009. Plants which do not meet this criterion are classed as "Disposal" operations and therefore lie on the same hierarchical level as landfill.

The definition of energy efficiency used in the revised Directive is:

$$\text{Energy Efficiency} = \frac{(E_p - (E_f + E_i))}{(0.97 \times (E_w + E_f))}$$

- E_p* means annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (units of GJ/yr)
- E_f* means annual energy input to the system from fuels contributing to the production of steam (units of GJ/yr)
- E_w* means annual energy contained in the treated waste calculated using the lower calorific value of the waste (units of GJ/yr)
- E_i* means annual energy imported excluding *E_w* and *E_f* (units of GJ/yr)
- 0.97 is a factor accounting for energy losses due to bottom ash and radiation.

The interpretation of the R1 formula has proved to be difficult. Accordingly, the European Commission set up an expert panel to discuss this. The panel has prepared a guidance note "for the use of the R1 energy efficiency formula for incineration facilities dedicated to the processing of Municipal Solid Waste", which has now been adopted by the European Commission.

We have therefore used the formula, interpreted in accordance with the guidance, to assess the energy efficiency of the Facility. The calculation is based on predicted design figures and predicted levels of fuel consumption and electricity usage.

The R1 efficiency is predicted to be 0.86 (based on gross generated power) which is well above the threshold for new incineration plants. Therefore, the Facility will meet the definition of recovery.