Report

Energy from Waste Facility – Air Quality and Greenhouse Gas Assessment

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Pacific Environment Pty Ltd: ABN 86 127 101 642

BRISBANE
Level 19 24 Queen Street
Brisbane Qld 4000Qld 4000
Ph: +61 7 3004 6400
Fax: +61 7 3844 5858

SYDNEY
Suite 1, Level 1, 146 Arthur Street
North Sydney, NSW 2060
Ph: +61 2 9870 0900
Fax: +61 2 9870 0999

ADELAIDE
The Hub, 5 Peel Street
Adelaide SA 5000
Ph: +61 8 8332 0960
Fax: +61 7 3844 5858

PERTH
Level 1, Suite 3
34 Queen Street, Perth WA 6000
Ph: +61 8 9481 4961
Fax: +61 2 9870 0999

EXECUTIVE SUMMARY

INTRODUCTION

The Next Generation NSW Pty Ltd (TNG NSW) proposes to construct and operate an Energy from Waste (EfW) facility on land adjacent to the Genesis Xero Waste facility in Eastern Creek. This development site is part of a proposal to construct and operate NSW's largest EfW facility using residual waste as fuel which would otherwise be landfilled, to allow for a "green" electricity generation facility.

The Proponent clarifies that the current State Significant Development Application (NSW DPE reference: SSD 6236) seeks approval only for Stage 1 of the EfW facility and is the subject of this technical assessment. Any future Stage 2 is to be the subject of a separate and future development application.

Operation of Stage 1 is proposed to have an engineering capacity of up to 675,000 tonnes annually and a planned operation to treat 552,500 tonnes per annum of residual waste fuel, involving the following plant and systems:

- Tipping Hall and fuel storage
- Waste Bunker
- Combustion Line 1
- Combustion Line 2
- Two independent boilers
- Flue Gas Treatment systems
- One stack
- One turbine
- One Air Cooled Condenser
- Associated auxiliary equipment
- Control room, workshop, offices and amenities
- Laydown Areas 1, 2 and 3.

Unlike earlier iterations of this air quality assessment report, the current document therefore assesses potential impacts associated with operation of *two combustion lines reporting to a single stack*. This is in contrast to previous versions of the air quality assessment that evaluated four combustion lines, two stacks, and treatment of 1,105,000 tonnes of residual waste fuel per annum

Pacific Environment has been engaged by TNG NSW to prepare an Air Quality and Greenhouse Gas Assessment for the facility. Air quality impacts are assessed at the closest sensitive receptors, including locations such as schools and hospitals, located within the closest residential suburbs of Minchinbury and Erskine Park. Also included are the potential future receptors within the adjacent industrial estate.

EMISSIONS

The primary emissions from the EfW facility, as defined by emission limits for waste incineration set by the European Union (EU) Industrial Emissions Directive (IED; Directive **2010/75/EU**), are anticipated to be as follows:

- Particulate matter (PM), assumed to be emitted as PM_{10} and $PM_{2.5}$[a].
- Hydrogen Chloride (HCl).
- Hydrogen Fluoride (HF).

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[a] Particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres respectively.

- Carbon Monoxide (CO).
- Sulfur Dioxide (SO_2)
- Oxides of nitrogen (NO_x) (expressed as Nitrogen Dioxide (NO_2)).
- Heavy metals (including Mercury (Hg), Cadmium (Cd), Thallium (Tl), Antinomy (Sb)Arsenic (As), Chromium (Cr (III) and Cr (VI)), Lead (Pb), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V).
- Gaseous and vaporous organic substances (expressed as total organic carbon (TVOC)).
- Dioxins and furans (PCCD/F).

In addition to the emission identified in the EU IED, the following potential emissions have been evaluated:

- Benzoic Acid
- Hexa-decanoic Acid
- Ethyl Benzoic Acid
- Toluene
- Phthalate
- Dichloro-methane
- Acetone (propanone)
- Tetra-decanoic Acid
- Benzene
- Acetonitrile
- Xylene
- Trichloro-phenol
- Methyl-hexane
- Trichloro-ethylene
- Heptane
- Hydrogen sulphide (H_2S)
- Ammonia (NH_3)
- Metals Beryllium (Be), Silver (Ag), Zinc (Zn), Tin (Sn), Molybdenum (Mo), Selenium (Se)
- Polychlorinated biphenyls (PCBs)
- Hexachlorobenzene (HCB)
- Polycyclic aromatic hydrocarbons (PAHs)
- Phenol
- Hexane
- Phthalate
- Hydrogen bromide (HBr)
- Brominated flame retardants (BFR)
- Total brominated dioxins.

In March 2014 the NSW Environment Protection Authority (EPA) published its Energy from Waste Policy Statement ("the EfW Policy Statement"). The EfW Policy Statement requires that any facility proposing to recover energy from waste will need to meet current international best practice. The policy also requires that emissions from EfW facilities must satisfy, as a minimum, current emission limits prescribed by the POEO (Clean Air) Regulations.

BEST AVAILABLE TECHNOLOGY

The proposed technology for the EfW facility is based on existing facilities in the United Kingdom and Europe and will incorporate best available technology (BAT) for flue gas treatment. The flue gas treatment is designed to meet the in-stack concentrations limits for waste incineration set by the EU IED, which are generally more stringent than those prescribed within the POEO (Clean Air) Regulations. The flue gas treatment system includes:

- Selective Non-Catalytic Reduction (SNCR) for reducing emissions of oxides of nitrogen (NO_x).
- Dry lime scrubbing for reducing emissions of acid gases, including hydrogen chloride (HCl) and sulfur dioxide (SO_2).
- Activated carbon injection for reducing emissions of dioxins and mercury (Hg).
- Fabric filters for reducing emissions of particle matter (PM) and metals.
- Following flue gas treatment, emissions will be dispersed via a 100m stack.

A review of existing EfW facilities shows that the facility meets current international best practice and can satisfy the emission limit requirements of the IED.

DISPERSION MODEL

The AERMOD atmospheric dispersion model was determined to be a suitable dispersion model due to the source type, location of nearest receiver and nature of local topography. Furthermore, the AERMOD model is supported by the US EPA and is now the model of choice for nearfield (less than 50 km from an emission source) applications **(US EPA, 2017)**.

As part of the US EPA's process in endorsing AERMOD **Paine *et al.* (1998)** evaluated the use of AERMOD for a number of tall stack scenarios across the United States. **Paine *et al.* (1998)** identified that AERMOD generally has a tendency to *over-predict* across the range of databases that were evaluated. Apparent under predictions for annual averages were found likely to be artefacts of the low concentrations (close to the instrument thresholds) and the uncertainty in determining background concentrations that need to be subtracted from the reported total concentrations

As noted above, the dispersion modelling completed as part of this assessment is now based on the evaluation of a single stack.

Dispersion modelling predictions have been based on the assumptions described in this report. The results have been summarised as follows:

SCENARIO 1: EXPECTED

The incremental results are as follows:

- The maximum predicted 1-hour NO_2 is 5% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 1% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 0.6% of the impact assessment criterion, for 1-hour 0.5%, for 24-hour SO_2, 0.3% and for annual, 0.3%.
- The maximum predicted 24-hour PM is 0.05% of the impact assessment criterion for PM_{10} and 0.09% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 0.02% of the impact assessment criterion for PM_{10} and 0.07% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 0.01% or less than the relevant impact assessment criterion.
- The maximum predicted 24-hour HF is 0.4% of the impact assessment criterion, for 7-day 0.4%, for 30-day HF, 0.6% and for 90-day, 0.8%.
- The annual average lead concentration is 0.2% of the impact assessment criterion.

Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary. The individual odour compound H_2S is assessed against the 99th percentile prediction.

In summary, the modelling results for these additional parameters show that the 99.9th percentile predicted:

- HCl is 1% of the impact assessment criterion.
- Cd is 6% of the impact assessment criterion.
- Hg is 0.3% of the impact assessment criterion.
- dioxins and furans are 0.1% of the impact assessment criterion.
- benzene is 0.006% of the impact assessment criterion.
- toluene is 0.001% of the impact assessment criterion.
- xylene is 0.0002% of the impact assessment criterion.
- NH_3 is 0.1% of the impact assessment criterion.
- PAH (as benzo(a)pyrene) is 0.02% of the impact assessment criterion.
- H_2S is 5.2% of the impact assessment criterion.
- dichloromethane is 0.0001% of the impact assessment criterion.
- acetone is 0.00001% of the impact assessment criterion.
- trichloroethylene is 0.0001% of the impact assessment criterion.
- Be is 0.02% of the impact assessment criterion.
- Ag is 0.002% of the impact assessment criterion.
- Zn is 0.005% of the impact assessment criterion.
- As is 3.3% of the impact assessment criterion.
- Sb is 0.02% of the impact assessment criterion.
- Cr(III) is 0.1% of the impact assessment criterion.
- Cr(VI) is 0.02% of the impact assessment criterion.
- Ni is 14.7% of the impact assessment criterion.
- Cu is 0.05% of the impact assessment criterion.
- Mn is 0.04% of the impact assessment criterion.
- phenol is 0.01% of the impact assessment criterion.
- hexane is 0.003% of the impact assessment criterion.
- TVOC (assessed as benzene) is 0.5% of the impact assessment criterion.

Cumulative predictions are also presented for the criteria air quality metrics:

- The maximum predicted 1-hour NO_2 is 46% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 38% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 16% of the impact assessment criterion, for 1-hour 10%, for 24-hour SO_2, 5% and for annual, 5%.
- The maximum predicted 24-hour PM is 98% of the impact assessment criterion for PM_{10} and 99% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 76% of the impact assessment criterion for PM_{10} and 88% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 30% or less than the relevant impact assessment criterion.

There are no exceedances of the EPA criteria when the EfW contribution is added to maximum background concentration under expected operating conditions.

SCENARIO 2: REGULATORY (POEO LIMITS)

The modelling of the Regulatory (POEO Limits) scenario indicates that application of the POEO emission limits within the Environmental Protection Licence for the facility would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

However, given that the IED limits investigated as part of Scenario 4 are more stringent, and are reflective of the facility's design specifications, it is suggested that these limits are adopted in the Environmental Protection Licence.

For the cumulative assessment, there are no predicted exceedances of the EPA criteria when the EfW facility contribution is added to maximum background, with the exception of $PM_{2.5}$, which results in a cumulative concentration marginally above the 24-hour $PM_{2.5}$ criterion of 25 µg/m^3. However, this occurs on a day when the background $PM_{2.5}$ concentration is already high and the probability of the EfW facility resulting in additional exceedances of the impact assessment criterion is considered to be low.

SCENARIO 3: UPSET

The results of the modelling for Scenario 3 'Upset' conditions indicate that, under worst-case dispersion conditions Cd is predicted to exceed the NSW impact assessment criterion. A probabilistic approach has then been adopted, with results indicating that the probability of the above pollutant resulting in adverse ground level impacts (i.e. the potential for upset conditions to coincide with worst-case dispersion conditions) would be less than 0.012%.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

SCENARIO 4: REGULATORY (IED LIMITS)

Additional modelling of a Regulatory (IED Limits) scenario indicates that application of the IED emission limits within the Environmental Protection Licence for the facility would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

In view of the more stringent emissions limits of the IED compared with those of the POEO Regulations, it is suggested that the EfW Facility be regulated to the IED limits within their Environmental Protection Licence.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

SCENARIO 5: DIESEL GENERATORS

The results of the dispersion modelling for the diesel generators scenario show that there would not be an exceedance of the relevant impact assessment criteria when the generators operate in isolation or combined with the EfW stack and background sources.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

CONSTRUCTION

A semi-quantitative screening assessment of construction phase impacts identified human receptors within 350 m of the boundary of the site.

Various measures for limiting the impacts of construction dust have been recommended. Most of the recommended measures are routinely employed as 'good practice' on construction sites. At the EfW facility, particular attention should be paid to controlling dust generated by track-out due to the overall level of risk and the potential close proximity of track-out emissions to sensitive receptors.

GREENHOUSE GASES

The operation of the EfW facility would have a net positive GHG impact, potentially eliminating over a 25 year period between 13.6 to 17.1Mt CO_2-e. The emission intensity for electricity generated from waste incineration is significantly lower than that derived from the current NSW electricity grid.

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1 INTRODUCTION

The Next Generation NSW Pty Ltd (TNG NSW) proposes to construct and operate an Energy from Waste (EfW) facility on land adjacent to the Genesis Xero Waste facility, located at Honeycomb Drive, Eastern Creek, approximately 36 km west of the Sydney CBD.

Pacific Environment has been engaged by TNG NSW to prepare an Air Quality and Greenhouse Gas Assessment as part of an Environmental Impact Statement (EIS), required under State Significant Development (SSD) provision in Schedule 1 of the State Environmental Planning Policy (State and Regional Development) 2011.

This assessment has followed the procedures outlined in the NSW Environment Protection Authority (EPA) document titled "Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW" ("The Approved Methods", **NSW EPA, 2016**).

1.1 Background and Context

The proposed EfW facility has been designed to comply with the NSW Environment Protection Authority (EPA) *Energy from Waste Policy Statement* ("the EfW Policy Statement"; **EPA, 2014**).

The development involves the construction and operation of an electricity generation facility, which will allow for unsalvageable and uneconomic residue waste from the Genesis Xero Material Processing Centre (MPC) and external bona fide recycling and resource recovery facilities to be used for generation of electrical power. The EfW facility is proposed to be located on Lots 2 and 3, DP 1145808.

This development site is part of a proposal to construct and operate NSW's largest EfW facility using residual waste as fuel which would otherwise be landfilled, to allow for a "green" electricity generation facility.

Pacific Environment was originally commissioned by TNG NSW to complete an air quality assessment for the operation of an EfW facility that processes up to 1.35 million tonnes of waste per year. Since the time of the original air quality assessment in 2015, there have been several iterations of the air quality assessment, a summary of each is as follows:

- **Pacific Environment (2015):** Pacific Environment prepared an air quality assessment for the proposed TNG EfW facility entitled: "Energy from Waste Facility – Air Quality and Greenhouse Gas Assessment". This document was published as part of the original Environmental Impact Statement (EIS) for the Project. The modelling was based on emissions that were derived from the European Union (EU) Industrial Emissions Directive (IED; Directive 2010/75/EU) half hourly or daily in-stack concentration limits only.
- **Pacific Environment (2016):** Pacific Environment revised the air quality assessment, with this document exhibited as part of the 'Amended' EIS on public exhibition from 9 December 2016 to 1 March 2017. This assessment included an update to the stack discharge assumptions including stack exit parameters and volumetric flow rates. In addition, at the request of the NSW EPA, the assessment adopted emissions that were based on in-stack concentration measurements from similar operating facilities around the world.
- **Pacific Environment (2017 June):** Pacific Environment completed a further revision of the air quality assessment as part of the response to submissions process, which provided additional feedback from EPA, and incorporated comments from an internal peer review. This document referenced a staged approach to the approval pathway, clarifying that approval is being sought for two combustion lines reporting to a single stack (although dispersion modelling conservatively presented for both Stage 1 and

Stage 2 proposals). The dispersion modelling completed within **Pacific Environment (2017c)** incorporated a number of updates including:

- New meteorological file that replaces all calm periods in meteorological input file with 0.5 m/s wind speeds.
- Terrain information based on the higher resolution STRM1 data set (to address internal peer reviewer comments).
- Updated emissions for the expected and upset scenarios, including the adoption of the UK Environment Agency metals data (to address Department of Health's peer reviewer comments).
- Addition of the regulatory IED limits scenario, similar to that originally completed within Pacific Environment (2015).

Within the current document, the Proponent clarifies that the current State Significant Development Application (NSW DPE reference: SSD 6236) seeks approval only for Stage 1 of the EfW facility and is the subject of this technical assessment. Any future Stage 2 addition is to be the subject of a separate and future development application.

The construction and operation of Stage 1 with an engineering capacity of up to 675, 000 tonnes annually but treating a planned 552,500 tonnes per annum of residual waste fuel, involving the following plant and systems:

- Tipping Hall and fuel storage
- Waste Bunker
- Combustion Line 1
- Combustion Line 2
- Two independent boilers
- Flue Gas Treatment systems
- One stack
- One turbine
- One Air Cooled Condenser
- Associated auxiliary equipment
- Control room, workshop, offices and amenities
- Laydown Areas 1, 2 and 3
- Two back up diesel generators.

Unlike earlier iterations of this air quality assessment report, the current document therefore assesses potential impacts associated with operation of *two combustion lines reporting to a single stack*. This is in contrast to previous versions of the air quality assessment that evaluated four combustion lines, two stacks, and treatment of 1,105,000 tonnes of residual waste fuel per annum

1.2 Assessment Requirements

The Air Quality and Greenhouse Gas Assessment is guided by the Director-General's Requirements (DGRs) and Agency requirements, as outlined in **Table 1-1**.

Table 1-1: Agency requirements

Government Agency	Requirement	Relevant Section
DP&I	Air Quality and Human Health - including:	
	- a quantitative assessment of the potential air quality and odour impacts for the development on surrounding landowners and sensitive receptors under the relevant Environment Protection Authority guidelines;	Section 9
	- a description of construction and operational impacts, including air emissions from the transport of materials;	Section 6 and 9
	- a human health risk assessment covering the inhalation of criteria pollutants and exposure (from all pathways i.e., inhalation, ingestion and dermal) to specific air toxics;	Standalone report - note [b]
	- details of any pollution control equipment and other impact mitigation measures for fugitive and point source emissions;	Section 6
	- a demonstration of how the waste to energy facility would be operated in accordance with best practice measures to manage toxic air emissions with consideration of the European Union's *Waste Incineration Directive 2000* and the Environment Protection Authority's draft policy statement *NSW Energy from Waste*;	Section 6
	- an examination of best practice management measures for the mitigation of toxic air emissions;	Section 6
	- details of the proposed technology and a demonstration that it is technically fit for purpose.	Section 2
	Greenhouse Gas - including: - a full greenhouse gas assessment (including an assessment of the potential scope 1, 2 and 3 greenhouse gas emissions of the project, and an assessment of the potential impacts of these emissions on the environment	Section 10
	- a detailed description of the measures that would be implemented on site to ensure that the project is energy efficient.	Section 10.3
EPA	Assess the risk associated with potential discharges of fugitive and point source emissions.	Section 9
	Assessment of risk relates to environmental harm, risk to human health and amenity. Justify the level of assessment undertaken on the basis of risk factors, including but not limited to: a. proposal location; b. characteristics of the receiving environment; and c. type and quantity of pollutants emitted.	Section 3, 4, 6, 8 and 9
	Describe the receiving environment in detail. The Proposal must be contextualised within the receiving environment (local, regional and inter-regional as appropriate). The description must include but need not be limited to:	Section 2, 5, 6 and 7

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[b] A Human Health Risk Assessment has been prepared as a standalone assessment as part of the EIS.

	a. meteorology and climate; b. topography; c. surrounding land-use; receptors; and d. ambient air quality. e. Include a detailed description of the Proposal.	
	All processes that could result in air emissions (including odour) must be identified and described. Sufficient detail to accurately communicate the characteristics and quantity of all emissions must be provided.	Section 6
	Demonstrate that the proposed facility complies with the requirements of the NSW Energy from Waste *Draft* Policy Statement (2013). In particular: a. An international best practice techniques demonstration with respect to process design and control, emission control equipment design and control and emission monitoring with real time feedback to the controls of the process; and b. Energy Recovery Facility Technical Criteria.	Section 4, 6, 9
	Include a detailed emissions inventory for the Proposal. All point and fugitive sources are to be included in the inventory together with estimates of emission concentration and rate of all air pollutants emitted.	Section 6
	Any nominated controls must be explicitly linked to calculated emission reductions adopted in the air quality impact assessment emissions inventory, with all assumptions documented and justified.	Section 6
	Include a consideration of 'worst case' emission scenarios and impacts at proposed emission limits.	Section 9
	Account for cumulative impacts associated with existing emission sources as well as any currently approved developments linked to the receiving environment.	Section 9
	Include air dispersion modelling where there is a risk of adverse air quality impacts, or where there is sufficient uncertainty to warrant a rigorous numerical impact assessment? Air dispersion modelling must be conducted in accordance with the Approved Methods or the Modelling.	Section 8, 9
	An odour impact assessment must additionally have regard to the technical Framework and Notes for the assessment and Management of odour from discretionary sources in NSW (2006).	Section 6.9
	Include a quantitative photochemical smog assessment in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2016).	Standalone report – note [c]
	ODOUR	Section 6.11

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[c] An ozone impact assessment / photochemical smog assessment has been prepared as a standalone assessment, submitted as part of the EIS.

	A quantitative assessment of the potential odour impacts from the construction and operation of the facility on surrounding landowners and sensitive receptors.	

2 TECHNICAL DESCRIPTION OF THE FACILITY

2.1 EfW Facility Overview

The EfW facility will operate a well-established technology known as 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. Residual waste fuel is gravity fed onto the incinerator grate. The grate is continually moving thus promoting continuous mixing of the residual waste fuel with the combustion air, extracted from the tipping hall and introduced from beneath the grate into the heart of the fire. Further air is injected just above the fire to promote mixing and complete combustion of the gases.

The turbine exhaust cooling system for the EfW facility is an Air Cooled Condenser (ACC) that does not require water and does not generate an effluent discharge. Furthermore there is no visual plume impact through the ACC, as there would be for an evaporative cooling tower.

A diesel generator will be installed for start-up and to maintain the furnace temperature, if required. However, during expected operation no support fuel is required to maintain a minimum combustion temperature of 850°C.

Ash from the grate is discharged into a water filled quench bath from where it is moved by conveyor to the enclosed ash storage bunkers prior to being transported off site.

Hot gases from the combustion of the residual waste fuel pass through a heat recovery boiler. The temperature of the gases is reduced from over 850°C to around 150°C. The energy from the hot gases is transferred to the boiler to produce high pressure steam. This steam is fed to the steam turbine driven generator capable of generating up to 68.65 MW, which, after supplying the site electrical load is exported to the National Grid.

As set out in the Project Definition Brief **(Ramboll, 2017)**, The Next Generation NSW's Electricity Generation Plant is proposed to have a maximum total engineering capacity of 675,000 tonnes per annum with a planned nominal operational input of 552,500 tonnes per annum when the residual waste fuel has a net calorific value of 12.3 MJ/kg.

The facility is proposed to be constructed comprising the following:

- Tipping Hall
- Waste Bunker
- Combustion Line 1
- Combustion Line 2
- Two independent boilers
- Flue Gas Treatment systems (FGTs)
- One stack
- One turbine
- One Air Cooled Condenser (ACC)
- Associated auxiliary equipment.

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

Operation of the EfW facility will generate three types of solid waste by-products, while producing no excess effluent during operation:

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

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.

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.

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.

All ash and residues will be effectively managed to avoid accidental discharge. Further information on ash residue processing and management is provided in **Ramboll (2017)**.

The operational parameters of waste flow, combustion air and temperatures will be automatically controlled by the Distributed Control System based on the incoming waste parameters. This will provide the necessary combustion conditions and maintain the necessary temperature and residence time in the secondary combustion chamber. As part of the operational requirements, appropriate waste sorting procedures will be refined to incorporate any Conditions of Consent issued by the Department of Planning and Environment.

The EfW facility will operate 24 hours a day, seven days a week, with occasional offline periods for maintenance. Over the entire year, the EfW facility would be operational for a minimum of 8,000 hours as an annual average. Some residual waste fuels would be delivered directly to the EfW facility (by B-double) with the remaining transferred from the existing Genesis Xero Waste facility either via a covered electrically powered conveyor or by truck. It is anticipated that as a result of the EfW facility operating at the Stage 1 maximum capacity the site would receive a maximum of 126 trucks per day, comprising:

- 84 truck deliveries associated with the waste material
- 2 truck deliveries for miscellaneous deliveries such as hydrated lime or activated carbon
- 40 trucks collections for the removal of ash residue and bottom ash.

All roads will be sealed to reduce potential for wheel generated dust emissions.

A general arrangement for the EfW facility if approval is granted for Stage 2 is shown in **Appendix A**. A list of all adopted assumptions in this assessment is provided in **Appendix B**.

2.2 Flue Gas Treatment

The proposed technology for the EfW facility is based on existing facilities in the United Kingdom (UK) and rest of Europe and will incorporate best available technology (BAT) for flue gas treatment. The flue gas treatment is designed to meet the in-stack concentration limits for waste incineration set by the European Union (EU) Industrial Emissions Directive (IED; Directive **2010/75/EU**).

The flue gas treatment system is designed to achieve the emission limits as required by the Industrial Emissions Directive (IED) (further discussed in **Section 4.3**). The flue gas treatment system includes:

- Selective Non-Catalytic Reduction (SNCR) for reducing emissions of oxides of nitrogen (NO_x).
- Dry lime scrubbing for reducing emissions of acid gases, including hydrogen chloride (HCl) and Sulfur Dioxide (SO_2).
- Activated carbon injection for reducing emissions of dioxins and mercury (Hg).

- Fabric filters for reducing emissions of particulate matter (PM) and metals.

Following flue gas treatment, emissions will be dispersed via a 100m stack. Further details of the flue gas treatment are discussed in **Section 6**.

The owner's engineer, Ramboll, has produced a memorandum presented in **Appendix C** noting that waste is ignited and burnt on the grate in the furnace at temperatures around 1,100° C and the temperature of the flue gases is thereafter kept above 850 °C for at least 2[d] seconds in the afterburning chamber. For the design case the temperature will remain above 850° for more than 5 seconds, therefore far longer than the required minimum residence time.

- The owner's engineers (Pers. Comm. Martin Brunner, Ramboll) have provided further information to demonstrate the suitability of a minimum operating temperature of 850°C within the secondary the combustion chamber. The information has been summarised as follows: The process design maintains an adiabatic temperature of at least 1,170° C after secondary air injection in every load point. This is more than 300°C above the required temperature of 850°C. The secondary combustion chamber is designed to limit the heat transfer to the boiler and maintain the temperature of the flue gas above 850°C for an extended period. In the design case the temperature will remain above 850°C for approximately 4 seconds, therefore far above the required minimum. On that basis, the high combustion temperature and the design of the secondary combustion allows to achieve the minimum temperature and residence time in any operating condition. See also Section 5.4 of the Project Definition Brief **(Ramboll, 2017)**.
- The processing facility has been designed such that waste feeding is not possible when the conditions of a minimum of 850°C are not achieved.
- In the event that the temperature falls below 850°C during operation the auxiliary burners start to operate and maintain the temperature above the required level of 850°C
- If for any reason it is not possible to maintain the required temperature even with the auxiliary burners in operation the waste feeding is automatically stopped and the facility shut down.
- The combustion control system (CCS) supports the largely automated and dependable operation of the facility under different load conditions. The CCS makes it possible to rapidly adjust the temperature distribution on the grate and in the secondary combustion chamber to the profiles needed in response to changing waste compositions. This assures optimised gas and bottom ash burnout while safeguarding compliance with legislation regarding combustion chamber temperatures, oxygen concentrations in the flue gas, and other operating parameters. See also Section 5.3 of the Project Definition Brief **(Ramboll, 2017)**.

The flue gas treatment stage consists of a reactor with injection of lime and activated carbon followed by a bag house filter for PM removal, including the activated carbon. In this manner, the flue gas treatment system is designed to ensure that the stack emissions comply with in-stack emission limits regardless the content in the raw, untreated flue gas within any realistic operational range.

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 toxic organic compounds (i.e. dioxins and furans) are reduced by adsorption on activated carbon.

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[d] The value was revised from 2 seconds to 4 seconds following additional information received from Ramboll (Pers. Comm. Martin Brunner, Ramboll in May 2017).

Features of this system are illustrated in **Figure 2-1**. For additional information please see Section 6.1 of the Project Definition Brief **(Ramboll, 2017)**.

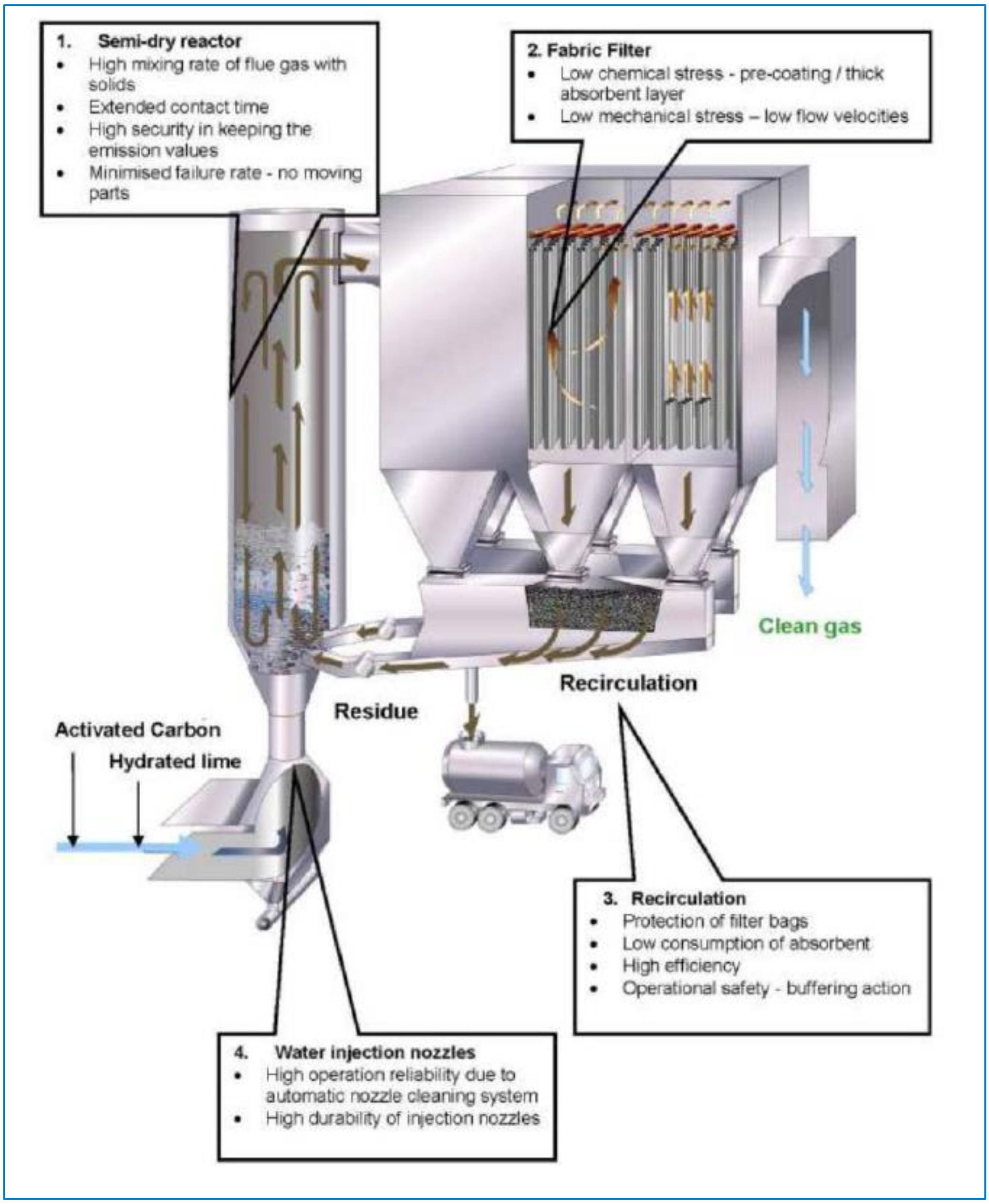

Figure 2-1: Semi-dry Flue Gas System (Ramboll, 2017)

2.3 Fuels

The following residual waste fuel types have been identified as the main sources of fuel for the EfW facility:

- Chute Residual Waste (CRW) from the Genesis Facility Output
- General Solid Waste [non putrescible] currently Landfill Facility Direct Input
- Material Recovery Facility (MRF) waste from bona fide resource recovery facilities [currently Genesis Landfill Facility Direct Input]
- Floc waste from car and metal shredding and resource recovery carried out by others
- Commercial and Industrial (C&I) residual after resource recovery carried out by Genesis or by others operating bona fide resource recovery facilities

- Other specified waste fractions (SWF) compliant with the EfW Policy Statement (**EPA, 2014**)

These waste fuels will go through the sorting processes at the adjacent Genesis Recycling Facility prior to going to TNG. As the net calorific value (NCV) of waste fuels vary depending on type, the EfW facility will operate within a range of NCVs to support operational flexibility.

2.3.1 Design Fuel

Based upon the fuel types listed above, a design fuel composition has been developed and is provided in **Appendix D**. This is based on typical values for each of the proposed fuels and an estimated fuel mix from **Ramboll (2017)**. Input fuel will be mixed as part of the expected operational process to produce as homogenous an input as possible. Further, technical information outlining the waste composition is provided in **Ramboll (2017)** and further supporting material in **Appendix C**.

It is acknowledged that fuel will comprise some fractions containing PVC and the chlorine content within that fraction will be slightly above 1%, nevertheless the waste in total and as an average will not contain more than 1% chlorine **(Ramboll, 2017)**.

This will be achieved through the extensive mixing of waste before feeding it to the combustion process. As described in **Ramboll (2017)**, the mixing and homogenisation of the different waste streams is a very important aspect of the operation of an EfW facility 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 as 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. Further discussion is provided in in **Section 4.2**. Further information on the homogenisation process including analysis results are provided in **Ramboll (2017)**.

2.4 Start-up / Shut-down Conditions

The EfW facility is designed to operate continuously, therefore start-up and shutdown are infrequent events and anticipated to be required during the EfW facility's annual maintenance program. However, any required start/stop operations will be completed automatically, under the supervision of trained operators, in a controlled and safe manner.

The EfW 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.

When required, the EfW facility is turned off in a controlled manner through reversing the start-up process. The solid fuel feeding is stopped, with the EfW facility then operating to ensure that all material is burnt and flue gases are cleaned out of the process. Finally, the air flows are left on to allow the boiler unit to cool before the EfW facility can be fully shut off (**Ramboll, 2017**).

2.5 Upset Conditions

Upset operating conditions at the EfW facility could occur for a number of reasons (**Ramboll, 2017**), of which have been reproduced below in **Table 2-1** along with the appropriate management strategy.

Table 2-1: Sources of potential upset condition and management strategy

Incident	Root cause	Consequence in emission	Indication	Management strategy
Failure of lime dosing	Dysfunction of the dosing device, the pneumatic conveying system or clogging of lime in the silo or ducts.	Gradual increase of HCl and SO2 emissions over time (within 15-20 minutes). Due to the remaining lime in the system and the in system there is sufficient time for the operator to take necessary actions.	Alarm caused by increased HCl and SO2 emission in stack.	- Restart lime dosing system - actuate anti-clogging system in silos - Switch to the reserve dosing and conveying system
Failure of activated carbon dosing	Dysfunction of the dosing device, the pneumatic conveying system or clogging of activated carbon in the silo or ducts.	Gradual increase of mercury emissions over time (within several hours). No relevant increase of dioxins and furans emissions due to remaining active carbon in the system and high recirculation rate.	Alarm caused by no usage of activated carbon	- Restart lime dosing system - actuate anti-clogging system in silos - Switch to the reserve dosing and conveying system
Failure of filter bags	Gradual wear of bags (mainly seam), wrong installation, manufacturing defect(s) of bags or cages.	Gradual increase of dust and heavy metals during in short spikes whenever cleaning of bags is in operation (note: the complete rupture of a bag is in extremely rare incident)	Dust peaks during online cleaning, alarm as a result of increasing dust emissions in stack	- Monitoring the emission to detect relevant filter compartment - replacement of damaged bag (possible during continuous operation of the plant)
Failure of SNCR system	Breakdown of pumps, failure of piping, clogging of nozzles	Increase of NOx emission	Alarm due to increased NOx emissions	- Change to standby pump - repair piping - Unblock nozzles (possible during continuous operation of the plant)
Insufficient combustion conditions	Low combustion temperature, dysfunction of the primary or secondary air system, of the grate or the pusher, blockage in the feed hopper	Increase of CO and VOC emissions	Alarm due to low furnace temperature and/or increased CO/VOC emissions	- Start auxiliary burners - if root cause cannot be solved during operation then normal shutdown of plant.

Under any of the circumstances identified in **Table 2-1**, the operator will reduce or shut-down operations as soon as practicable until expected operations can be restored. In accordance with the a design to the requirements of the EU IED, such events shall under no circumstance occur for more than four hours uninterrupted where the emission values exceed the limits and no more than 60 hours per year.

It should be noted that during upset conditions, not all air quality parameters will simultaneously increase, but rather individual parameters may increase by an approximate factor of 10 under specific upset conditions.

As discussed in (**Ramboll, 2017**), during upset conditions certain emissions will increase, sometimes even above the IED emission limit. While during normal operation the emissions remain well below the required limit an increase will be immediately detected by the continuous emission monitoring system (CEMS) or other facility process monitoring systems. The evaluation of operational results shows that in case of upset operation conditions there might be an increase of the emissions above the required limit by a factor of 2 to 3. In case the upset condition remains for more than 4 hours, the facility has to be shut down. For this reason, a conservative approach assuming a factor of 10 for individual emission during upset conditions has been chosen. This conservative factor takes into considerations that 10% of the total gas flow bypasses the APC as a result of bag failure (see **Appendix C**, Ramboll Memo: Compounds of Potential Concern (COPC) for HHRA).

2.6 Emergency Conditions

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 EfW 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 EfW facility in the event of a loss of grid connection and failure of the steam turbine to transfer to island mode operation.

To facilitate this safe shutdown and black start[e] there will be two emergency diesel generators with one dedicated to each purpose. Each diesel generator[f] will have a capacity of 2.4 MW that will provide sufficient power for the two incineration lines. A photograph of a diesel generator representative of the technology proposed for the diesel generators is shown in **Figure 2-2**.

The emergency generators will not be used during expected operation of the EfW facility. This includes during planned (scheduled) or forced (unscheduled) outages. Circumstances where the emergency generators may be used include:

- Routine maintenance and specific testing; units will operate for one hour a month.
- In the event of a fire, to provide power supply for emergency lighting and fire-fighting pumps.
- In the simultaneous event of:
  - High Voltage electric grid blackout in the Eastern Creek area or in the whole of Sydney requiring island mode operation of the EfW facility, and
  - an extremely hot day in the summer time with ambient air temperatures above 35°C (depends on the final sizing of the ACC and on the steam turbine manufacturer) causing an excessively high back pressure in the ACC, in turn initiating a turbine trip and necessitating a shutdown of the whole EfW facility.

This latter event is considered to have a low probability of occurrence, with a worst case frequency estimated to be once every ten years for the two events combined (**HZI, 2015**).

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[e] Black start is the process of restoring power station operation without relying on the external electric power transmission network.

[f] Representative of a technology similar to a Cummins QSK78 or MTU 20V4000G63L 6ETC.

In the event of requiring safe shutdown/black start, it is anticipated that the diesel generators would be required to run for approximately two hours, with a maximum of six hours for black start required if the facility shutdown is over a longer period of time.

Figure 2-2: Example of an emergency diesel generator

3 LOCAL SETTING

The proposed EfW facility is located at Eastern Creek, approximately 36 km west of the Sydney CBD and surrounded by the residential areas of Minchinbury, Mt Druitt and Rooty Hill to the north, Erskine Park to the east and Colyton to the northwest (shown in **Figure 3-1**).

The site which is accessed off Honeycomb Drive at Eastern Creek is surrounded by land owned by the Corporate Group Alexandria Landfill Pty Ltd, ThaQuarry Pty Ltd, Australand, Hanson, Jacfin, the Department of Planning and Infrastructure and Sargents.

The site and surrounding land is identified as part of the '*State Environmental Planning Policy (Western Sydney Employment Area) 2009 (WSEA SEPP)*' to be redeveloped for higher end industrial and employment uses over the next decade. The site has a total area of approximately 56 hectares including the Riparian Corridor, with a specific development area circa 9 hectares.

A sensitive receptor is defined as a location where people are likely to work or reside; and may include a dwelling, school, hospital office or public recreational area in addition to known or likely future locations (**NSW EPA, 2016**).

Air quality impacts are assessed at the closest residential areas as shown, including particularly sensitive receptors such as schools and hospitals, as well as isolated semi-rural residential receptors off Burley Road to the southeast. Included in this assessment are the potential future receptors that may be located within the adjacent industrial estate. Listed in **Appendix E** are the particularly sensitive receptors (schools, childcare centres), located within the residential suburbs of Minchinbury and Erskine Park (also shown in **Figure 3-1**) along with the existing and future industrial/commercial sites.

For the purposes of this assessment air quality predictions have been made at both the site boundary receptor points (a nominal 52 points located along the site boundary as shown in **Figure 3-1**) and also 'sensitive receptors' that include:

- 4,945 residential receivers
- 14 particularly sensitive locations (schools, hospitals, etc)
- 68 existing industrial receivers
- 10 new industrial receivers
- 1 Environmental receiver (Prospect Dam).

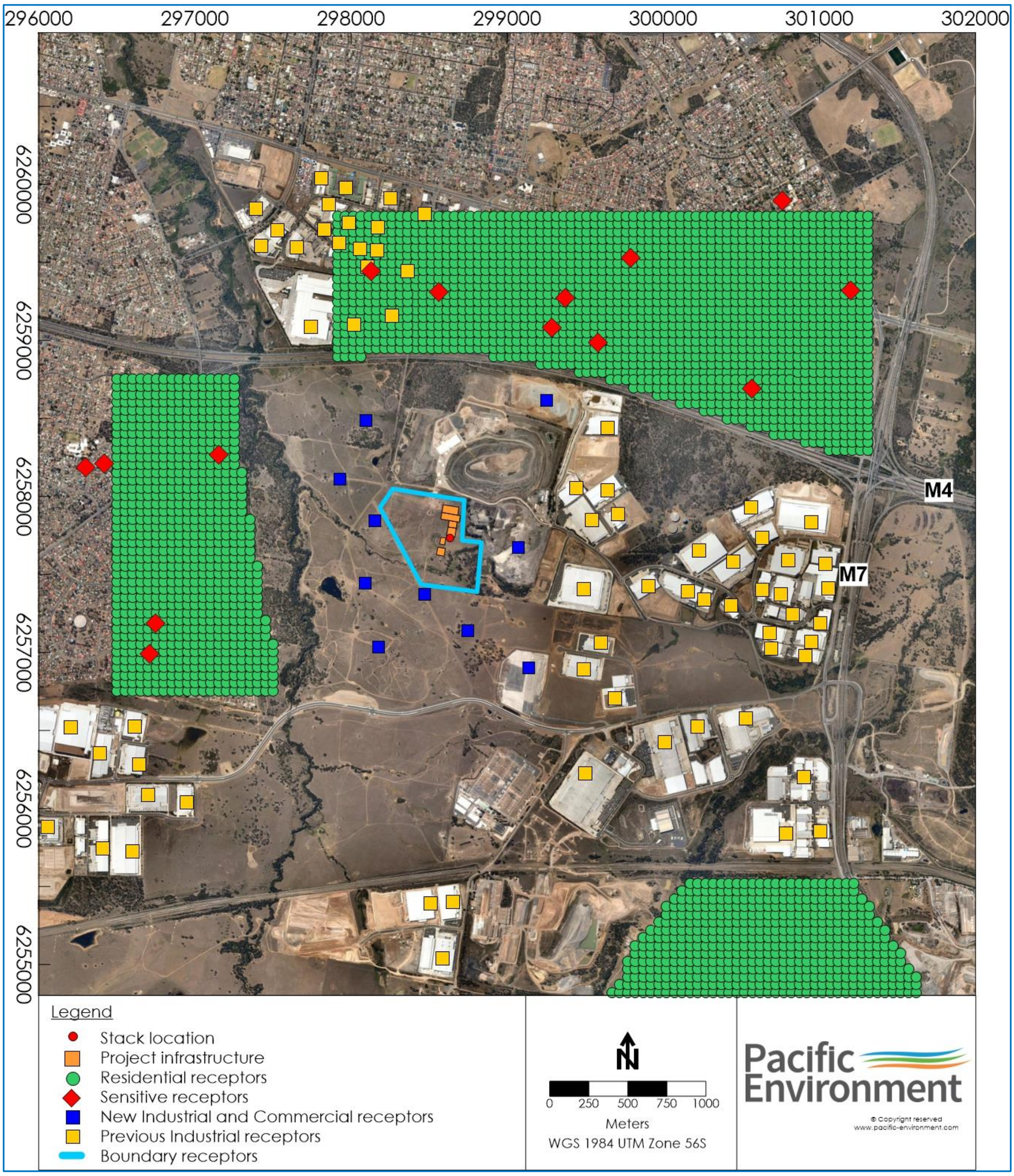

Figure 3-1: Local setting and representative sensitive receptor locations

4 LEGISLATIVE SETTING

4.1 Introduction

The EfW facility design has been developed to align with the relevant environmental, operational and safety requirements of Australian and NSW regulatory frameworks. Key performance requirements have been used to inform the development of the design and operation of the EfW facility.

The starting point for the environmental performance of the EfW facility has been the compliance with legislative standards which are required of Waste-to-Energy facilities in Europe. The European Industrial Emissions Directive IED 2010/75 EC (EU IED) 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 EfW facility.

The primary emissions from the EfW facility, as defined by emission limits for waste incineration set by the EU IED, are as follows:

- Particulate matter (PM), assumed to be emitted as PM_{10} and $PM_{2.5}$[g].
- Hydrogen Chloride (HCl).
- Hydrogen Fluoride (HF).
- Carbon Monoxide (CO).
- Sulfur Dioxide (SO_2)
- Oxides of nitrogen (NO_x) (expressed as Nitrogen Dioxide (NO_2)).
- Heavy metals (including Mercury (Hg), Cadmium (Cd), Thallium (Tl), Antinomy (Sb)Arsenic (As), Chromium (Cr (III) and Cr (VI)), Lead (Pb), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V).
- Gaseous and vaporous organic substances (expressed as total organic carbon (TVOC)).
- Dioxins and furans (PCCD/F).

In addition to the emission identified in the EU IED, potential emissions also include:

- Benzoic Acid
- Hexa-decanoic Acid
- Ethyl Benzoic Acid
- Toluene
- Phthalate
- Dichloro-methane
- Acetone (propanone)
- Tetra-decanoic Acid
- Benzene
- Acetonitrile
- Xylene
- Trichloro-phenol
- Methyl-hexane
- Trichloro-ethylene
- Heptane
- Hydrogen sulphide (H_2S)
- Ammonia (NH_3)
- Metals Beryllium (Be), Silver (Ag), Zinc (Zn), Tin (Sn), Molybdenum (Mo), Selenium (Se)
- Polychlorinated biphenyls (PCBs)
- Hexachlorobenzene (HCB)

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[g] Particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres respectively.

- Polycyclic aromatic hydrocarbons (PAHs)
- Phenol
- Hexane
- Phthalate
- Hydrogen bromide (HBr)
- Brominated flame retardants (BFR)
- Total brominated dioxins (TBD).

The EfW facility will incorporate best available technology (BAT) for flue gas treatment designed to meet the most stringent in-stack concentrations limits and ambient air quality criteria applicable for NSW. An overview of the applicable limits and criteria are provided below.

4.2 NSW EPA Energy from Waste Policy Statement

In March 2014 the NSW Environment Protection Authority (EPA) published its Energy from Waste Policy Statement ("the EfW Policy Statement"; **EPA, 2014**). The EfW Policy Statement sets out the policy framework and overarching criteria that apply to facilities in NSW proposing to thermally treat waste or waste-derived materials for the recovery of energy. Thermal treatment is defined as combustion, thermal oxidation, thermal or plasma gasification, pyrolysis and torrefaction.

Facilities proposing to thermally treat wastes that are not listed as an eligible waste fuel (such as this EfW facility) must meet the requirements of an energy recovery facility, that is must meet international best practice with respect to:

- Process design and control
- Emission control equipment
- Emission monitoring with real time feedback to process controls
- Arrangements for receipt of waste
- Management of residues.

The EfW Policy Statement notes that meeting international best practice will ensure that air toxics and particulate emissions are below levels that may pose a risk of harm to the community or environment. The EfW Policy Statement also specifies technical criteria which must be met, as outlined in **Table 4-1**.

Table 4-1: Technical criteria as outlined in EfW Policy Statement

Technical Criteria	
1	Combustion chamber minimum temperature of 850°C for at least 2 seconds, after the last injection of air.
2	Where waste contains >1% halogenated organic substances (expressed as chlorine), the combustion chamber temperature should be raised to 1100°C for at least 2 seconds, after the last injection of air.
3	The air emissions must satisfy, as a minimum, the Group 6 emission standards prescribed by the Protection of the Environment Operations (Clean Air) Regulation, 2010.
4	There must be continuous measurement of NO_x, CO, particles (total), total organic compounds, HCl, HF and SO_2.
5	There must be continuous measurement of temperature in the combustion chamber.
6	There must be continuous measurement of temperature, oxygen, pressure in the stack and water vapour in the exhaust gases.
7	Proof of performance trials must be conducted to demonstrate compliance with the emission standards. At least two measurements per year are required for heavy metals, PAHs and dioxins and furans (quarterly for the first year).
8	The total organic carbon (TOC) or loss on ignition (LOI) content of the slag and ash residue must be not greater than 3% and 5% respectively of the dry weight material.
9	Waste interlocks are required to prevent waste being fed before the requirement combustion temperature has been reached.
10	The net energy produced must be positive with at least 25% thermal efficiency (25% of thermal energy capture as electricity).

With regard to the second technical criterion, it is understood that the >1% chlorine trigger for waste has been incorporated because EfW Policy Statement references the original EU Waste Incineration Directive. However, the EfW Policy Statement refers simply to "waste" with > 1% chlorine, whereas the EU Waste Incineration Directive refers to "hazardous waste with halogenated organic substances >1%".

The main contribution to the chlorine content of the waste is PVC. PVC (C_2H_3Cl) itself contains approximately 57% chlorine by weight. In municipal waste typically approximately 50 % of the chlorine within the waste stream comes from PVC, in C&I waste the contribution of PVC to the overall chlorine content is expected to be even higher (**Ramboll, 2017**).

The European EfW experience has shown that EfW facilities typically have to handle concentrations of PVC of around 1% (MSW) with around 0.4% residual (i.e. non-PVC) chlorine contents. Residual fractions from recycling, C&D and C&I can also reportedly reach up to nearly 10%.

It is highlighted that PVC is not classified as a hazardous waste in either the EU or NSW jurisdictions.

The waste in total and as an average will not contain more than 1% chlorine **(Ramboll, 2017)**. This will be achieved through the extensive mixing of waste before feeding it to the combustion process. **Ramboll (2017)** conducted a sensitivity analysis of how a changing percentage of the different fractions influences the final chlorine content of the fuel. The analysis showed that the fractions with higher chlorine content can increase by a factor of at least 5 without the resulting fuel exceeding the 1% limit specified. Such a change is highly unlikely and therefore the fuel mix is expected to remain below a composition of 1% chlorine.

Current technology (from all EfW providers) does not allow efficient energy recovery at the higher temperature of 1,100°C referenced in Point 2 in **Table 4-1**.

TNG NSW have expressed that the current wording of the NSW EfW Policy Statement should be amended to reflect the wording within the EU legislation that it was based upon. Within the context of the current assessment, it is understood that, while flue gas treatment is able to abate significantly greater peaks in chlorine concentration of the residual waste fuel, the waste in total and as an average will not contain more than 1% chlorine **(Ramboll, 2017)** and therefore subject to an 850°C combustion temperature (**Appendix C**). Equally, the EfW facility would not be handling any 'hazardous' waste (with or without halogenated organic substances) as referenced in the EU legislation. As such, the technical criteria around the use of higher combustion temperatures referenced within the EU legislation would not require to be invoked in any event.

4.3 Emission Limits

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").

In accordance with Section 128 (2) the *Protection of the Environment Operations Act (1997)* also requires that "*The occupier of any premises must carry on any activity, or operate any plant, in or on the premises by such practicable means as may be necessary to prevent or minimise air pollution if: (a) in the case of point source emissions - neither a standard of concentration nor a rate has been prescribed for the emissions for the purposes of subsection (1), or (b) the emissions are not point source emissions.*"

The Clean Air Regulation sets standards for various activities and those that are applicable to an EfW facility are outlined in **Table 4-2**.

As the proposed flue gas treatment will be designed to employ Best Available Technology (BAT) and achieve the emission limits specified by the EU IED[h]. The IED emissions limits (refer **Table 4-3**) are generally more stringent that the Clean Air Regulation limits. The proposed technology is based on existing facilities operated throughout Europe, which are designed to meet the IED limits.

Table 4-2: POEO Clean Air Regulation Standards of Concentration

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
Fluorine (F_2) and any compound containing fluorine, as total fluoride (HF equivalent)	50	Electricity generation	Any activity of plant using liquid or solid standard fuel or non-standard fuel
Nitrogen dioxide (NO_2) or nitric oxide (NO) or both, as NO_2 equivalent	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	1×10^{-7} (0.1 ng/m^3)	Electricity generation	Any activity of plant using non-standard fuel that contains precursors of dioxin or furan formation
Volatile organic compounds (VOCs), as n-propane equivalent	40 (VOC) or 125 (CO)	Electricity generation	Any activity of plant using non-standard fuel

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[h] The IED replaces the EU Waste Incineration Directive (2000/76/EC)

Reference conditions defined as dry, 273.15 K, 101.3 kPa and 7% O_2 for all air impurities when burning a solid fuel, with the exception of dioxins and furans where the required O_2 concentration is 11% for waste incineration.

Table 4-3: IED Air Emission Limit Values

Pollutant	Daily Average (mg/Nm^3) (a)	Average of between a half hour and 8 hours (mg/Nm^3) (a)	Half Hourly Average (mg/Nm^3) (a)	
			100%	97%
Total Dust	10	n/a	30	10
Total Organic Carbon (TOC)	10	n/a	20	10
HCl	10	n/a	60	10
HF	1	n/a	4	2
SO_2	50	n/a	200	50
NO_x as NO_2	200	n/a	400	200
Cd	n/a	0.05	n/a	
Thallium (Tl)	n/a	0.05	n/a	
Hg	n/a	0.05	n/a	
Type 1 and 2	0.5	0.5	n/a	
Dioxins	n/a	1×10^{-7} (0.1 ng/m^3) (b)	n/a	
CO	50		100 (c)	

Notes: (a) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 11% O_2. (b) Averaging period is between 6 hours and 8 hours for dioxins and furans. (c) 10-minute limit of 150 mg/Nm^3 also applies to CO.

No emission limits are prescribed for a number of the air quality parameters listed in **Section 4.1** (e.g. NH_3 or PAHs) under the Australian or European legislative framework. Notwithstanding, these are important emissions that have been addressed within this assessment.

In accordance with clauses 56 of the Clean Air Regulation, power station emissions during start-up and shut-down periods are exempt from the in-stack concentration limits specified in **Table 4-2**. In addition, clause 57A of the Clean Air Regulation states that NO_x emissions from the emergency generators is also exempt if the generators are used no more than 200 hours per year.

4.4 Ambient Air Quality Criteria

The emissions from the EfW facility are also required to comply with the ground level concentrations criteria outlined in the Approved Methods (**NSW EPA, 2016**). **Table 4-4** summarises the ambient impact assessment criteria applicable to this assessment.

Impact assessment criteria for NO_2, SO, PM_{10}, CO and HF are applied at the nearest existing or likely future off-site sensitive receptor and are reported as the 100th percentile (i.e. maximum) of the dispersion modelling prediction. For the assessment of impact, background concentrations for these pollutants needs to be considered.

Impact assessment criteria for 'air toxics' (HCl, Hg, Cd, dioxins, NH_3 and PAHs) are applied beyond the site boundary and reported as the 99.9th percentile of the dispersion modelling prediction. Only incremental impacts for these pollutants need be reported.

Table 4-4: EPA ambient impact assessment criteria

Pollutant	Criterion	Averaging Period
NO_2	246 $\mu g/m^3$	1-hour average
	62 $\mu g/m^3$	Annual average
SO_2	712 $\mu g/m^3$	10-minute average
	570 $\mu g/m^3$	1-hour average
	228 $\mu g/m^3$	24-hour average
	60 $\mu g/m^3$	Annual average
PM < 10 µm (PM_{10})	50 $\mu g/m^3$	24-hour average
	25 $\mu g/m^3$	Annual average
PM < 2.5 µm ($PM_{2.5}$)	25 $\mu g/m^3$	24-hour average
	8 $\mu g/m^3$	Annual average
CO	100 mg/m^3	15-minute average
	30 mg/m^3	1-hour average
	10 mg/m^3	8-hour average
HF (a)	2.9 $\mu g/m^3$	24-hour average
	1.7 $\mu g/m^3$	7 days
	0.84 $\mu g/m^3$	30 days
	0.5 $\mu g/m^3$	90 days
HCl	0.14 mg/m^3	1-hour
Hg (inorganic)	0.0018 mg/m^3	1-hour
Cd	0.000018 mg/m^3	1-hour
Dioxins and furans	2.0 x 10^{-9} mg/m^3	1-hour
Benzene	0.029 mg/m^3	1-hour
Toluene	0.19 mg/m^3	1-hour
Xylene	0.36 mg/m^3	1-hour
NH_3	0.33 mg/m^3	1-hour
PAHs (as benzo(a)pyrene)	0.0004 mg/m^3	1-hour
Dichloro-methane	3.19 mg/m^3	1-hour
Acetone (propanone)	22 mg/m^3	1-hour
Trichloro-ethylene	0.5 mg/m^3	1-hour
Be	0.000004 mg/m^3	1-hour
Ag	0.0018 mg/m^3	1-hour
Zn (as ZnO)	0.09 mg/m^3	1-hour
As	0.00009 mg/m^3	1-hour

Pollutant	Criterion	Averaging Period
Sb	0.009 mg/m³	1-hour
Cr (as Chromium III)	0.009 mg/m³	1-hour
Pb	0.5 µg/m³	Annual
Ni	0.00018 mg/m³	1-hour
Cu (dusts and mists)	0.0037 mg/m³	1-hour
Mn	0.018 mg/m³	1-hour
Phenol	0.02 mg/m³	1-hour
Hexane	3.2 mg/m³	1-hour
TVOCs	0.029 mg/m³	1-hour

Notes: a. Applies to general land use other than areas with vegetation sensitive to fluoride e.g. grape vines and stone fruit.

Not all of the air quality parameters listed in **Section 4.1** have corresponding ground level concentration criteria within the Approved Methods. These air quality parameters include Benzoic Acid, Hexa-decanoic Acid, Ethyl Benzoic Acid, Phthalate, Tetra-decanoic Acid, Acetonitrile, Trichloro-phenol, Methyl-hexane, Heptane, Thallium (Tl), Tin (Sn), Molybdenum (Mo), Selenium (Se), Cobalt (Co), Vanadium (V) and Phthalate. These respective air quality parameters are important for the assessment of health risk and for completeness the results have been included **Appendix J**. The model predictions made within this report are also referenced in a stand-alone Human health Risk Assessment for the proposed EfW facility (**AECOM, 2017**).

4.5 Load Based Licensing

The load-based licensing (LBL) scheme, sets limits on the pollutant loads emitted by holders of environment protection licences and links licence fees to pollutant emissions.

Schedule 1 of the *Protection of the Environment Operations (General) Regulation 2009* sets out the licence fee system and lists assessable pollutants for energy recovery from waste and hazardous waste. The threshold limits for energy recovery are listed in **Table 4-5**.

Table 4-5: Threshold limits for energy recovery from waste

Air quality parameter	Threshold factor (tonnes)
Arsenic	0.00005
Benzene	0.0000011
Benzo(a)pyrene	0.00002
Fine particulates	0.7
Lead	0.035
Mercury	0.003
Nitrogen oxides and nitrogen oxides (summer)	2.5
Sulfur oxides	0.07

It is acknowledged that the EfW facility will likely be liable under the LBL scheme for a number of air quality parameters.

4.5.1 Hydrogen Sulfide

The Approved Methods also include ground-level concentration (glc) criteria for individual odorous air pollutants such as H_2S, taking account of population density in a given area. **Table 4-6** lists the H_2S criteria to be exceeded not more than 1% of the time, for different population densities.

The differences between odour criteria are based on considerations of risk of odour impact rather than differences in odour acceptability between urban and rural areas. For a given odour level there will be a wide range of responses in the exposed population. In a densely populated area there will therefore be a greater risk that some individuals within the community will find the odour unacceptable than in a sparsely populated area.

An H_2S criterion of 1.38µg/m^3 would apply to the built up areas around the EfW facility in any further detailed assessment of proposed operations.

Table 4-6: Odour performance criteria for the assessment of hydrogen sulfide

Population of affected community	Criterion for H_2S 99th percentile (µg/m^3)
≤ ~2	1.38
~10	2.07
~30	2.76
~125	3.45
~500	4.14
Urban (2000) and/or schools and hospitals	4.83

5 EXISTING AIR QUALITY

To assess potential impacts against the relevant air quality standards and criteria (see **Section 4.4**) it is necessary to have information or estimates on existing concentrations for the area in which the EfW facility would contribute to these levels.

The OEH monitoring station at St Marys collects air quality data for pollutants including PM_{10}, NO_x and O_3. The OEH monitoring station at Prospect collects air quality data for other pollutants not monitored at St Marys, including SO_2 and CO.

In addition, the adjacent Genesis facility operates a continuous PM_{10} monitor (BAM) at a residence in the suburb of Minchinbury, as a requirement of their Environmental Protection Licence (EPL).

A summary of the available air quality data is provided in the subsequent sections. Generally, air quality for the local area can be described as good, with the exception of isolated high pollution days or extreme events such as dust storms and bushfires.

5.1 Particulate Matter (PM_{10})

5.1.1 NSW OEH Monitoring at St Marys

A summary of the annual average and maximum 24-hour PM_{10} concentrations measured between January 2009 and December 2013 at St Marys are presented in **Table 5-1**. There were several exceedances of the 24-hour average PM_{10} criterion at St Marys in the last 5 years. During 2009 there were a number of elevated dust events including one of eastern Australia's most significant dust storms events, occurring on 23 September 2009 and recording a maximum 24 hour average concentration of 1,680µg/m^3.

Table 5-1: Annual average and maximum 24 hour average PM_{10} concentrations – St Marys (µg/m^3)

Year	Maximum 24-hour average (µg/m^3)	Annual average (µg/m^3)
EPA Criterion	***50***	***25***
2009	*1,661*	23
2010	*52*	15
2011	*74*	15
2012	34	14
2013	93	16

A time-series of the 24-hour average PM_{10} concentration for 2013 (the year chosen for modelling) is presented in **Figure 5-1**. The data indicates that concentrations above the EPA criterion of 50µg/m^3 were experienced on two days during 2013 (21 October – 93 µg/m^3, 25 October – 56 µg/m^3).

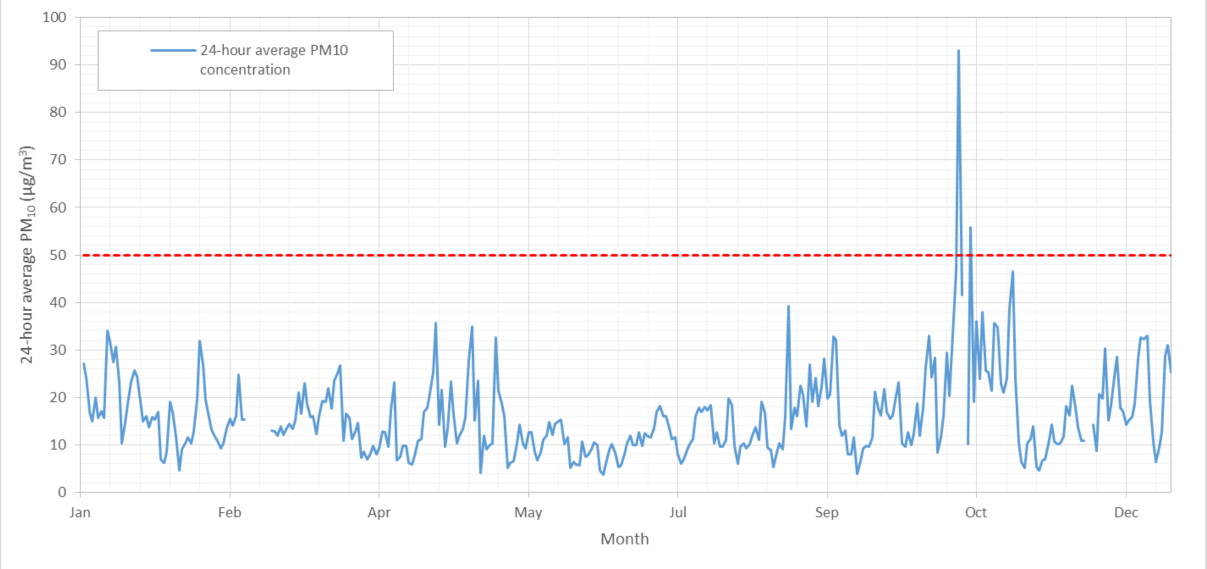

Figure 5-1: 24 hour average PM$_{10}$ concentrations – St Marys (2013)

5.1.2 NSW OEH Monitoring at Prospect

A summary of the annual average and maximum 24-hour average PM$_{10}$ concentration measured between January 2009 and December 2013 at Prospect are presented in **Table 5-2**. The annual average PM$_{10}$ concentration at Prospect appears to display an upward trend in the past 4 years which is not reflected in the data recorded at St Marys.

Table 5-2: Annual average and maximum 24 hour average PM$_{10}$ concentrations (µg/m³)

Year	Maximum 24-hour average (µg/m³)	Annual average (µg/m³)
EPA Criteria	***50***	***25***
2009	1,680	26
2010	40	15
2011	42	16
2012	39	17
2013	82	19

A time-series of the 24-hour average PM$_{10}$ concentration for 2013 (the year chosen for modelling) is presented shown in **Figure 5-2**. During 2013 there were three exceedances of the NSW criterion of 50µg/m³ (21 October 82 µg/m³, 3 November – 55µg/m³, 8 November - 54µg/m³).

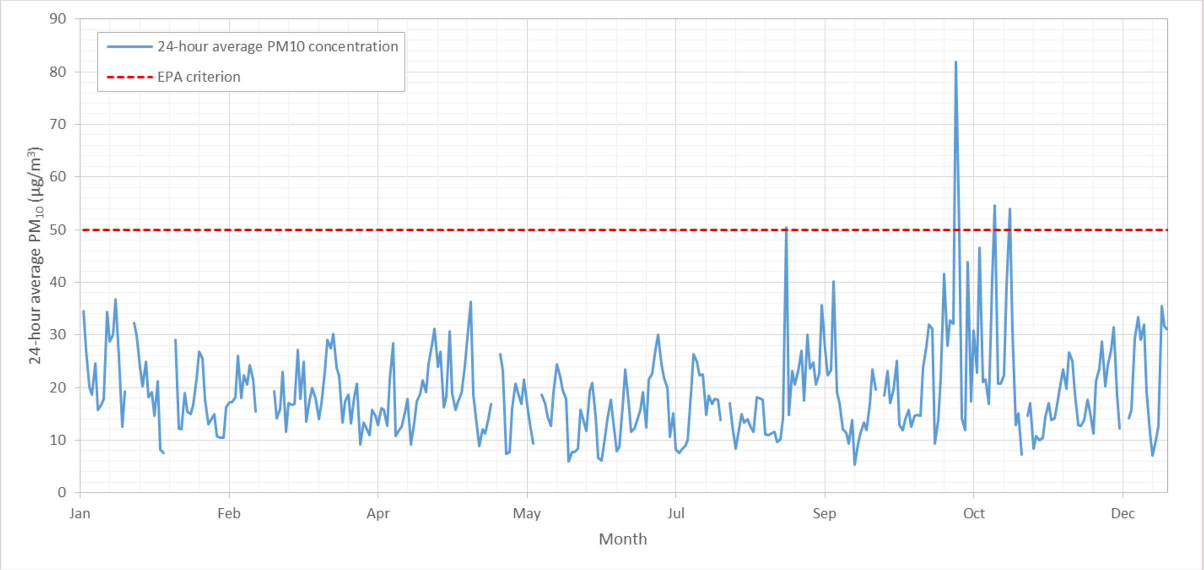

Figure 5-2: 24 hour average PM_{10} concentrations – Prospect (2013)

5.1.3 Industry Monitoring at Minchinbury

The adjacent Genesis facility operates a BAM PM_{10} monitor at Minchinbury, which has been operational since mid-2012. The 2013 annual average at Minchinbury is the same as Prospect (19µg/m³) and the maximum 24-hour average for the year is also similar (77 µg/m³). A summary of the annual average and maximum 24-hour average PM_{10} concentration measured between July 2012 and December 2015 at Prospect are presented in **Table 5-3**.

Table 5-3: Annual average and maximum 24 hour average PM_{10} concentrations – Minchinbury (µg/m³)

Year	Maximum 24-hour average (µg/m³)	Annual average (µg/m³)
EPA Criteria	***50***	***25***
2012	23	13
2013	77	19
2014	40	18
2015	55	16

A plot of the 24-hour PM_{10} concentration collected between July 2012 and February 2014 is presented in **Figure 5-3**. For comparative purposes, the St Marys and Prospect datasets are also presented within **Figure 5-3**. With the exception of the winter months, the 24-hour average PM_{10} concentration measurements show consistency between the three stations. During winter, the Minchinbury measures higher concentrations and is likely the result of being located in a residential area where there is likely to be significant influences from domestic wood heating.

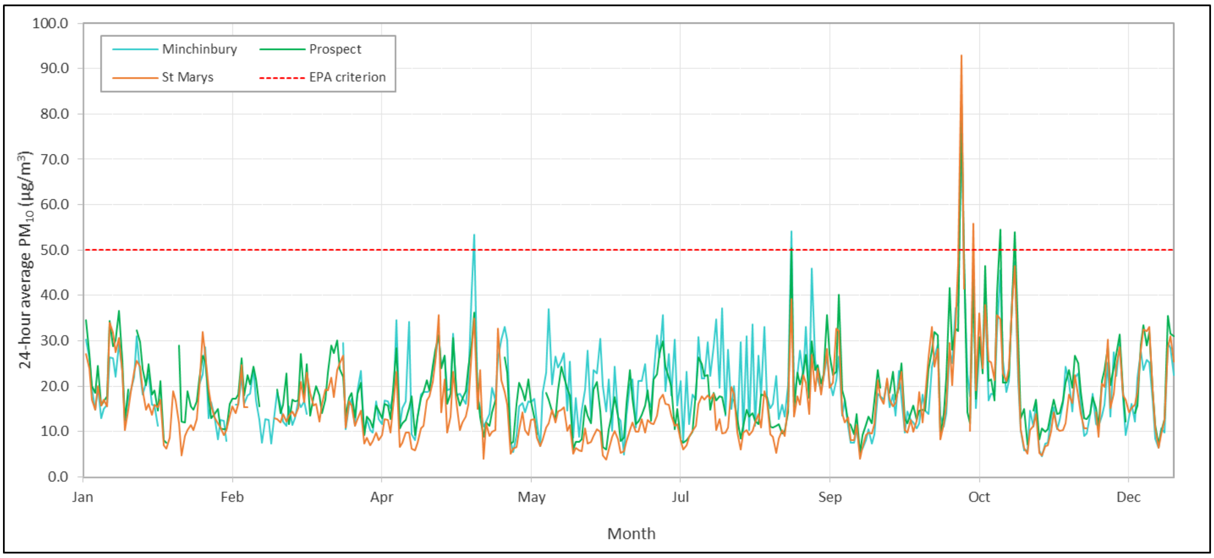

Figure 5-3: 24-Hour PM_{10} monitoring at Minchinbury

5.1.4 Background PM_{10} concentration

For the purposes of establishing a background PM_{10} concentration to be used in the dispersion modelling the exceedances measured at St Marys and Prospect monitoring stations have been removed from the data sets. This has been completed in accordance with the Approved Methods, whereby the Project must demonstrate no additional exceedances should occur as a result of the Project.

The next highest value at both sites is 49 µg/m^3 and has conservatively been adopted as the background concentration for the 24-hour PM_{10} concentration in the area of the Project.

5.2 Particulate Matter ($PM_{2.5}$)

The two closest OEH monitoring stations do not currently measure $PM_{2.5}$. Rather than adopt $PM_{2.5}$ data from further afield, a $PM_{2.5}$:PM_{10} ratio (0.35:1) has been applied to the PM_{10} data measured at St Marys and Prospect to establish an annual average background estimation. The ratio is based on PM measurements from Richmond and Liverpool between 2009 and 2013. The derivation of this factor is shown in the linear regression plot shown in **Figure 5-4**. Both data sets have been plotted (see **Figure 5-5**) to show the frequency distribution of $PM_{2.5}$:PM_{10} ratios at these sites. This results in an annual average value of 7µg/m^3.

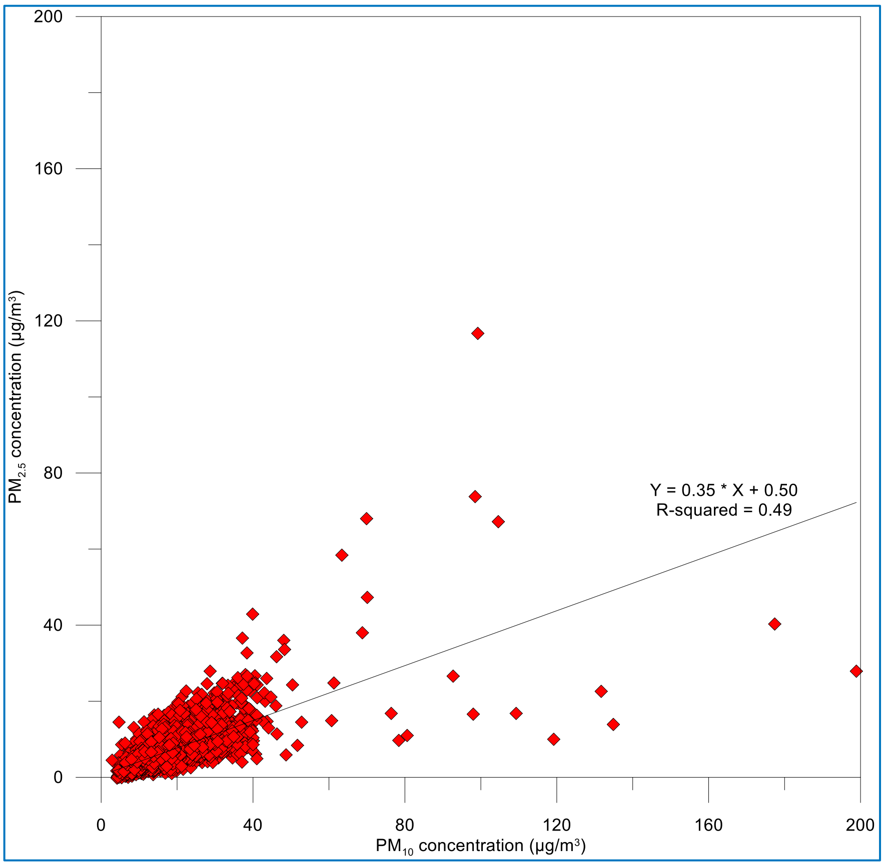

Figure 5-4: Derivation of $PM_{2.5}$:PM_{10} ratios from Liverpool and Richmond (2009 – 2013) using linear regression

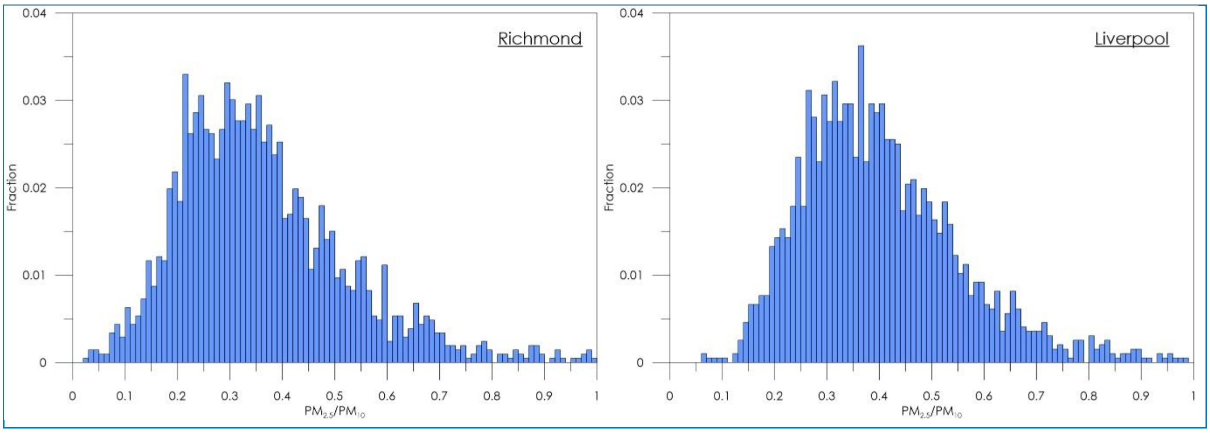

Figure 5-5: Frequency distribution of observed $PM_{2.5}$:PM_{10} ratios from Liverpool and Richmond (2009 – 2013)

It is acknowledged that adopting 0.35:1 ratio on a daily basis may not provide a conservative representation of local conditions and therefore background data from further afield at Liverpool also been referenced.

A summary of the calculated annual average and maximum 24-hour average $PM_{2.5}$ concentrations between January 2009 and December 2013 for St Marys, Prospect and Liverpool are presented in **Table 5-4**.

Table 5-4: Annual average and maximum 24 hour average $PM_{2.5}$ concentrations (µg/m^3)

Year	St Marys Annual average (µg/m^3)	Prospect Annual average (µg/m^3)	Liverpool Maximum 24-hour average (µg/m^3)
EPA Criterion	**8**	**8**	**25**
2009	8	9	268
2010	5	5	22
2011	5	6	38
2012	5	6	25
2013	6	7	74

As discussed in **Section 5.1.4**, the adopted background PM_{10} concentration removed the days above the criterion to allow for a background that would demonstrate an additional exceedance. This results in a 24-hour average value of 24.8 µg/m^3.

5.3 Nitrogen Dioxide (NO_2)

5.3.1 NSW EPA Monitoring at St Marys

A summary of the NO_2 annual and 1 hour maximum data from 2009 to 2013 at St Marys is presented in **Table 5-5**. During this period there were no exceedances of the 1-hour maximum criterion of 246µg/m^3 or the annual average criterion of 62 µg/m^3.

A time-series of the 1-hour average NO_2 concentrations recorded at St Marys during 2013 (modelling year) is presented in **Figure 5-6**. The results indicated that hourly NO_2 concentrations are well below the EPA criterion of 246 µg/m^3. The maximum recorded 1-hour average concentration in 2013 was 76 µg/m^3.

Table 5-5: Annual average and maximum 1 hour average NO_2 concentrations – St Marys (µg/m^3)

Year	Maximum 1-hour average (µg/m^3)	Annual average (µg/m^3)
EPA Criteria	**246**	**62**
2009	72	12
2010	74	12
2011	74	12
2012	88	10
2013	76	10

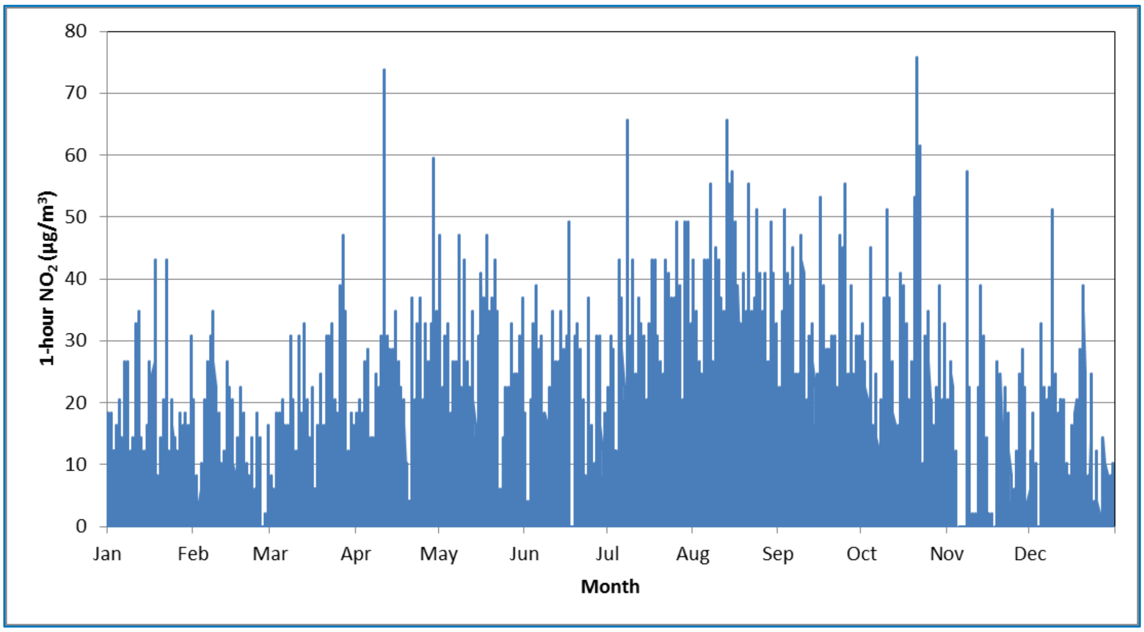

Figure 5-6: 1-hour NO_2 concentrations – St Marys (2013)

5.3.2 NSW EPA Monitoring at Prospect

A summary of the NO_2 annual and 1 hour maximum data from 2009 to 2013 at Prospect is presented in **Table 5-6**. During this period there were no exceedances of the 1-hour maximum criterion of 246 µg/m^3 or the annual average criterion of 62 µg/m^3. The maximum 1-hour and annual average concentrations are generally higher than at St Marys.

Table 5-6: Annual average and maximum 1 hour average NO_2 concentrations (µg/m^3)

Year	Maximum 1-hour average (µg/m^3)	Annual average (µg/m^3)
EPA Criterion	***246***	***62***
2009	105	23
2010	88	25
2011	80	21
2012	103	21
2013	100	23

5.4 Sulfur Dioxide (SO_2)

5.4.1 NSW EPA Monitoring at Prospect

A summary of the annual average and 1-hour maximum data for the 2009 to 2013 period at Prospect is presented in **Table 5-7**. During this period there were no exceedances of the 1-hour maximum criterion of 570µg/m^3 or the annual average criterion of 60 µg/m^3.

Table 5-7: Annual average and maximum 1 hour average SO_2 concentrations (µg/m^3)

Year	Maximum 15-minute average (µg/m^3)$^{(a)}$	Maximum 1-hour average (µg/m^3)	Maximum 24-hour average (µg/m^3)	Annual average (µg/m^3)
EPA Criterion	***712***	***570***	***228***	***60***
2009	92	49	9	N/A
2010	97	52	11	3
2011	75	40	9	3
2012	64	34	9	3
2013	107	57	11	3

*Notes: (a) Sub hourly data was not available. See **Section 7.3** for calculation methodology.*

5.5 Carbon Monoxide (CO)

5.5.1 NSW EPA Monitoring at Prospect

A summary of the CO monitoring data from the Prospect station for the 2008 to 2012 period at Prospect is presented in **Table 5-8**. During this period there were no exceedances of the 1 hour maximum criterion of 30µg/m^3 or the 8-hour criterion of 10 µg/m^3.

Table 5-8: Maximum 8-hour average CO concentrations (mg/m^3)

Year	Maximum 15-minute average (mg/m^3)$^{(a)}$	Maximum 1-hour average (mg/m^3)$^{(a)}$	Maximum 8-hour average (mg/m^3)
EPA Criterion	***100***	***30***	***10***
2009	13	8	4
2010	8	5	3
2011	8	5	3
2012	8	5	3
2013	8	5	3

*Notes: (a) Sub hourly data was not available. See **Section 7.3** for calculation methodology.*

5.6 Summary of Background Data

The background pollutant concentrations adopted for the assessment, based on the available monitoring data described above, are presented in **Table 5-9**.

Table 5-9: Summary of adopted background data

Air quality parameter	Averaging period	EPA criterion	Adopted background concentration
PM_{10}	Annual	25 µg/m³	19 µg/m³
	24 hour	50 µg/m³	49 µg/m³
$PM_{2.5}$	Annual	8 µg/m³	7 µg/m³
	24 hour	25 µg/m³	24.8 µg/m³
NO_2	Annual	62 µg/m³	23 µg/m³ (c)
	1 hour	246 µg/m³	100 µg/m³ (c)
SO_2	Annual	60 µg/m³	3 µg/m³
	24-hour	228 µg/m³	11 µg/m³
	1-hour	570 µg/m³	57 µg/m³
	10-minute (a)	712 µg/m³	107 µg/m³
CO	8-hour	10 mg/m³	3 mg/m³
	1-hour (a)	30 mg/m³	5 mg/m³
	15-minute (a)	100 mg/m³	8 mg/m³

6 EMISSIONS TO AIR

As noted in **Section 4.2**, the EfW Policy Statement indicates that any facility proposing to recover energy from waste will need to meet current international best practice. The EfW Policy Statement also requires that emissions from EfW facilities must satisfy, as a minimum, emission limits prescribed by the Clean Air Regulations.

The proposed technology for the EfW facility is based on existing facilities in Europe and will incorporate best available technology (BAT) for flue gas treatment. The flue gas treatment is designed to meet the in-stack concentrations limits for waste incineration set by the EU IED. The IED emissions limits (**Table 4-3**) are generally more stringent that the Clean Air Regulation limits (**Table 4-2**).

6.1 Best Available Techniques

A summary of the technologies used to control emissions from waste incineration at existing EfW facilities is presented to examine what constitutes current international best practice. The purpose of the review is to demonstrate that existing technology can satisfy the emission limit requirements of the EU IED, and therefore is appropriate for the EfW facility.

A commitment from the owner's engineer (Ramboll) to the operation of the proposed EfW Facility in accordance with BAT has been provided in **Appendix C** (see BAT Evaluation Memo 4, dated 18/2/2016). The memorandum lists the BAT, description of the approach used by TNG and an evaluation of the fulfilment of the BAT. There is a total of 68 BAT requirements, with all relevant techniques having been committed to.

6.1.1 General

In 2006 the European Commission published a reference document for best available techniques for waste incineration (**EC, 2006**). The Best Available Techniques Reference Documents (**BREF**) are made under the European directive on Integrated Pollution Prevention and Control (**IPPC**) (Council Directive 96/61/EC).

The BREF defines five sectors for waste incineration (mixed municipal, pre-treated municipal, hazardous, sewage sludge, chemical waste) and covers three types of thermal treatment (pyrolysis, gasification, incineration). The focus of the BAT review within the BREF is for flue gas treatment, however process control is also important and **Table 6-1** presents good practice process control proposed for the EfW facility.

Table 6-1: General good practice procedures / process control

Process	Details

Types of waste received	The technology has been chosen having regard to the characteristics of waste received, which are well known from the operation of the existing Genesis facility, and based on a minimum calorific value of 12.3 MJ/kg.
	A quality control process will be established for waste received at the EfW facility.
Maintenance	Regular maintenance will ensure equipment remains in good working order
Combustion	The furnace and boiler technology is designed for optimal combustion performance
	Proposed use of automated combustion control system, including control and optimisation of oxygen supply, temperature, residence time.
	Air injection
	Minimising uncontrolled ingress of air into combustion chamber during loading.
	Minimise start up / shut downs
	Preheating the combustion chamber for lower calorific wastes.
Monitoring	The EfW facility will employ a Continuous Emissions Monitoring System (CEMS).

6.1.2 Flue Gas Treatment

A range of pollution control equipment are available for the pollutants generated at EfW facilities and an overview of existing BAT for flue gas treatment is provided below and summarised in **Table 6-2**.

Fabric filters (bag houses) are used in the majority of existing EfW facilities as they have high particle removal efficiency and also work in combination with scrubbing systems (i.e. activated carbon injection). Electrostatic Precipitators (ESPs) have been used in conjunction with fabric filters to provide additional level of control where needed.

Scrubbing systems are used to remove acid gases and can be wet, dry or semi-dry. Scrubbers work by adsorption, bringing flue gas into contact with a scrubbing material such as lime, sodium hydroxide or sodium carbonate. Dry/semi dry scrubbers work well in conjunction with activated carbon injection, which is typically used to remove volatile heavy metals (e.g. Hg, Pb, Cd) and dioxins and furans. The used carbon and lime, along with the adsorbed pollutants, are collected on the fabric filter.

NO_x is produced in the combustion process (combining the nitrogen and oxygen present in air) and also from the nitrogen contained within the residual waste fuel. Thermal NO_x is typically controlled with good practice combustion and flue gas recirculation (FGR). FGR lowers the excess air rate, thereby increasing the thermal efficiency and reducing the available nitrogen for NO_x formation.

The NO_x removal system comprises Selective Non-Catalytic Reduction (SNCR). With an SNCR system, ammonia water is injected into the first pass of the boiler at a temperature of approximately 900°C. Here the chemical reaction takes places, converting NO_X to nitrogen and water. With an SNCR system the requirement of an in-stack concentration of 200 mg/Nm^3 NO_x can be comfortably reached.

The SNCR technology can be optimised to reach 120 mg/Nm^3 for a sophisticated SNCR (as a daily average) and has been adopted for the EfW facility. The increased efficiency comes with a modest increase of CAPEX and additional consumption of ammonia.

Ammonia slippage from an SNCR system (i.e. surplus NH_3 going to atmosphere) normally constitutes in-stack concentrations of between 1 mg/Nm^3 and 10 mg/Nm^3, with an average of 4 mg of NH_3/Nm^3 (**EC, 2006**). The effects of ammonia slip have been conservatively factored into the upset conditions emissions scenario, which assumes in-stack concentrations of ammonia of 20 mg/Nm^3.

The only metal which is present in relevant quantity in vapour phase is mercury (Hg). The emission of mercury is controlled by injection of Powdered Activated Carbon (PAC) into the flue gas at the entrance of the semi-dry reactor. The Hg (as well as any other metal found in vapour phase) is adsorbed by the PAC and then removed from the flue gas in the fabric filter (for further details see Section 6 of the Project Design Brief **(Ramboll, 2017)**.

A detailed description of each of the above pollution control technologies is provided in **Ramboll (2017)**.

Table 6-2: Best Available Techniques for EfW flue gas treatment (FGT)

Substance	BAT	Comments
Particles	Fabric filters / bag filters Cyclones Electrostatic precipitators	Fabric filters are generally sufficient to meet the emissions limits than prescribed by the EU IED and typically employed at existing EfW facilities.
Hydrogen chloride (HCl) Hydrogen Fluoride (HF) Sulfur Dioxide (SO2)	Waste control Wet scrubbers Dry and semi dry scrubbers	Wet FGT results in lowest emissions; however Dry FGT has the co-benefit of removing PCDD/F and mercury (with addition of activated carbon injection). Dry/semi dry most commonly employed at existing EfW facilities.
Oxides of Nitrogen (NOx)	Reduction of thermal NOx through combustion control and Flue Gas Recirculation Selective Catalytic Reduction (SCR) Selective Non Catalytic Reduction (SNCR)	Waste and combustion control with SNCR/SCR can generally result in emissions within limits prescribed by the EU IED. SNCR typically employed at existing EfW facilities.
Carbon Monoxide Gaseous and various organic substance (TOC)	Combustion control	Activated carbon injection may provide additional benefit of VOC control.
Mercury	Wet scrubbing with injection Activated carbon injection Condensing scrubbers Resin filters	Adsorption using carbon based reagents generally needed to meet limits prescribed by the IED. Activated carbon injection typically employed at existing EfW facilities.
Metals	Activated carbon injection Fabric filters	Techniques that control dust will also control metal emissions and fabric filters commonly used. Activated carbon injection additionally controls volatile metals (Hg).
Dioxins and Furans (PCDD/F)	Primary (combustion control) techniques, flue gas recirculation Selective Catalytic Reduction (SCR) Catalytic filter bags Adsorption by activated carbon injection / static beds Wet scrubbing with carbon injection / carbon slurries	Secondary abatement generally needed in combination with primary (combustion control) to meet limits prescribed by the EU IED.

A review of existing EfW facilities (mostly in the UK and Europe) indicates that these BAT are routinely implemented at EfW facilities. **Table 6-3** summarises the flue gas treatment that will be installed on commissioning of the TNG EfW facility (in addition to combustion and other process control). The owner's engineer, Ramboll, has produced a technical memorandum as to 'real world' in-stack concentrations of a comprehensive list of air quality metrics, referenced from existing EfW facilities internationally. This memorandum is provided in full as **Appendix C.** This memorandum provides publicly available emission data from facilities fired by C&I and C&D waste and / or semi dry APC system, as proposed for the TNG project. These facilities include:

- Hurth-Knapsack (Germany) – 2 x 150,000 tpa

- Heringen (Germany) – 2 x 148,500 tpa
- Premnitz (Germany) – 1 x 150,000 tpa
- Grossraschen (Germany) – 1 x 276,250 tpa
- TIRME Mallorca (Spain) – 2 x 208,000 tpa
- Riverside (UK) – 3 x 195,000 tpa.

Stage 1 of the Next Generation's proposed EfW facility is proposed to have a maximum engineering capacity of 675, 000 tonnes per annum and a usual operating capacity to process waste volumes up to a maximum of 552,500 tonnes per annum when the waste fuel does not exceed NCV 12.3 MJ/kg. This would give it a similar size and scale as both TIRME and Riverside examples above.

A further technical memorandum as to 'real world' in-stack concentrations of a comprehensive list of air quality metrics, referenced from existing EfW facilities internationally is provided in **Appendix C**.

Table 6-3: Flue Gas Treatment for existing EfW facilities

Facility	Flue Gas Treatment	Fuel Type
Lakeside, London, UK	SNCR for NOx control Semi-dry scrubbing using lime Activated carbon injection Fabric filter 75m stack	Household and municipal waste
Ferrybridge, UK	DeNOx SNCR semi-dry flue gas treatment process using hydrated lime Circulating fluidised bed reactor Hydrated lime and activated carbon dosing Fabric filter Flue gas Ducting 90m stack	Commercial and industrial, construction and demolition, municipal solid waste, waste wood.
Issy Les Moulineaux, Paris, France	Fabric filter plus ESP Dry scrubbing using sodium bicarbonate Activated carbon injection SCR low temperature deNOx system Gas exit temperature of 200°C and velocity of 30m/s (due to short stack)	Municipal solid waste
Riverside, London, UK	Semi-dry scrubber with lime and activated carbon injection Fabric filter 85m stack	Municipal solid waste
Mainz, Germany	SNCR for NOx control High dust catalytic converter to remove surplus ammonia Spray absorption using lime milk Activated coke injection Fabric filter 95m stack	Household waste, bulky waste and commercial waste.
AEB, Amsterdam, The Netherland (1,370,000 tpa)	SNCR for NOx control ESP plus fabric filter with activated carbon/coke injection Packed bed scrubber for HCl, lime milk injection for SO_2 Fabric filter Polishing scrubber	Municipal and industrial waste
Spitteleu, Vienna, Austria	SCR for NOx control ESP Wet scrubber for acid gases, lime slurry for HCl, NaOH for SO_2	Municipal solid waste
Kwinana Facility, Western Australia	SNCR for NOx control Spray dryer (lime) / high temperature lime scrubbing Activated carbon injection Fabric filter	Combustion of Municipal Solid Waste (MSW) in twelve Ultra High Temperature Combustors (UHTC's)

Greatmore Facility, Buckinghamshire, UK	Ammonia injection to reduce NO_x Lime injection Injection of activated carbon Bag filter 95m stack	Municipal solid waste (MSW) using Steam condensation by the means of air-cooled vacuum condenser.
Newhaven Facility, UK	Ammonia injection Lime injection Activated carbon Fabric filter 65m stack	Mixed municipal waste.
Worcestershire EfW facility, UK	Activated carbon injection Dry lime scrubbing Selective Non-Catalytic Reduction (SNCR) Fabric filter 75m stack	Household and municipal waste
Montgomery County, Maryland, USA	Thermal deNOx using aqueous ammonia Hydrated lime injection and spray dryer adsorber Carbon injection Baghouse 84m stack	Municipal solid waste

Source: Mercier EnviRecover (2010); SLR (2010); WA EPA (2000); Veolia (2013); WSP (2013)

6.2 Emissions Performance

The emission performance of a number of case studies is summarised in **WSP (2013)**, including some of the facilities presented in **Table 6-3**. A number of the case studies presented use the technology provider for the proposed EfW facility (i.e. Issy Les Moulineaux, Paris, and Riverside, London) and most apply the same flue gas treatment as the proposed EfW facility.

The data reviewed in the case studies demonstrates that emissions consistently meet the IED limits. **Appendix I** presents some of this data from **WSP (2013)**.

CEMS reports for the Riverside EfW facility have also been reviewed. Riverside employs similar technology (Hitachi Zosen Inova (HZI)) and flue gas treatment to the proposed EfW facility. The CEMS reports (2011 – 2014) demonstrate that the EfW facility consistently meets the EU IED limits for the pollutants monitored by CEMS and in most cases are significantly lower.

The Riverside EfW CEMS reports are publicly available on the internet (http://www.coryenvironmental.co.uk/page/rrremissions2012.htm). A sample report is presented in **Appendix I**.

HZI has also provided a summary of heavy metals emissions from a number of reference facilities in the UK which employ semi-dry FGT (as is proposed for the EfW facility). These results show that emissions of Hg and Cd are an order of magnitude below the EU IED limits. A summary of the data is provided in **Appendix I**.

6.3 Emissions scenarios

6.3.1 Scenario 1 - Expected

The in-stack concentrations for all air quality metrics anticipated to be released during 'expected conditions' were provided by Ramboll and shown in **Appendix G**. The emissions that are regulated under the *Approved Methods* and therefore modelled are presented in **Table 4-3.** It is noted that the emission rates for modelling were originally estimated based on the EfW facility meeting the more stringent limits prescribed in the IED (**Pacific Environment, 2015**). In October 2015, Ramboll, the owner's engineers, updated the in-stack concentration estimates for all air quality parameters. These updated concentration estimates were based on stack testing data for existing reference facilities. More information is provided in the technical memorandum provided by Ramboll in **Appendix C**. The adopted values were then updated by Ramboll in May 2017 to reflect data published by the UK Environment Agency **(UK EA, 2016)** on metal emissions from waste incineration and include updated values for several metals (As, Cr (III), Cr (VI), Ni, Co, Mn and V). It is noted that both Co and V are not regulated under the Approved Methods and therefore not explicitly assessed as part of this technical assessment, however, results for all air quality metrics, including those that are not regulated by the Approved Methods are provided in **Appendix J**.

Where the in-stack concentrations adopted in the 2016 emissions estimation were higher than the UK EA metals data, the original values was retained for conservatism (including Sb, Pb, Cu). In addition, updated in-stack concentration estimates for HF and H_2S were also provided by Ramboll (Pers. Comm. Martin Brunner, Ramboll). The in-stack concentration for HF was 4 mg/Nm^3 (**Pacific Environment, 2017c** and based on the IED half hourly limit. This value was revised down to 0.5 mg/Nm^3 by Ramboll to reflect low measured values within existing EfW facilities. Similarly for H_2S, Ramboll revised down the in-stack concentration estimates from 5 mg/Nm^3 to 1 mg/Nm^3 in-line with expected concentrations.

As discussed in **Section 6.1.2**, the proposed SNCR technology for NOx reduction can be optimised to reach 120 mg/Nm^3. The adopted NOx concentration of 188 mg/Nm^3 used previously (**Pacific Environment, 2017c**) has been revised down based on the outcome of the regional ozone modelling (**Pacific Environment, 2017b**) as TNG have committed to the employment of best available technology for NOx emissions abatement using the optimised SNCR.

The emission rates (g/s) adopted for modelling of each stack presented in **Table 6-4** are derived from the in-stack concentrations provided by Ramboll in **Appendix G** and the flue gas flow rate per stack (Nm^3/s) shown in **Table 6-9**.[i] A summary of the in-stack concentration estimates adopted is additionally documented within **Appendix G**.

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[i] It is noted that the in-stack concentration data for all air quality metrics provided by Ramboll were quoted at reference conditions, dry at 11% O_2. As the normalised volumetric flow rate was also provided at these conditions (127 Nm^3/s), mass emission rates have been based on these data. Information on the calculation of the actual flow rates when released from the stack are provide in **Appendix G.**

Table 6-4: In-stack concentrations and emission rates during Expected operations

Emission Parameter	In-stack concentration during Expected operations (mg/Nm^3) $^{(a)}$	Mass emission rate used to model Expected operations (g/s)
NO_x as NO_2	120	15.2
SO_2	27	3.4
CO	23	2.9
PM_{10}	1	0.13
$PM_{2.5}$	1	0.13
HCl	9	1.14
HF	0.5	0.06
Cd	0.009	0.0011
Hg	0.004	0.0005
PCDD/F	1.0×10^{-8}	1.3×10^{-9}
Benzene	0.015	0.0019
Toluene	0.03	0.0038
Xylene	0.01	0.0013
NH_3	2	0.25
H_2S	1	0.13
PAHs	0.0005	0.00006
Dichloro-methane	0.02	0.003
Acetone (propanone)	0.018	0.002
Trichloro-ethylene	0.005	0.001
Be	0.000007	0.000001
Ag	0.00034	0.000043
Zn	0.037	0.005
As	0.025	0.003
Sb	0.0148	0.002
Cr (III)	0.092	0.01
Cr (VI)	0.00013	0.00002
Pb	0.172	0.02
Ni	0.22	0.028
Cu	0.0163	0.002
Mn	0.06	0.008
Phenol	0.005	0.001
Hexane	0.005	0.001
TVOC	1.2	0.15

Notes: (a) Conditions defined as dry, 273.15 K, 101.3 kPa and 11% O_2. As the normalised volumetric flow rate was also provided at these conditions (127 Nm^3/s), mass emission rates have been based on these data. Information on the calculation of the actual flow rate when released from the stack is provided in **Appendix G**.

6.3.2 Scenario 2 - Regulatory (POEO Limits)

To inform future Environmental Protection Licensing of the EfW facility, in addition to the expected and upset conditions, ground level concentrations resulting from a Regulatory scenario (in-stack concentrations at the POEO emission limits) have also been investigated. The POEO Regulation in-stack concentration criteria relevant to this assessment are presented in **Table 6-5**. The in-stack concentration limits are based on the limits prescribed under Schedule 3 (Standards of concentration for scheduled premises: activities and plant used for specific purposes) of the Regulation for 'Electricity generation'.

The air quality metrics evaluated within this scenario was expanded to include HF, Cd, Hg and Type 1 and Type 2 metals[j], in accordance with Schedule 3 of the POEO Regulations.

In **Pacific Environment (2017c)**, the in-stack concentrations for the Type 1 and Type 2 metals (excluding Cd and Hg, where specific limits are prescribed) were ratioed in accordance with the relevant percentage contributions established for the 'Expected' emissions scenario. This methodology has since been revised to adopt a more conservative approach whereby all metals are modelled as if they individually comprised 100% of the POEO Regulation limit (see **Table 6-5**).

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[j] POEO Regulations (2010): Type 1 substance refers to the elements antimony, arsenic, cadmium, lead or mercury or any compound containing one or more of those elements. Type 2 substance refers to the elements beryllium, chromium, cobalt, manganese, nickel, selenium, tin or vanadium or any compound containing one or more of those elements.

Table 6-5: POEO (Clean Air) Regulation Emission Limits and emission rates during Regulatory (POEO) scenario

Emission parameter	POEO Regulation limit (mg/Nm^3) (1)			Mass emission rate used to model Regulatory (POEO) scenario (g/s) (2)
Nitrogen dioxide (NO$_2$) or nitric oxide (NO) or both, as NO$_2$ equivalent	500			45.4
CO	125			11.3
Solid particles (Total) (PM$_{10}$)	50			4.5
Solid particles (Total) (PM$_{2.5}$)	50			4.5
Fluorine (F$_2$) and any compound containing fluorine, as total fluoride (HF equivalent)	50			4.5
Cd	0.2			0.018
Hg	0.2			0.018
Dioxins or furans	1.0E-07			1.3E-08
Type 1 substances and Type 2 substances (in aggregate)	1	As	1.0	0.09
		Sb	1.0	0.09
		Pb	1.0	0.09
		Be	1.0	0.09
		Cr (III)	1.0	0.09
		Cr (VI)	1.0	0.09
		Ni	1.0	0.09
		Mn	1.0	0.09
Volatile organic compounds (VOCs), as n-propane equivalent	40			6.4 (2)

Notes: (1) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 7% O$_2$ for all air impurities when burning a solid fuel, with the exception of dioxins and furans where the required O$_2$ concentration is 11% for waste incineration.

(2) For consistency with the other model scenarios the POEO emission limits have been converted to adopt an 11% O$_2$ concentration for the presented mass emission rates.

(3)TVOCs have been assessed against the impact assessment criterion for benzene. Therefore the 40 mg/Nm^3 limit has been adjusted to 71 mg/Nm^3 to account for the difference in molecular weight.

There are no provisions in NSW legislation or policy documents that prescribe the allowable number of hours that emission limits can be exceeded. The Proponent acknowledges the requirements to comply with the Clean Air Regulation and Environmental Protection Licence limits at all times.

In the event that the emission limit does not satisfy the ground level concentration criterion then a more stringent in-stack emission limit would be proposed.

6.3.3 Scenario 3 - Upset

As per the expected operations, in-stack concentrations for 'upset conditions' were provided by Ramboll, shown in **Appendix G**. The emissions that are regulated under the *Approved Methods* and therefore modelled are presented in **Table 7-5**. The results for all air quality metrics, including those that are not regulated by the Approved Methods are provided in **Appendix J**.

As no emissions data were available in the public domain reflective of conditions during a plant failure event, the approach used to develop the 'Upset' scenario was to adopt a ten-fold increase in emissions above the respective IED limit values (see **Table 4-3**).

For those parameters without an IED limit, a ten-fold increase in emissions relative to the 'Expected' scenario were adopted (see **Table 6-4**).

As discussed in **Section 2.5**, a conservative approach assuming a factor of 10 increase for individual emission during upset condition has been chosen. It is noted that there have been some exceptions to this assumption. For example for the air quality metrics listed in the IED (see **Section 4.3**) the recommendation by Ramboll (Pers. Comm. Martin Brunner, Ramboll) was to adopt a ten-fold increase on the IED limits, as well as ratioing each metal constituent based on the data published by the UK Environment Agency **(UK EA, 2016)**.

This general approach was provided by Ramboll as a conservative estimate of emissions under plant failure conditions. Further refinements were made for specific air quality metrics where such an approach was not deemed valid. This includes for NO_x where 400mg/Nm^3 was considered more appropriate given that this is reflective of post-combustion concentrations under failure of the SNCR emission controls.

The air quality metrics evaluated within this scenario was expanded to include PCDD/DF, various organics, H_2S, PAHs and metals.

Table 6-6: Emissions per stack during upset conditions

Emission parameter	In-stack concentration during upset conditions (mg/Nm^3) [(a)]	Mass emission rate used to model upset conditions (g/s)
NO_x as NO_2	400	51
SO_2	500	64
CO	500	64
PM_{10}	100	13
$PM_{2.5}$	100	13
HCl	100	13
HF	5	0.6
Cd	0.45	0.06
Hg	0.5	0.06
PCDD/F	1.0×10^{-6}	1.3×10^{-7}
Benzene	0.15	0.02
Toluene	0.3	0.04
Xylene	0.1	0.01
NH_3	20	2.5
H_2S	10	1.3
PAHs	0.005	0.0006
Dichloro-methane	0.2	0.03
Acetone (propanone)	0.2	0.02
Trichloro-ethylene	0.05	0.006
Be	0.0005	0.00007
Ag	0.0255	0.003
Zn	5.09	0.6
As	0.079	0.01
Sb	0.119	0.02
Cr (III)	0.674	0.09
Cr (VI)	0.0013	0.0002
Pb	0.872	0.11
Ni	1.189	0.151
Cu	0.595	0.076
Mn	1.348	0.171
Phenol	0.05	0.006
Hexane	0.05	0.006
TVOC	100	12.7

Notes: (a) Conditions defined as dry, 273.15 K, 101.3 kPa and 11% O_2

When considering upset operating conditions it is always a matter of balance between stated upset emission level, the probability of occurrence, and the duration of emission at such elevated rates. Very high emission rates would occur rarely and for short time because plant shutdown would likely be an imminent consequence, whereas slightly elevated levels could occur occasionally and for some length of time until the necessary actions are put into force.

In the event of upset conditions strict management measures should be followed to ensure that elevated emissions are minimised. As noted above, if the facility were to operate under upset condition for more than four hours then plant would be shut down. More information on management during upset is provided in **Section 9.3**.

6.3.4 Scenario 4 – Regulatory (IED Limits)

The IED in-stack concentration limits adopted for this regulatory scenario are presented in **Table 6-7**. This scenario is presented since facility is designed, and will be operated to meet, the IED emission limits.

It has been advised by Ramboll that it is appropriate to use the daily limit values as these represent a reasonable in stack concentration limit when the facility is operating on a continuous basis. However, there are several metrics that have a short term averaging period when assessed in accordance with their corresponding NSW impact assessment criterion, for example, HCl, HF and SO_2.

For this reason, and so as to provide a conservative assessment, those metrics with an impact assessment criterion of 1-hour or less, the half-hourly IED limit has been adopted. For those metrics with an assessment criterion of greater than 1-hour (such as PM) the daily limit has been adopted.

In the case where metrics are assessed against both a short term and long term criterion the relevant IED limit has been used. For example, for the 1-hour NO_2 predictions the half hourly IED limit of 40 mg/Nm^3 while for annual predictions the daily average of 200 mg/Nm^3 has been used. To inform future Environmental Protection Licensing of the EfW facility, in addition to the expected and upset conditions, ground level concentrations resulting from this Regulatory scenario have also been presented in **Section 9**.

In **Pacific Environment (2017c)** Emissions of speciated metals were based on the in-stack metal ratios established by the UK Environment Agency **(UK EA, 2016)** for waste incineration applied to the (aggregated) Type I and Type II metals emission limit of 0.5mg/m^3. This methodology has since been revised to adopt a more conservative approach whereby all metals are modelled as if they individually comprise 100% of the IED limit. It is noted that both Co and V are not regulated under the IED and therefore not directly assessed as part of this technical assessment, however, results for all air quality metrics, including those that are not regulated by the IED are provided in **Appendix J**.

Table 6-7: IED emission limits and corresponding mass emission rates under the Regulatory (IED) scenario

Emission parameter	Daily average limit (mg/Nm^3) [(a)]	Half hourly limit (mg/Nm^3) [(a)]	Mass emission at IED daily average (g/s)	Mass emission at IED half hourly limit (g/s)
NO_x as NO_2	200	400	25.4	50.8
SO_2	50	200	6.4	25.4
CO	50	100	6.4	12.7
PM_{10}	10	n/a	1.3	n/a
$PM_{2.5}$	10	n/a	1.3	n/a
HCl	10	60	1.3	7.6
HF	1	4	0.1	0.5
Cd	n/a	0.05	n/a	0.01
Hg	n/a	0.05	n/a	0.01
PCDD/F	n/a	1.0×10^{-7}	n/a	1.3×10^{-8}
Tl	n/a	0.05	n/a	0.01
As	n/a	0.5	n/a	0.1
Sb	n/a	0.5	n/a	0.1
Cr (III)	n/a	0.5	n/a	0.1
Cr (VI)	n/a	0.5	n/a	0.1
Pb	n/a	0.5	n/a	0.1
Ni	n/a	0.5	n/a	0.1
Cu	n/a	0.5	n/a	0.1
Mn	n/a	0.5	n/a	0.1
TVOC (assessed as Benzene)	n/a	20	n/a	2.5

Notes (a) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 11% O_2.

6.3.5 Scenario 5 - Diesel Generators

Two emergency diesel generators will operate as part of the Project. Dispersion modelling has been used to assess the ground level concentrations during the operation of the diesel generators during emergency conditions.

To reiterate that already outlined in **Section 2.6**, the diesel generators are only required in case of an emergency when there is a black out of the power grid and the facility fails to run in "island mode" (island mode is the generation of power by the turbine/generator of the facility for internal use without any connection to the power grid). The generators will then ensure a safe shutdown of the facility. The operation time of these generators is therefore maximum four hours per event. Further, the generators are not used to maintain the furnace temperature. For the purposes of modelling, the air quality metrics with a 1-hour averaging period criterion have been modelled on a 24/7 basis. For the PM fractions, it has been assumed that the diesel generators would operate daily for four hours, nominally between 10am and 2pm (reflective of likely generator testing / maintenance times).

The adopted mass emission rates and stack parameters are provided in **Table 6-8**. The calculation of emissions was based on equipment specification data that are generally representative of the type of technology that would be used for the diesel generators.

A manufacturer's guarantee has been provided by Cummins (**2015**) that confirms that the emergency diesel generators will operate within the US EPA Tier II emission limits.

It is noted that these do not directly transpose to the NSW POEO Regulation emission limits and that when calculated the anticipated PM concentrations do not comply with the 50 mg/Nm^3 limit at reference conditions. Therefore, the emission of PM, CO and VOCs have been modelled at the NSW POEO limits.

Given that modelling has been completed to the NSW POEO limits, final selection of diesel generators to meet, or exceed, this emission specification would comprise a statement of commitment for the project.

As already discussed in Section 4.3, under Clause 57A there are no NOx emission limits when operating for less than 200 hours per year. On this basis, the anticipated **Cummins (2015)** NO$_X$ engine emissions have been referenced as representative of the likely technology to be adopted. As the Cummins specification does not provide all of the required information for inputs required for the calculations, the oxygen content and moisture content were referenced from similar engine specifications. A copy of the emission performance specifications for representative emergency diesel generators is provided as **Appendix H.**

The owner's engineers have confirmed (Pers. Comm. Martin Brunner, Ramboll) that benzene composition within the emergency diesel generator exhaust is anticipated to be well below 1%, and this assumption has been adopted for conservatism for modelling purposes. It is anticipated that this can be confirmed during the commissioning stack testing. If not the case, generators can be retrofitted with catalysts to further reduce in-stack benzene concentrations, as required.

As no emission information was available for SO$_2$, emissions have been calculated in accordance with the *Fuel Standard (Automotive Diesel) Determination 2001*, adopting on the automotive diesel standard of 10 mg/kg valid from 1 January, 2009. A fuel consumption rate of 627 L/hr per engine was adopted and is based on the fuel consumption rate of a Cummins C30005e engine.

Table 6-8: Pollutant mass emission rates for each emergency diesel generator

Parameters	Input	
Stack coordinates (UTM)	298536 mE, 6257776 mN 298683 mE, 6257757 mN	
Stack height	3.2 m	
Stack diameter	0.5 m	
Exit velocity	46 m/s	
Exit temperature	754 K	
Air quality parameter	**Mass emission (g/s) (a)**	**In-stack concentration (mg/Nm^3)(b)**
NOx as NO$_2$	1.93 g/s	n/a (c)
CO	11.22 g/s	5880
PM	0.10 g/s	50
VOCs	0.064 g/s	1140
SO$_2$	0.003 g/s	n/a (c)

Notes (a) Mass emission rates based on the g/kWm-hr data provided by Cummins in ***Appendix H****.*

(b) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 7% O$_2$.

(c) There are no applicable emission POEO Regulation limits for NO$_2$ or SO$_2$.

6.3.6 Emissions during Start-up / Shut-down Conditions

As discussed in **Section 2.3** an auxiliary support fuel will be used in the combustion chamber to regulate the temperature. It is understood that the fuel would comprise diesel, with all emissions released from the 100m stack. As the nature of the emissions from the combustion of diesel fuel would burn significantly cleaner than the residual waste fuel, and in consideration of the infrequent occurrence of start-up and shut down, emissions during such conditions have not been further assessed.

6.4 Stack Parameters

As noted above, the current assessment evaluates a scenario whereby there is only one stack, with the facility processing approximately half the volume of waste that was previously proposed and assessed as part of **Pacific Environment (2015; 2016; 2017c)**.**Table 6-9** provides a summary of the stack parameters evaluated within the current assessment.

Ramboll produced a technical memorandum in which they document flue gas flow rates and exit parameters that have been derived during the detailed design process. The exit parameters advised by the owner's engineers are provided within their technical memorandum included as **Appendix C** and calculation methodology provided in **Appendix G**. It is noted that the EfW is intended to have two flues (i.e. one dedicated to each combustion line) that would be released through a single exhaust stack. For the purposes of dispersion modelling the stack diameter provided reflects an equivalent stack diameter from the two twin-flues, discharging through a single exit point.

Table 6-9: Stack parameters for modelling

Parameter	Revised (Current) Modelling
Stack Location (m, MGA, Zone 56)	298632.9 (E) 6257733.5 (N)
Base Elevation (m, AHD)	64.2
Stack Height (m)	100
Equivalent Stack Diameter (m)	3.1
Temperature (°C)	120
Flue Gas Flow (Nm^3/s)	127.0
Gas Exit Flow Rate (Am^3/s)	165.2
Gas Exit Velocity (m/s)	21.7

Nm$_3$/s = reference gas flow, dry at 11% O_2. Am$_3$/s = actual gas flow, wet, corrected for temperature.

6.5 Hours of operations an release of emissions

As discussed in **Section 6.2**, over the entire year, the EfW facility would be operational for 8,000 hours as an annual average.

For dispersion modelling purposes (further discussed in **Section 7**) emissions released from each of the above scenarios have been modelled such that the emissions are released over the entire modelled period (i.e. 8,760 hours of 2013). This allows for the worst case meteorological conditions to be accounted for in the ground level concentration predictions. This approach has been adopted for all averaging periods, thus providing a thorough assessment and conservative approach in consideration of the annual average predictions.

6.6 Release of Dioxins/Furans

Ramboll have provided a dedicated memorandum on the subject of dioxin control within **Appendix C,** which speaks directly to emission performance and implications under the Stockholm Convention. The following aspects are highlighted:

- The flue gas treatment stage consists of a reactor with injection of lime and activated carbon for dioxin adsorption followed by a bag house filter for dust separation, including the activated carbon particles with dioxin adsorbed.
- The flue gas treatment system ensures that the stack emissions comply with the emission requirement of 0.1 ng/m³ (at reference conditions; **EC, 2010**) regardless the content in the raw, untreated flue gas within any realistic operational range.
- This technology is compliant with provisions of the EU Best Available Techniques as described in the BAT reference note (**EC, 2006**).
- The dioxin content of the incoming waste is anticipated to grossly exceed the sum of the outputs such that the TNG EfW facility is a net destructor of dioxin (atmospheric emissions of dioxin are expected to comprise less than 1% of the content of the incoming waste).
- The total dioxin emission from the TNG EfW facility is estimated to be around 0.02% of the Australian inventory, and 0.05% of the contribution from Australian backyard incineration activities.

Appendix E.1 directly addresses the TNG EfW facility's emission performance and associated implications under the Stockholm Convention. The following aspects of this memorandum are highlighted:

- When waste is directed to the TNG EfW facility, less waste will be available for open and other uncontrolled burning of waste, including unintended landfill fires. This is anticipated to have a large beneficial impact on the control of persistent organic pollutants (POPs) from waste management because emissions from uncontrolled burning of waste are several orders of magnitude higher than from a modern EfW facility.
- The Stockholm Convention specifically mentions the following to be considered in determining best available techniques for dioxin control; "*Use of improved methods for flue-gas cleaning such as thermal or catalytic oxidation, dust precipitation, or adsorption*".
- The TNG EfW facility will be constructed using the Best Available Techniques (BAT) as described in the convention. It uses dust precipitation and adsorption in the flue gas treatment system.
- All residues from the process (bottom ash and flue gas treatment residue, including fly ash) are expected to be well below the "low POP content" threshold for wastes. This means that the Stockholm Convention does not require further treatment of the residues prior to disposal when it comes to the dioxin content.

The presence of ultra-fine and sub-micron particulate in the environment is acknowledged. It is highlighted that the particulate generated by the EfW facility is expected to be well below than 2.5 micrometres in aerodynamic diameter ($PM_{2.5}$) with particle size distribution as described in **Fachhochschule Nordwestschweiz (2007)** and **Buonanno *et al.* (2008)**, where mean particle diameters were largely in the sub-micron range.

6.7 Treatment of Emissions of Oxides of Nitrogen (NO_x)

Nitrogen oxides (NO_x) emitted from combustion are comprised mainly of nitric oxide (NO) and nitrogen dioxide (NO_2). Typically, at the point of emission, NOx would consist of approximately 90-95% of NO and 5-10% of NO_2. The dominant mechanism for short-term conversion of NO to NO_2 is through oxidation with atmospheric ozone (O_3) as an exhaust plume travels from source. Therefore, to predict the ground-level concentration of NO_2 (regulated oxide of nitrogen) it is important to account for the transformation of NO_x to NO_2. Ultimately, all NO emitted into the atmosphere will be oxidised to NO_2 and to other higher oxides of nitrogen. The rate at which this oxidation takes place depends on prevailing atmospheric conditions including temperature, humidity and the presence of other substances in the atmosphere such as O_3. It can vary from a few minutes to many hours. If the dispersion is sufficient to have diluted the plume to the point where the concentration is very low, it is unimportant that the oxidation has taken place. However, if the oxidation is rapid then high concentrations of NO_2 can occur when inadequate dispersion / dilution conditions exist. For this report we have conservatively assumed 100% conversion of NO_x to NO_2.

In the event that this conservative approach does not meet the criterion, a level 2 assessment was completed using the Ozone Limiting Method (OLM). The OLM is based on the assumption that approximately 10% of the NO_x emissions are generated as NO_2 **(Alberta Environment, 2003)**. The majority of the NO_X emission is in the form of NO, which reacts with ambient levels of ozone to form additional NO_2. If the ozone concentration is greater than 90% of the predicted NO_x concentration, all the NO_x is assumed to be converted to NO_2, otherwise NO_2 concentrations are calculated using the equation below, which assumes total conversion of the ozone and adds the 10% of the NOx that was emitted as NO_2:

$$NO_2 = O_3 + 0.1 \times NO_X$$

The predicted NO_2 concentration is then added to the background NO_2 concentration.

To apply the OLM, hourly background concentrations of ozone and NO_2 in 2013 were obtained from the NSW EPA monitoring station at Prospect. The NO_2 concentration at each receptor was calculated using the above equation for each hour of the year, and then added to the corresponding hourly background value from the Prospect site. The maximum hourly NO_2 concentration and annual mean concentration were then determined from the results.

6.8 Treatment of dust deposition

The Human Health Risk Assessment requires the deposition of particulate-phase pollutants (dioxins/furans, PAHs and all metals) to be calculated. An important component of deposition modelling is the particle diameter of the emission being released as the rate at which the particles settle is a function of the particle size and density. Previous assessments have adopted an overly conservative geometric mean particle diameter of 10 µm. Information subsequently received from the owner's engineer, Ramboll, on the particle size distribution of emissions from an equivalent air pollution control facility in Germany indicate that particles are dominated by those in sub-micrometre size range (**Fachhochschule Nordwestschweiz, 2007**). Particles in this size fraction were also measured by **Buonanno *et al.* (2008)**.

In view of the facility's expected particle diameter profile, a geometric mean diameter of 1 µm was adopted for the deposition modelling outputs referenced by the Health Risk Assessment (**AECOM, 2017**).

6.9 Odour

Residual waste fuel will arrive to the EfW facility in covered trucks or via an enclosed conveyor from the Genesis facility. The EfW facility will employ high speed roller doors for truck access to ensure fugitive odour emissions are minimal. All residual waste fuel storage and unloading will take place within the tipping hall building, which is kept at negative pressure with air extracted from the building will be used as excess air in the boiler. Odour emissions from the EfW facility have been addressed in a stand-alone quantitative assessment **(Pacific Environment, 2017a)**. The results of this assessment show that the odour concentrations would be below the impact assessment criterion of 2 ou.

6.10 Fugitive Dust Emissions

As discussed in **Section 2**, residual waste fuel would be transported onsite via sealed roads. The use of sealed roads is considered an effective management strategy in the reduction of fugitive dust emissions, specifically those related to wheel generated dust emissions.

As already discussed, the tipping hall building will also operate under negative pressure whereby air within the building will be used as excess air for the boilers, limiting the release fugitive dust emissions generated within the shed to the ambient environment (as this will subsequently pass through the FGT's bag house).

On the basis of the above, the EfW facility is considered to have minimal potential for the generation of fugitive dust emissions provided good dust management practices are adhered to. Therefore this aspect has not been addressed further.

6.11 Emissions from Trucks Entering the Site

As discussed in **Section 2.1**, a maximum of 126 trucks would enter the site per day, resulting in localised diesel vehicle emissions with the air quality metrics of interest being NO_x, CO, $PM_{2.5}$, SO_x and VOCs. These additional emission sources are anticipated to be negligible in view of the location of the Project abutting the M4 and M7 motorways (see **Figure 3-1**).

For example, the average daily traffic count for 2016 on the M4 at Homebush is 88,700 vehicles and at near Penrith (north of Loftus Street) is 59,600 vehicles per day (**RMS, 2016**) (no traffic data were available for Eastern Creek or for the M7 Motorway). The additional truck movements associated with the Project equates to a 0.1% to 0.2% increase of vehicles per day. Such a small change in vehicle numbers is anticipated to make a non-discernible difference in local air quality.

Furthermore, not only are some of the closest residential residences situated in much closer proximity to the respective motorways, but the motorways also are located between the Project and the majority of these receptors.

6.12 Construction

The main air pollution and amenity issues at construction sites are:

- Annoyance due to dust deposition (soiling of surfaces) and visible dust plumes.
- Elevated PM_{10} concentrations due to dust-generating activities.
- Exhaust emissions from diesel-powered construction equipment.

Exhaust emissions from on-site plant and site traffic are unlikely to have a significant impact on local air quality, and in the majority of cases they will not need to be quantitatively assessed (**IAQM, 2014**). Very high levels of soiling can also damage plants and affect the health and diversity of ecosystems.

Dust emissions can occur during the preparation of the land (*e.g.* demolition and earth moving) and during construction itself, and can vary substantially from day to day depending on the level of activity, the specific operations being undertaken, and the weather conditions. A significant portion of the emissions results from site plant and road vehicles moving over temporary roads and open ground. If mud is allowed to get onto local public roads, dust emissions can occur at some distance from the construction site **(IAQM, 2014)**.

The risk of dust impacts from a demolition/construction site causing loss of amenity and/or health or ecological impacts is related to the following **(IAQM, 2014)**:

- The nature of the activities being undertaken.
- The duration of the activities.

- The size of the site.
- The meteorological conditions (wind speed, direction and rainfall). Adverse impacts are more likely to occur downwind of the site and during drier periods.
- The proximity of receptors to the activities.
- The sensitivity of the receptors to dust.
- The adequacy of the mitigation measures applied to reduce or eliminate dust.

It is difficult to quantify dust emissions from construction activities. Due to the variability of the weather it is impossible to predict what the weather conditions would be when specific construction activities are undertaken. Any effects of construction on airborne particle concentrations would also generally be temporary and relatively short-lived. Moreover, mitigation should be straightforward, as most of the necessary measures are routinely employed as 'good practice' on construction sites.

Construction dust impacts are typically assessed as a qualitative assessment. The impacts of construction have not been modelled; rather a risk based approach is used based on a method outlined in **IAQM (2014)**. The IAQM guidance is designed primarily for use in the UK, although it may be applied elsewhere.

6.12.1 Construction Activities

Activities on construction sites can be divided into three types to reflect their different potential impacts, and the potential for dust emissions is assessed for each activity that is likely to take place. It is noted that there will be no demolition and therefore demolition works is not assessed.

The activities considered are:

- Earthworks. This covers the processes of soil stripping, ground levelling, excavation and landscaping. Earthworks will primarily involve excavating material, haulage, tipping and stockpiling.
- Construction. Construction is any activity that involves the provision of new structures, modification or refurbishment. A structure will include a residential dwelling, office building, retail outlet, road, etc.
- Track-out. This involves the transport of dust and dirt by HDVs from the construction/demolition site onto the public road network, where it may be deposited and then re-suspended by vehicles using the network.

The construction works will follow a staged approach as summarised in **Table 6-10**.

Table 6-10: EfW facility construction timeframes

Stage	Activity	Timeframe
Stage 1	Site establishment and clearance	2 weeks
Stage 2	Excavation/Services Lead-in	6-10 months
Stage 3	Structure	5 months
Stage 4	Technology provider plant Installation Structural Steel Works	16-18 months 4-6 months
Stage 5	Façade/Roofing	4 months
Stage 6	Fit out/Landscaping	5 months

6.12.2 Assessment Procedure

The IAQM assessment procedure for assessing risk is shown in **Figure 6-1**. The assessment is used to define appropriate mitigation measures to ensure that there will be no significant effect.

The assessment methodology considers three separate dust impacts:

- Annoyance due to dust soiling.

- The risk of health effects due to an increase in exposure to PM_{10}.
- Harm to ecological receptors.

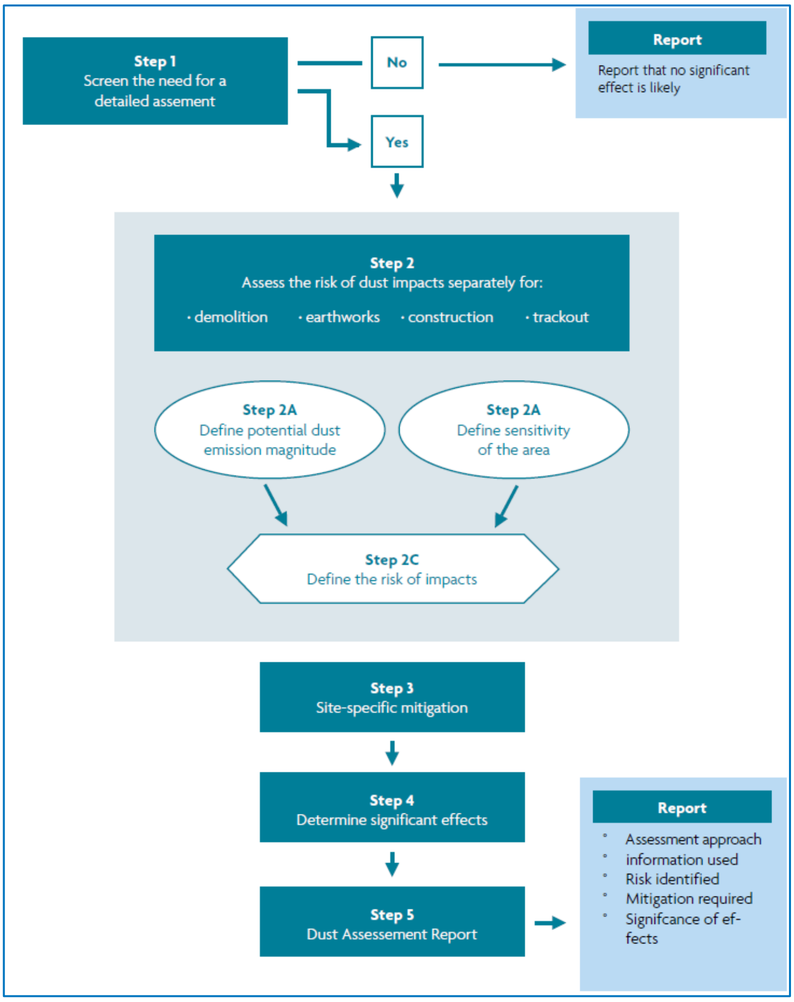

Figure 6-1: Steps in an assessment of construction dust (IAQM, 2014)

6.12.3 Assessment

Step 1 is a screening assessment to determine if detailed assessment is required. A construction dust assessment will normally be required where:

- There are human receptors within 350 m of the boundary of the site and/or within 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s).
- There are ecological receptors within 50 m of the boundary of the site and/or within 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s).

A 'human receptor', refers to any location where a person or property may experience the adverse effects of airborne dust or dust soiling, or exposure to PM_{10} over a time period relevant to air quality standards and goals. In terms of annoyance effects, this will most commonly relate to dwellings, but may also refer to other premises such as buildings housing cultural heritage collections (e.g. museums and galleries), vehicle showrooms, food manufacturers, electronics manufacturers, amenity areas and horticultural operations (e.g. salad or soft-fruit production). An 'ecological receptor' refers to any sensitive habitat affected by dust soiling. This includes the direct impacts on vegetation or aquatic ecosystems of dust deposition, and the indirect impacts on fauna (e.g. on foraging habitats) **(IAQM, 2014)**.

The construction footprint and nearest receptors are shown in **Figure 6-2**. In the context of the site, the nearest human receptors are works at the Genesis Xero MPC and the adjacent Hanson site. In the case of Genesis Xero MPC, the site is likely already exposed to dust arising from proximity to the former quarry and the operation of waste processing facility. In the case of the Hanson, it is noted that the site is currently vacant. Residential receptors are located at some distance, 1 km to the west and north well beyond the 350m buffer.

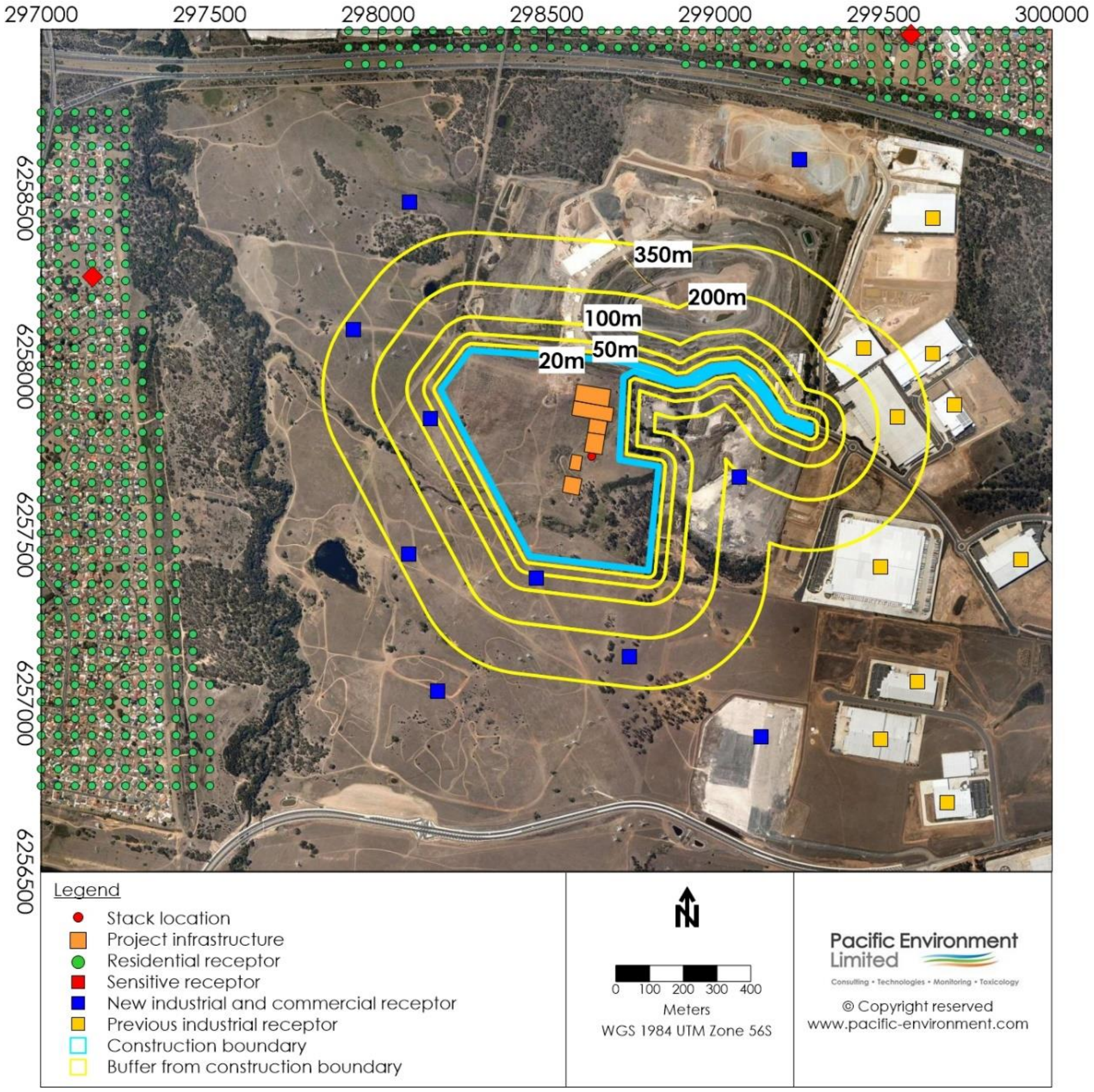

Figure 6-2: EfW Project construction footprint and nearest receptors

As the proposal involves the removal of existing vegetation from the site (and vegetation on the adjacent Hanson site has been approved for removal) there is limited potential to affect ecological receptors. The Ropes Creek Tributary to the south, despite its degraded state would be considered an ecological receptor.

As both human and ecological receptors were assumed to be located within a 350m buffer of the construction footprint a detailed assessment of the potential dust impacts from construction has been completed. Several assumptions were made in the assessment and include:

- In accordance with the scale of works risk categories defined by the **IAQM (2014)** it was assumed that demolition activities would be rated 'small' and earthworks, construction and track-out activities would be rated 'medium'.
- It has been assumed that all 'new industrial and commercial receptors' and 'old industrial receptors' would comprise 20 humans.
- Human receptors were rated with a high level of receptor sensitivity and the ecological receptor rated with a low level of sensitivity.

The results of the risk assessment are provided in **Table 6-11**. Demolition activities were both evaluated to be of negligible risk to human and ecological receptors while earthworks, construction and track-out were all determined to be of low risk.

Table 6-11: Summary of construction risk assessment

Type of activity	Step 2a: Potential for dust emissions	Step 2b: Sensitivity of area			Step 2c: Risk of dust impacts		
		Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Small	Low	Low	Low	Negligible	Negligible	Negligible
Earthworks	Medium	Low	Low	Low	Low Risk	Low Risk	Low Risk
Construction	Medium	Low	Low	Low	Low Risk	Low Risk	Low Risk
Track-out	Medium	Low	Low	Low	Low Risk	Low Risk	Low Risk

The proposed management strategies are outline in **Table 6-12**, which detail the issue, proposed mitigation measure and the applicable timing in the development process. Most of the recommended measures are routinely employed as 'good practice' on construction sites. At the airport site, particular attention should be paid to controlling dust generated by track-out due to the overall level of risk and the potential proximity to sensitive receptors.

A Dust Management Plan (DMP) should be developed to address the construction of the proposed airport. This document would form part of the overarching Construction Environmental Management Plan (CEMP). This should contain details of the site-specific mitigation measures to be applied. Additional guidance on the control of dust at construction sites is provided as part of the NSW EPA Local Government Air Quality Toolkit[k]. Detailed guidance is also available from the UK **(GLA, 2006)** and the United States **(Countess Environmental, 2006)**. It is assumed that routinely employed 'good practice' mitigation measures for construction sites would be sufficient to control dust impacts to acceptable levels. Such methods would include, but not be limited to the use of water sprays to suppress dust, stockpile management and planting of native couch grass at the lay down pads as soon as practicable following completion of works.

Table 6-12: Construction mitigation measures

Mitigation measure	Action for site risk
Mitigation for all sites: Communications	

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[k] http://www.epa.nsw.gov.au/air/lgaqt.htm

Mitigation measure		Action for site risk
2	Display the name and contact details of person(s) accountable for air quality and dust issues on the site boundary. This may be the environment manager/engineer or the site manager.	Highly recommended
3	Display the head or regional office contact information	Highly recommended
Mitigation for all sites: Dust management		
4	Develop and implement a Dust Management Plan (DMP), which may include measures to control other emissions, approved by the local authority. The level of detail will depend on the risk, and should include as a minimum the highly recommended measures in this document. The desirable measures should be included as appropriate for the site. The DMP may include monitoring of dust deposition, dust flux, real time PM_{10} continuous monitoring and/or visual inspections.	Desirable
Site management		
5	Record all dust and air quality complaints, identify cause(s), take appropriate measures to reduce emissions in a timely manner, and record the measures taken.	Highly recommended
6	Make the complaints log available to the local authority when asked.	Highly recommended
7	Record any exceptional incidents that cause dust and/or air emissions, either on- or offsite, and the action taken to resolve the situation in the log book.	Highly recommended
Monitoring		
9	Undertake daily on-site and off-site inspection, where receptors (including roads) are nearby, to monitor dust, record inspection results, and make the log available to the local authority when asked. This should include regular dust soiling checks of surfaces such as street furniture, cars and window sills within 100m of site boundary, with cleaning to be provided if necessary.	Desirable
10	Carry out regular site inspections to monitor compliance with the DMP, record inspection results, and make an inspection log available to the local authority when asked	Highly recommended
11	Increase the frequency of site inspections by the person accountable for air quality and dust issues on site when activities with a high potential to produce dust are being carried out and during prolonged dry or windy conditions.	Highly recommended
12	Agree dust deposition, dust flux, or real-time PM_{10} continuous monitoring locations with the local authority. Where possible commence baseline monitoring at least three months before work commences on site or, if it a large site, before work on a phase commences.	Not required
Preparing and maintaining the site		
13	Plan site layout so that machinery and dust causing activities are located away from receptors, as far as is possible.	Highly recommended
14	Erect solid screens or barriers around dusty activities or the site boundary that are at least as high as any stockpiles on site.	Highly recommended
15	Fully enclose site or specific operations where there is a high potential for dust production and the site is actives for an extensive period	Desirable
16	Avoid site runoff of water or mud.	Highly recommended
17	Keep site fencing, barriers and scaffolding clean using wet methods.	Desirable
18	Remove materials that have a potential to produce dust from site as soon as possible, unless being re-used on site. If they are being re-used on-site cover as described below.	Desirable
19	Cover, seed or fence stockpiles to prevent wind whipping.	Desirable
Operating vehicle/machinery and sustainable travel		

Mitigation measure		Action for site risk
20	Ensure all on-road vehicles comply with the requirements of the London Low Emission Zone and the London NRMM standards, where applicable	Highly recommended
21	Ensure all vehicles switch off engines when stationary - no idling vehicles.	Highly recommended
22	Avoid the use of diesel or petrol powered generators and use mains electricity or battery powered equipment where practicable.	Highly recommended
23	Impose and signpost a maximum-speed-limit of 15 mph on surfaced and 10 mph on unsurfaced haul roads and work areas (if long haul routes are required these speeds may be increased with suitable additional control measures provided, subject to the approval of the nominated undertaker and with the agreement of the local authority, where appropriate)	Desirable
Operations		
26	Only use cutting, grinding or sawing equipment fitted or in conjunction with suitable dust suppression techniques such as water sprays or local extraction, e.g. suitable local exhaust ventilation systems.	Highly recommended
27	Ensure an adequate water supply on the site for effective dust/particulate matter suppression/mitigation, using non-potable water where possible and appropriate.	Highly recommended
28	Use enclosed chutes and conveyors and covered skips.	Highly recommended
29	Minimise drop heights from conveyors, loading shovels, hoppers and other loading or handling equipment and use fine water sprays on such equipment wherever appropriate.	Highly recommended
30	Ensure equipment is readily available on site to clean any dry spillages, and clean up spillages as soon as reasonably practicable after the event using wet cleaning methods.	Desirable
Waste management		
31	Avoid bonfires and burning of waste materials	Highly recommended
Mitigation specific to construction		
39	Avoid scabbling (roughening of concrete surfaces) if possible.	Desirable
40	Ensure sand and other aggregates are stored in bunded areas and are not allowed to dry out, unless this is required for a particular process, in which case ensure that appropriate additional control measures are in place.	Desirable
41	Ensure bulk cement and other fine powder materials are delivered in enclosed tankers and stored in silos with suitable emission control systems to prevent escape of material and overfilling during delivery.	Not required
42	For smaller supplies of fine power materials ensure bags are sealed after use and stored appropriately to prevent dust.	Not required
Mitigation specific to track-out		
43	Use water-assisted dust sweeper(s) on the access and local roads, to remove, as necessary, any material tracked out of the site. This may require the sweeper being continuously in use.	Desirable
44	Avoid dry sweeping of large areas.	Desirable
45	Ensure vehicles entering and leaving sites are covered to prevent escape of materials during transport.	Desirable
47	Record all inspections of haul routes and any subsequent action in a site log book.	Desirable

	Mitigation measure	Action for site risk
49	Implement a wheel washing system (with rumble grids to dislodge accumulated dust and mud prior to leaving the site where reasonably practicable).	Desirable

7 MODELLING APPROACH

The overall approach to the assessment has followed the Approved Methods using the Level 2 assessment methodology. The Approved Methods specify how assessments based on the use of air dispersion models should be completed. They include guidelines for the preparation of meteorological data to be used in dispersion models and the relevant air quality criteria for assessing the significance of predicted concentration and deposition rates from the EfW facility. The approach taken in this assessment has followed as closely as possible the approaches provided within the Approved Methods.

7.1 Dispersion model

7.1.1 Model overview

AERMOD was chosen as a suitable dispersion model due to the source type, location of nearest receiver and nature of local topography. AERMOD is the US EPA's recommended steady-state plume dispersion model for regulatory purposes. AERMOD replaced the Industrial Source Complex (ISC) model for regulatory purposes in the US in December 2006. Ausplume, a steady state Gaussian plume dispersion model developed by the Victorian EPA and frequently used in Australia for simple near-field applications is based on ISC, which has now been replaced by AERMOD. While AERMOD has not been explicitly listed as an approved model by the EPA in the Approved Methods, AERMOD has been used for a number of assessments that have been approved by NSW EPA (**Pacific Environment 2013a; 2013b**).

The AERMOD dispersion model is anticipated to be the most widely used atmospheric dispersion model internationally, and has been the subject of many validation exercises to confirm its satisfactory performance for both calm conditions and tall stack applications using standard model validation data sets further discussed below.

7.1.2 Model justification

In NSW, over and above guidance provided within the Approved Methods, dispersion model selection is not prescriptive. Rather, some flexibility in the selection of the most appropriate model for a particular application is provided, based on professional judgement. The current version of the Approved Methods (**NSW EPA 2016**) specifies AUSPLUME (a steady state model), CALPUFF (non-steady state model) and TAPM (non-steady state model) as appropriate models for NSW applications. The Approved Methods specifies that AUSPLUME is not approved for the following applications:

- complex terrain, non-steady-state conditions
- buoyant line plumes
- coastal effects such as fumigation
- high frequency of stable calm night-time conditions
- high frequency of calm conditions
- inversion break-up fumigation conditions.

Under the above conditions it is considered appropriate to use a more complex non-steady state model (i.e. CALPUFF or TAPM). However, the conditions described above are not applicable for this application. The Project site is located in flat terrain free from complex interactions from night time drainage flows, significant terrain or coastal effects. It is acknowledged that there is a prevalence of calm conditions in the area (24.7% in 2013). It is highlighted that this percentage of calms is reflective of observations at 10m. Such conditions are not expected to be relevant for the current application which principally relates to point source emissions at 100m aloft. The frequency of calm conditions is discussed further in terms of the dispersion meteorology (see **Section 8.2.1**).

Industry wide, the steady-state option of AUSPLUME has been replaced by the AERMOD dispersion modelling system and is now approved for regulatory purposes in Victoria **(EPA Victoria, 2017)**.

The AERMOD model was developed, and is supported by the US EPA and is now the model of choice for nearfield (less than 50 km from an emission source) applications in the United States **(US EPA, 2017)**. Furthermore, the US EPA no longer endorses CALPUFF as the preferred model for long range sources (greater than 50km from an emissions source), with this modelling system now considered a screening technique.

As part of the US EPA's process in endorsing AERMOD **Paine *et al.* (1998)** evaluated the use of AERMOD for a number of tall stack scenarios across the United States. **Paine *et al.* (1998)** identified that AERMOD generally has a tendency to *over-predict* across the range of model validation databases that were evaluated. Apparent under predictions for annual averages were found likely to be artefacts of the low concentrations (i.e. close to the instrument thresholds) within the validation databases and the uncertainty in determining background concentrations that need to be subtracted from the reported total concentrations to allow for an annual average validation exercise.

7.1.3 AERMOD model inputs

A significant feature of AERMOD is the Pasquil-Gifford stability based dispersion is replaced with a turbulence-based approach that uses the Monin-Obukhov length scale to account for the effects of atmospheric turbulence based dispersion.

The AERMOD system includes AERMET, used for the preparation of meteorological input files and AERMAP, used for the preparation of terrain data. Ground level concentrations were modelled across a 10km by 10km domain at 100m resolution. The size of the modelling domain is considered adequate to capture the maximum predicted ground level concentrations associated with the Project's activities, including emissions from the proposed 100m stack.

Terrain data was sourced from NASA's Shuttle Radar Topography Mission Data (3 arc second [~90m] resolution) and processed to create the necessary input files.

AERMET requires surface and upper air meteorological data as input. Wind speed, wind direction, temperature, relative humidity and sea level pressure were sourced from the EPA St Marys meteorological station. Cloud cover and cloud height were sourced from the BoM Bankstown Airport AWS. In the absence of upper air sounding data for the area, upper air parameters were calculated using the upper air estimator (UAE) within the Lakes Environment AERMODview software package. The use of the UAE in AERMOD is further discussed in **Section 8.2.1**.

Appropriate values for three surface characteristics are required for AERMET as follows:

- Surface roughness, which is the height at which the mean horizontal wind speed approaches zero, based on a logarithmic profile.
- Albedo, which is an indicator of reflectivity of the surface.
- Bowen ratio, which is an indicator of surface moisture.

Values of surface roughness, albedo and Bowen ratio were determined based on a review of aerial photography for a radius of 3 km centred on the EPA St Marys station. Default values for cultivated land and urban areas were chosen over two sectors across this area.

7.2 Building Wake Effects

Wind flow is often disrupted in the immediate vicinity of buildings. Plumes emitted nearby are assumed to be unaffected by building wakes if they manage to reach building height plus 1.5 times the lesser of building height or projected building width. If this is not the case, pollutants can be brought to ground within a highly turbulent, generally recirculating cavity region in the immediate lee of the building and/or be subject to plume downwash and enhanced dispersion in a turbulent region which extends further downwind behind the building.

A simplified building geometry was incorporated for simulation of building wake effects, modelled using BPIP-PRIME model, as shown in **Figure 7-1**. BPIP-PRIME uses heights and corner locations of buildings in the vicinity of the plume to simulate the effective height and width of the structures. The downwash algorithm calculates effective building dimensions relative to the plume, resolved down to ten degree intervals. AERMOD then calculates the impact of these buildings on plume dispersion and consequently on GLCs.

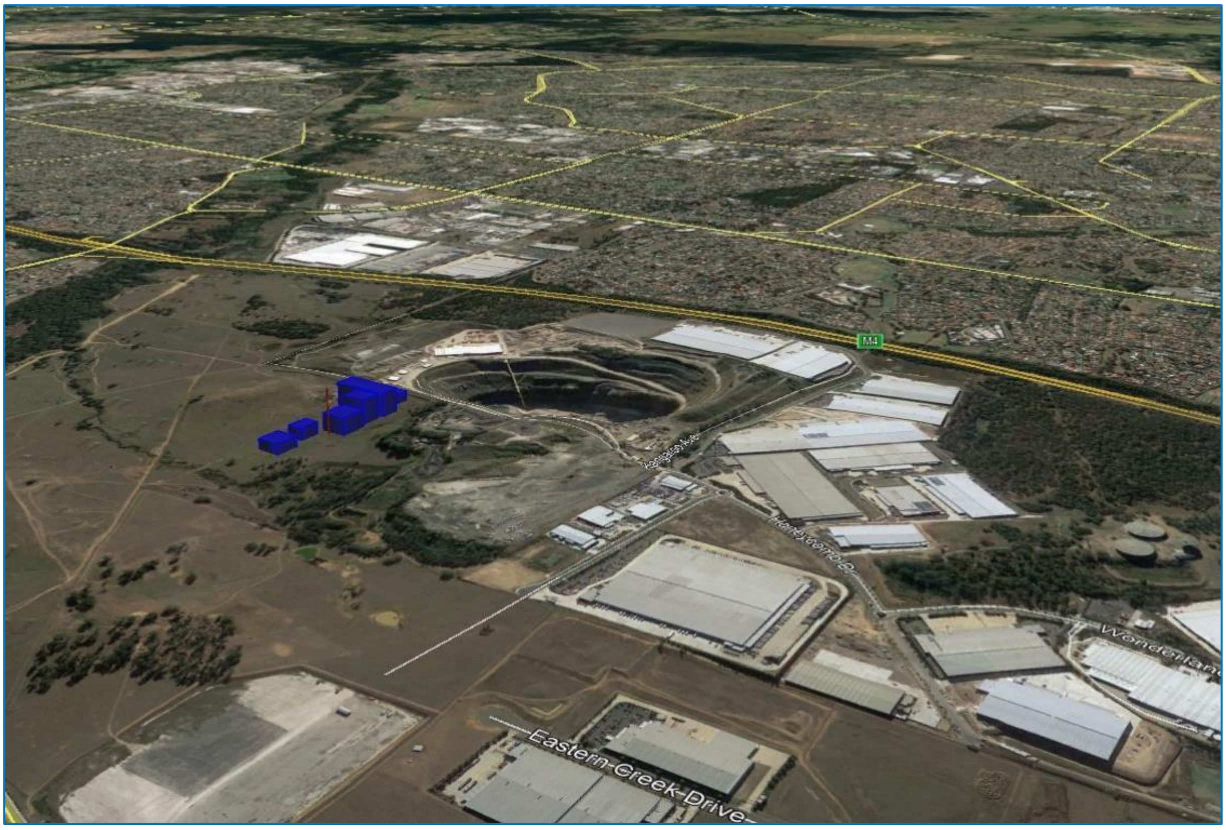


Figure 7-1: Visualisation of the Incorporation of EfW Building Dimensions within the Model

7.3 Sub-hourly Predictions

The AERMOD model outputs ground level concentration predictions for averaging periods of 1-hour and greater. The assessment of SO_2 and CO requires estimation of pollutant concentrations over 10-minute and 15-minute averaging periods, respectively.

Hourly averaged model predictions have been converted to 10-minute and 15-minute averaging periods using the power law conversion provided in the EPA Victoria draft guideline *Guidance notes for using the regulatory air pollution model AERMOD in Victoria* **(EPA Victoria, 2013)**. This conversion accounts for fluctuations in pollutant levels within the larger averaging period, and is provided below for SO_2:

$$C_{10\text{-minute}} = C_{1\text{-hour}} \times (60/10)^{0.2} = 1.43$$

Where:
$C_{1\ hour}$ is the 1 hour average prediction.
C10-minute is the 10-minute average prediction. In applying this for CO, the factor is 1.32

This method was also adopted to extrapolate sub-hourly air quality monitoring data presented in **Section 5.4** and **Section 5.5** for SO_2 and CO, respectively.

8 DISPERSION METEOROLOGY

8.1 Review of available meteorological stations

Air quality impacts are influenced by meteorological conditions, primarily in the form of gradient wind flow regimes, and by local conditions generally driven by topographical features and interactions with coastal influences, such as the sea breeze. The local dispersion meteorology for the site, in relation to wind speed and direction, has been reviewed based on the data available at nearby meteorological stations.

The Bureau of Meteorology (BoM) collects climatic information at the Horsley Park Equestrian Centre Automatic Weather Station (AWS), located approximately 6 km southeast of the site. The NSW Office of Environment and Heritage (OEH) operate a meteorological station at St Marys, located approximately 5 km west and at Prospect, located approximately 6 km east of the Project.

The closest site and most representative location in terms of land use and surface roughness is the OEH monitoring site at St Marys. Annual and seasonal wind roses for 2013 at St Marys are shown in **Figure 8-2**. The dominant annual winds are from the south and south-southwest with a significant portion also from the north-northwest. This pattern is similar in all seasons with summer also showing a proportion of winds from the southeast. The percentage calms (defined as wind speeds less than 0.5 m/s) was 24.7% for 2013.

8.2 Representative year for modelling

As specified in the Approved Methods, five years of meteorological data are required to be reviewed so that a representative year of meteorological conditions can be selected. **Appendix F** provides an analysis of the five years of meteorological data from St Marys. Data from the Horsley Park Equestrian Centre was used to analyse rainfall trend as this parameter was not available from St Marys. The review identified 2013 as a representative year for dispersion modelling with no anomalous wind patterns compared to the other years examined and is therefore considered a representative year for dispersion modelling.

8.2.1 Calm conditions and wind speed aloft

The prevalence of calm conditions in the western Sydney area is shown to be a common feature of the meteorology in the vicinity of the EfW facility. The percentage of calms measured at the St Marys ranged between 20.4% and 24.7% annually. However, as noted above, these wind observations are made at 10m above ground level.

The principal atmospheric emissions of concern from the Project would be occurring via a point (i.e. stack) source at 100m above ground level where wind speeds are significantly higher and calm conditions far less frequent.

The observed calm conditions are most common during autumn and winter and are often a function of temperature inversions that also occur during these cooler months.

In view of the slightly higher percentage of calm conditions for 2013 measured at St Marys, using these data for dispersion modelling will provide an additional level of conservatism in the prediction of ground level pollutant concentrations.

It is highlighted that the AERMOD modelling system allows for wind speed and direction variation in the vertical, through reference to a ‘surface’ meteorological input file, and a ‘profile’ input file (characterising winds aloft). The profile input file contains information on the (logarithmic) increase in wind speed with height. Thus, it is noted that the wind speeds interacting with the stack exit (100m aloft) do not reflect any calm observation occurring within the surface input file.

To demonstrate this, the wind speed predictions were extracted from the AERMOD model profile file at 100m above ground level (agl), the same height as the point of release of the EfW facility stack and compared with those from the surface file (10m agl). The results are shown in **Figure 8-1**.

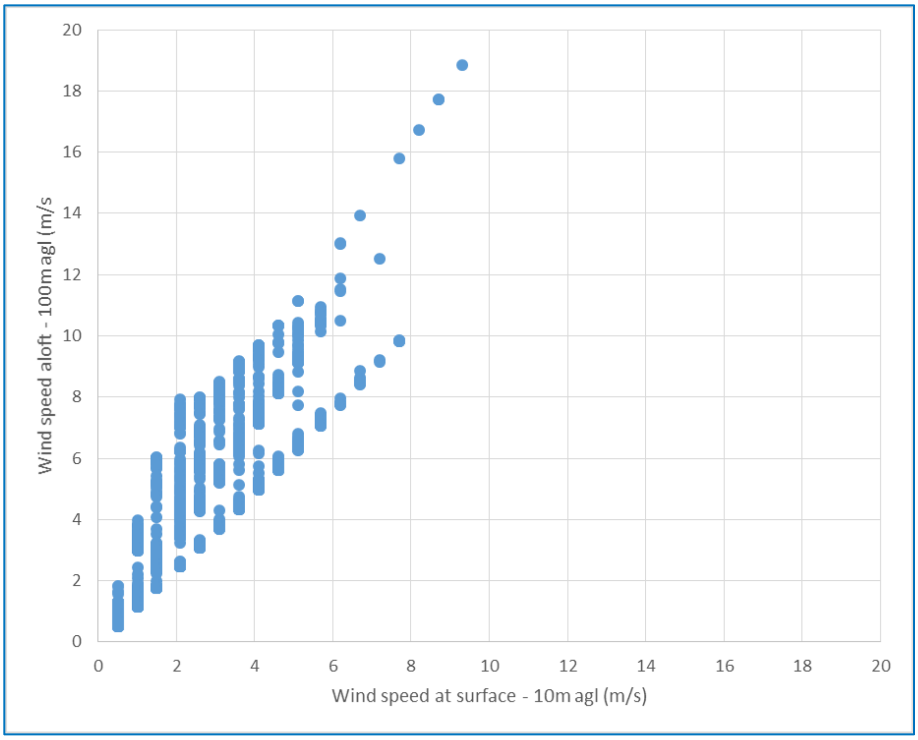


Figure 8-1: Hourly wind speed at surface versus 100m aloft

Figure 8-1 shows that there are no hours where calm wind speeds are predicted at 100m above the ground. The data also demonstrate the significant increase in wind speed in general at layers aloft.

It has been previously identified that the calculation of convective mixing height can be compromised during unstable hours as a result of calm conditions present in the surface file when using AERMOD's UAE. This may result in the under prediction of ground level impacts from tall stacks, as demonstrated by **Rayner (2013)**.

To overcome this issue, all wind speeds below 0.5 m/s were treated at being 0.5m/s, thus removing the potential effect of null convective mixing height data in the AERMOD model. This approach was adopted for the modelling work completed in May 2017. Therefore the results presented in previous air quality assessment for this project **(Pacific Environment, 2015; 2016)** are not directly comparable to those presented in this assessment.

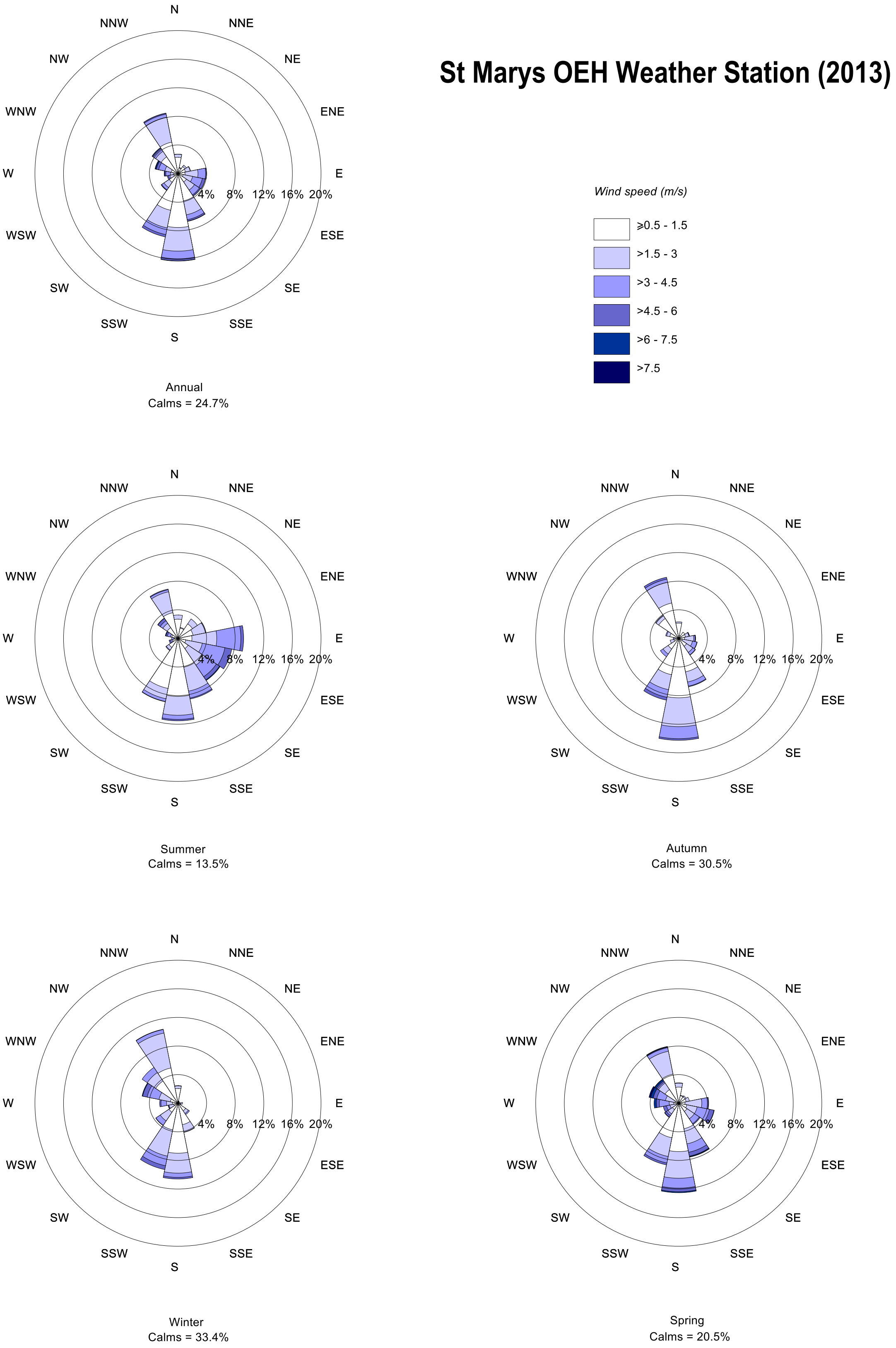


Figure 8-2: Wind roses for St Marys (2013)

8.3 Atmospheric Stability

An important aspect of pollutant dispersion is the level of turbulence in the lowest 1 km or so of the atmosphere, known as the planetary boundary layer (PBL). Turbulence controls how effectively a plume is dispersed into the surrounding air and hence diluted. It acts by increasing the cross-sectional area of the plume due to random motions. With stronger turbulence, the rate of plume dispersion increases. Weak turbulence limits dispersion and contributes to high plume concentrations downwind of a source.

Turbulence is generated by both thermal and mechanical effects to varying degrees. Thermally driven turbulence occurs when the surface is being heated, in turn transferring heat to the air above by convection. Mechanical turbulence is caused by the frictional effects of wind moving over the earth's surface, and depends on the roughness of the surface as well as the flow characteristics.

Turbulence in the boundary layer is influenced by the vertical temperature gradient, which is one of several indicators of stability. Plume models use indicators of atmospheric stability in conjunction with other meteorological data to estimate the dispersion conditions in the atmosphere.

Stability can be described across a spectrum ranging from highly unstable through neutral to highly stable. A highly unstable boundary layer is characterised by strong surface heating and relatively light winds, leading to intense convective turbulence and enhanced plume dispersion. At the other extreme, very stable conditions are often associated with strong temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning. Under these conditions plumes can remain relatively undiluted for considerable distances downwind. Neutral conditions are linked to windy and/or cloudy weather, and short periods around sunset and sunrise, when surface rates of heating or cooling are very low.

The stability of the atmosphere plays a large role in determining the dispersion of a plume and it is important to have it correctly represented in dispersion models. Current air quality dispersion models (such as AERMOD and CALPUFF) use the Monin-Obukhov Similarity Theory (MOST) to characterise turbulence and other processes in the PBL. One of the measures of the PBL is the Monin-Obukhov length (L), which approximates the height at which turbulence is generated equally by thermal and mechanical effects (**Seinfeld and Pandis 2006**). It is a measure of the relative importance of mechanical and thermal forcing on atmospheric turbulence.

Because values of L diverge to + and - infinity as stability approaches neutral from the stable and unstable sides, respectively, it is often more convenient to use the inverse of L (i.e., 1/L) when describing stability.

Figure 8-3 shows the hourly averaged 1/L for the Project site computed from all data in the AERMET surface file. Based on Figure 8-3**,** this plot indicates that the PBL is stable overnight and becomes unstable as radiation from the sun heats the surface layer of the atmosphere and drives convection. The changes from positive to negative occur at the shifts between day and night. This indicates that the diurnal patterns of stability are realistic.

Table 8-1: Inverse of the Monin-Obukhov length L with respect to Atmospheric stability

1/L	Atmospheric Stability
Negative	Unstable
Zero	Neutral
Positive	Stable

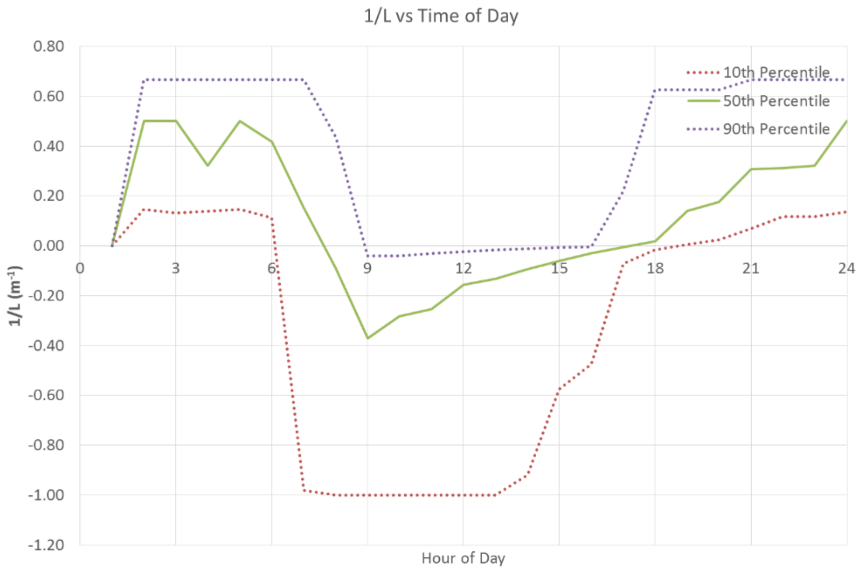


Figure 8-3: Annual statistics of 1/L by hour of the day

Figure 8-4 shows the variations in stability over the year by hour of the day, with reference to the widely known Pasquill-Gifford classes of stability. The relationship between L and stability classes is based on values derived by **Golder (1972)** set out in **NSW EPA (2016).** Note that the reference to stability categories here is only for convenience in describing stability. The model uses calculated values of L across a continuum.

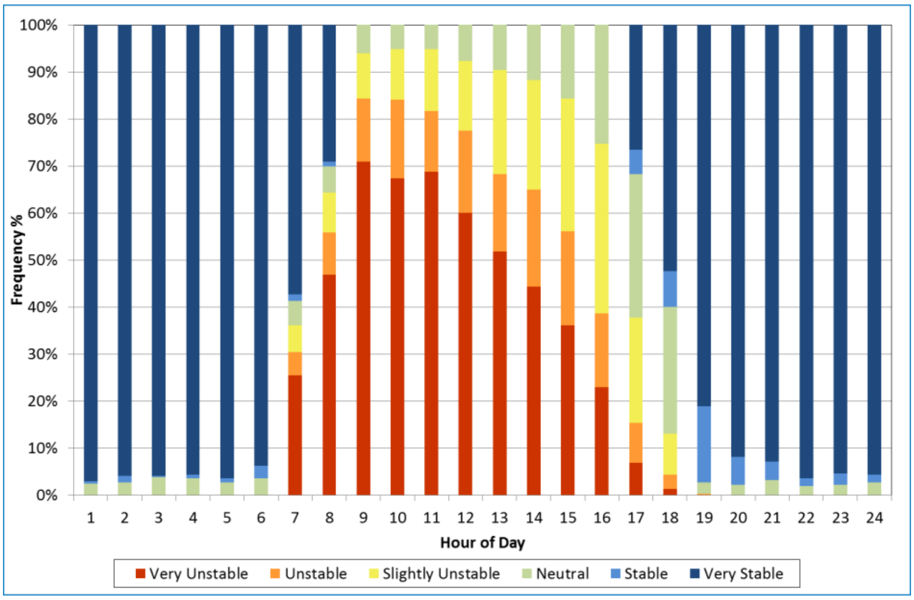


Figure 8-4: Annual distribution of stability type by hour of the day

Figure 8-4 shows that stable and very stable conditions occur for about 50% of the time, which is typical for inland locations that regularly experience temperature inversions at night. Atmospheric instability increases during the day and reaches a peak around noon as solar-driven convective energy peaks. A stable atmosphere is prevalent during the night. These profiles indicate that pollutant dispersion is most effective during the daytime and least effective at night.

Values of surface roughness, albedo and Bowen ratio were determined based on a review of aerial photography for a radius of 3 km centred on the EPA St Marys station. Default values for cultivated land and urban areas were chosen over two sectors across this area. The default values for these three surface characteristics required for AERMET are as follows:

- Surface roughness, which is the height at which the mean horizontal wind speed approaches zero, based on a logarithmic profile. Values adopted = 1.0 (urban) and 0.07 (cultivated land)
- Albedo, which is an indicator of reflectivity of the surface. Values adopted = 0.2075 (urban) and 0.28 (cultivated land)
- Bowen ratio, which is an indicator of surface moisture. Values adopted = 1.625 (urban) and 0.75 (cultivated land).

9 LOCAL AIR QUALITY ASSESSMENT

The concentrations of the air quality parameters assessed in this study were determined for 52 boundary receptors and 5,038 sensitive receptors which are defined in **Section 3.** In view of the of very large number of sensitive receptors that have been addressed in this assessment, results have been limited to the most affected boundary receptor and most affected sensitive receptor. Tabulated results for all 5,090 receptors are available in spreadsheet format upon request.

Contour plots have also been prepared to show the spatial distribution of the assessed pollutants, and these are provided in **Section 9.1**. Contour plots of pollutant concentrations show the areas that are predicted to be affected by the EfW Project under worst-case dispersion conditions. It is important to note that the contour figures are presented to provide a visual representation of the predicted (worst-case) impacts spatially. To produce the contours it is necessary to make interpolations, and as a result the contours will not always match exactly with predicted impacts at any specific location.

A number of air quality metrics were included in the emissions list provided by Ramboll (see **Appendix G**) are not regulated under the Approved Methods. However, these data are required for the stand-alone Health Risk Assessment (**AECOM, 2017**) in maximum 1-hour, 24-hour and annual averaging periods. The modelled results for all 5,090 receptors (boundary and sensitive) was provided to AECOM in spreadsheet format. Given the very large number of results tables required for all receptors, presentation of these results has been limited to the prediction at the grid maximum (outside of the project boundary)for each scenario and relevant air quality metric and are provided in **Appendix J**.

9.1 Incremental Ground Level Concentrations

9.1.1 Scenario 1 - Expected

A summary of the predicted ground level concentration (GLC) for each pollutant is presented in **Table 9-1**. GLCs are presented at and beyond the site boundary, as well as the maximum prediction at sensitive receptors.

Contour plots of predicted GLCs are presented **Figure 9-1** to **Figure 9-13**.

Table 9-1: Summary of predicted ground level concentrations during expected operations

Pollutant	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
NO$_2$ (a)	1 hour	µg/m^3	246	15.8	12.4
	Annual	µg/ m^3	62	0.78	0.71
SO$_2$	10-minute	µg/ m^3	712	5.1	4.0
	1 hour	µg/ m^3	570	3.6	2.8
	24 hours	µg/ m^3	228	0.9	0.6
	Annual	µg/ m^3	60	0.2	0.2
CO	15-minute	mg/ m^3	100	0.004	0.003
	1 hour	mg/ m^3	30	0.003	0.002
	8 hours	mg/ m^3	10	0.002	0.001
PM$_{10}$	24 hours	µg/ m^3	50	0.03	0.02
	Annual	µg/ m^3	25	0.01	0.01
PM$_{2.5}$	24 hours	µg/ m^3	25	0.03	0.02
	Annual	µg/ m^3	8	0.01	0.01
HCl	1 hour	mg/ m^3	0.14	0.001	0.001
HF	24 hours	µg/ m^3	2.9	0.02	0.01
	7 days	µg/ m^3	1.7	0.007	0.006
	30 days	µg/ m^3	0.84	0.005	0.005
	90 days	µg/ m^3	0.5	0.004	0.004
Cd (b)	1 hour	mg/ m^3	0.000018	1.1E-06	7.2E-07
Hg (b)	1 hour	mg/ m^3	0.00018	4.8E-07	3.2E-07
Dioxins and furans (b)	1 hour	mg/ m^3	0.000000002	1.2E-12	8.0E-13
Benzene(b)	1 hour	mg/ m^3	0.029	1.8E-06	1.2E-06
Toluene(c)	1 hour	mg/ m^3	0.19	2.1E-06	1.8E-06
Xylene(c)	1 hour	mg/ m^3	0.36	7.2E-07	6.1E-07
NH$_3$ (b)	1 hour	mg/ m^3	0.33	2.4E-04	1.6E-04
H$_2$S (c)	1 hour	µg/ m^3	1.38	0.07	0.06
PAH (as benzo(a)pyrene) (b)	1 hour	mg/ m^3	0.0004	6.0E-08	4.0E-08
Dichloro-methane(b)	1 hour	mg/ m^3	3.19	2.4E-06	1.6E-06
Acetone (propanone) (b)	1 hour	mg/ m^3	22	2.2E-06	1.4E-06
Trichloro-ethylene(b)	1 hour	mg/ m^3	0.5	6.0E-07	4.0E-07
Be(b)	1 hour	mg/ m^3	0.000004	8.4E-10	5.6E-10
Ag(b)	1 hour	mg/ m^3	0.0018	4.1E-08	2.7E-08
Zn (as ZnO) (b)	1 hour	mg/ m^3	0.09	4.5E-06	2.9E-06
As(b)	1 hour	mg/ m^3	0.00009	3.0E-06	2.0E-06
Sb(b)	1 hour	mg/ m^3	0.009	1.8E-06	1.2E-06

Pollutant	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
Cr (III) (b)	1 hour	mg/ m^3	0.009	1.1E-05	7.3E-06
Cr (VI) (b)	1 hour	mg/ m^3	0.00009	1.6E-08	1.0E-08
Pb	Annual	µg/ m^3	0.5	1.1E-03	1.0E-03
Ni(b)	1 hour	mg/ m^3	0.00018	2.7E-05	1.8E-05
Cu (dusts and mists) (b)	1 hour	mg/ m^3	0.0037	2.0E-06	1.3E-06
Mn(b)	1 hour	mg/ m^3	0.018	7.2E-06	4.8E-06
Phenol(c)	1 hour	mg/ m^3	0.0037	3.6E-07	3.1E-07
Hexane(b)	1 hour	mg/ m^3	0.018	6.0E-07	4.0E-07
TVOC(b)	1 hour	mg/ m^3	0.029	1.4E-04	9.6E-05

Note: (a) based on the assumption of 100% conversion from NO_x to NO_2[I]
(b) expressed as the 99.9th percentile of the dispersion modelling prediction.
(c) expressed as the 99th percentile of the dispersion modelling prediction.

Modelling results for criteria pollutants are assessed against the maximum prediction at sensitive receptors. In summary, the modelling results show:

- The maximum predicted 1-hour NO_2 is 5% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 1% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 0.6% of the impact assessment criterion, for 1-hour 0.5%, for 24-hour SO_2, 0.3% and for annual, 0.3%.
- The maximum predicted 24-hour PM is 0.05% of the impact assessment criterion for PM_{10} and 0.09% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 0.02% of the impact assessment criterion for PM_{10} and 0.07% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 0.01% or less than the relevant impact assessment criterion.
- The maximum predicted 24-hour HF is 0.4% of the impact assessment criterion, for 7-day 0.4%, for 30-day HF, 0.6% and for 90-day, 0.8%.
- The annual average lead concentration is 0.2% of the impact assessment criterion.

For the pollutants above it is also important to consider cumulative impacts due to existing “background” air quality, and other sources of pollution in the area. The cumulative predictions are presented in **Section 9.2.1**.

Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary. The individual odour compounds (H_2S, Toluene, Xylene and Phenol) are assessed against the 99th percentile prediction.

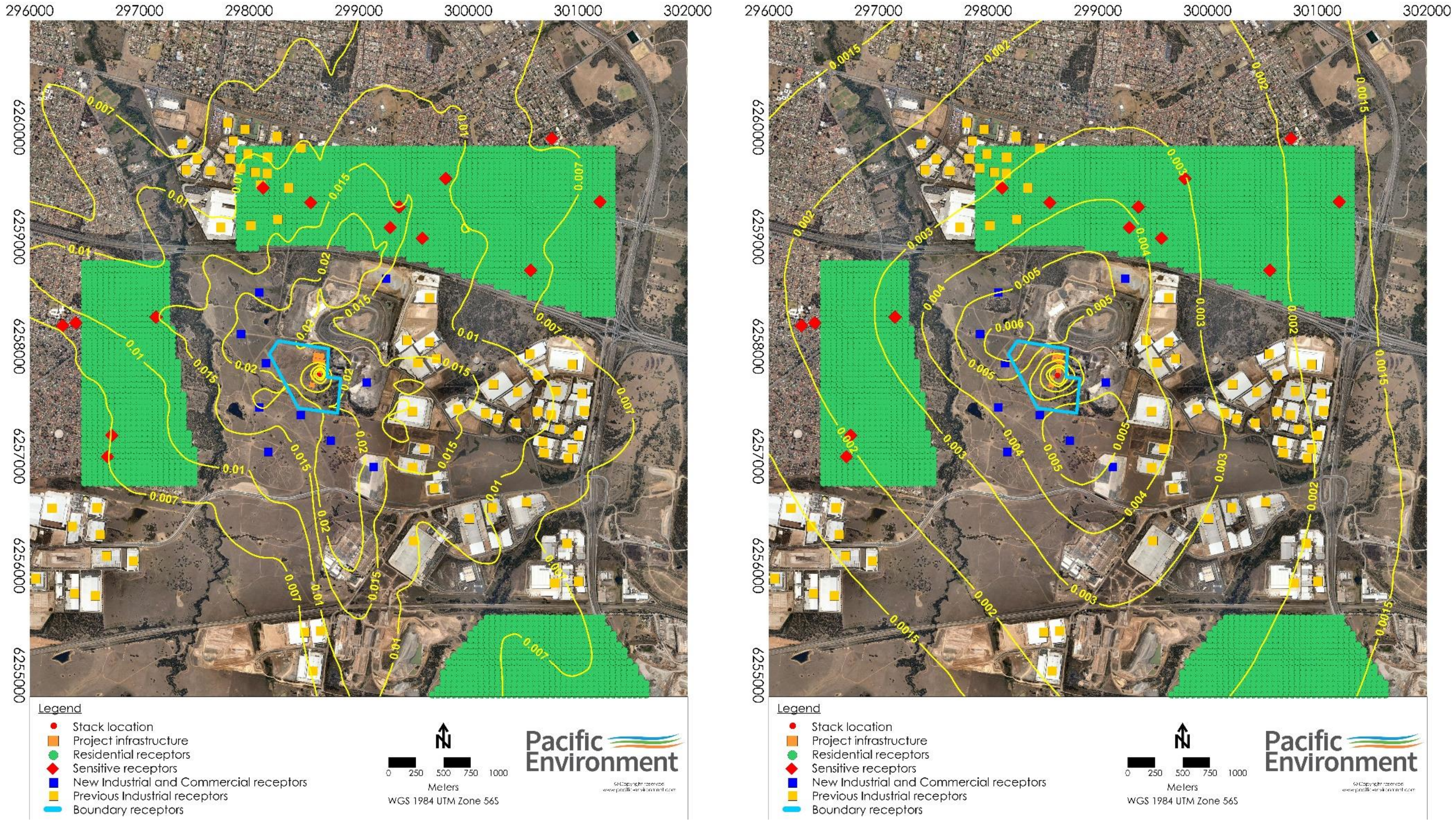
In summary, the modelling results show that the 99.9th percentile predicted:

- HCl is 1% of the impact assessment criterion.
- Cd is 6% of the impact assessment criterion.

[I] As discussed, we have conservatively assumed 100% conversion of NO_x to NO_2.

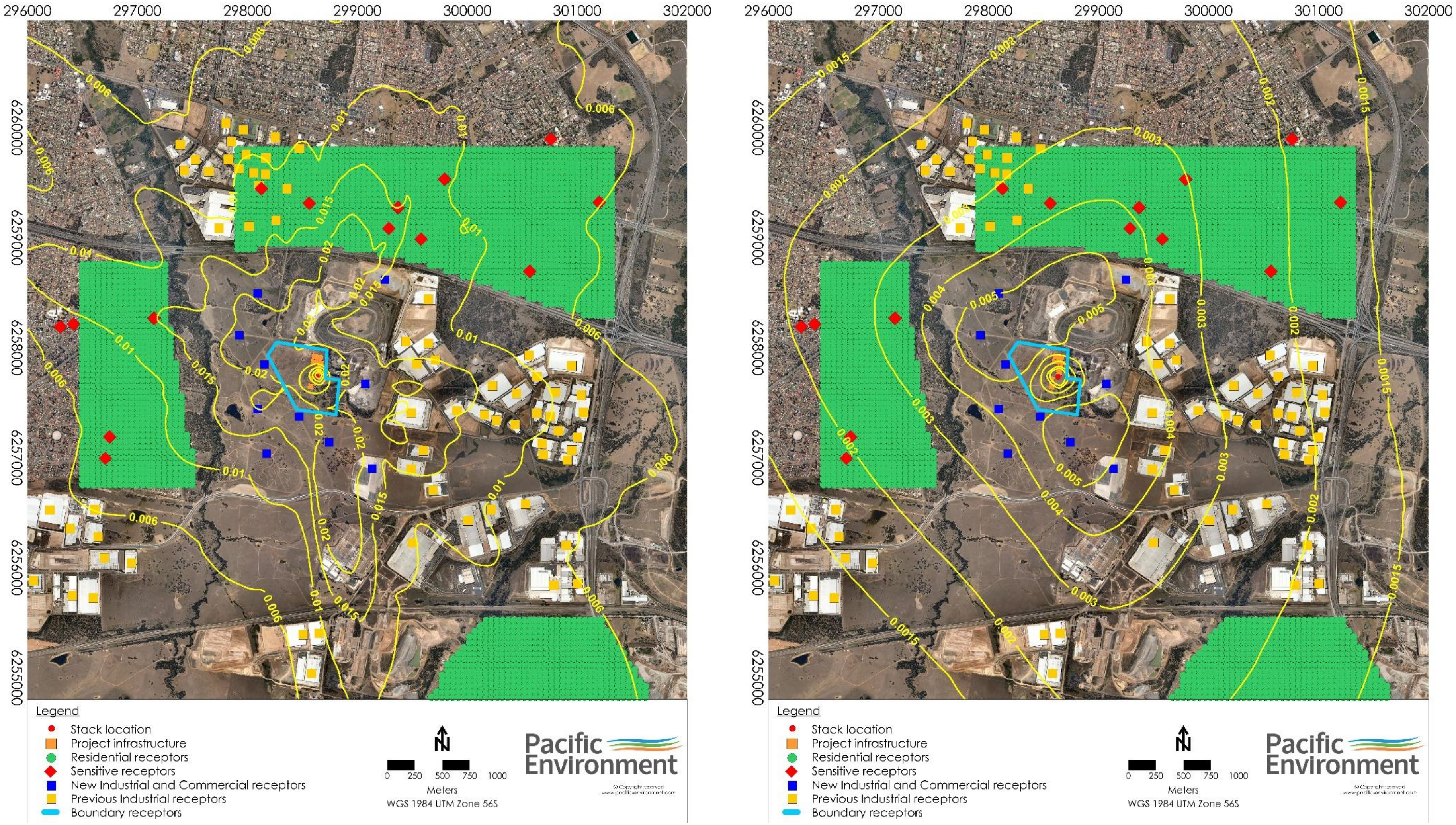
- Hg is 0.3% of the impact assessment criterion.
- dioxins and furans are 0.1% of the impact assessment criterion.
- benzene is 0.006% of the impact assessment criterion.
- toluene is 0.001% of the impact assessment criterion.
- xylene is 0.0002% of the impact assessment criterion.
- NH_3 is 0.1% of the impact assessment criterion.
- PAH (as benzo(a)pyrene) is 0.02% of the impact assessment criterion.
- H_2S is 5.2% of the impact assessment criterion.
- dichloromethane is 0.0001% of the impact assessment criterion.
- acetone is 0.00001% of the impact assessment criterion.
- trichloroethylene is 0.0001% of the impact assessment criterion.
- Be is 0.02% of the impact assessment criterion.
- Ag is 0.002% of the impact assessment criterion.
- Zn is 0.005% of the impact assessment criterion.
- As is 3.3% of the impact assessment criterion.
- Sb is 0.02% of the impact assessment criterion.
- Cr(III) is 0.1% of the impact assessment criterion.
- Cr(VI) is 0.02% of the impact assessment criterion.
- Ni is 14.7% of the impact assessment criterion.
- Cu is 0.05% of the impact assessment criterion.
- Mn is 0.04% of the impact assessment criterion.
- phenol is 0.01% of the impact assessment criterion.
- hexane is 0.003% of the impact assessment criterion.
- TVOC (assessed as benzene) is 0.5% of the impact assessment criterion.

There is overall significant improvement in the ground level concentrations predictions for both the criteria pollutants and air toxics compared with previous studies **(Pacific Environment, 2015; 2016; 2017c)**. This is attributed to there now being a single stack source and an effective halving of the predicted mass emission rates from the facility.



Maximum 24-Hour PM_{10} (criterion = 50 µg/m^3) **Annual Average PM_{10} (criterion = 25 µg/m^3)**

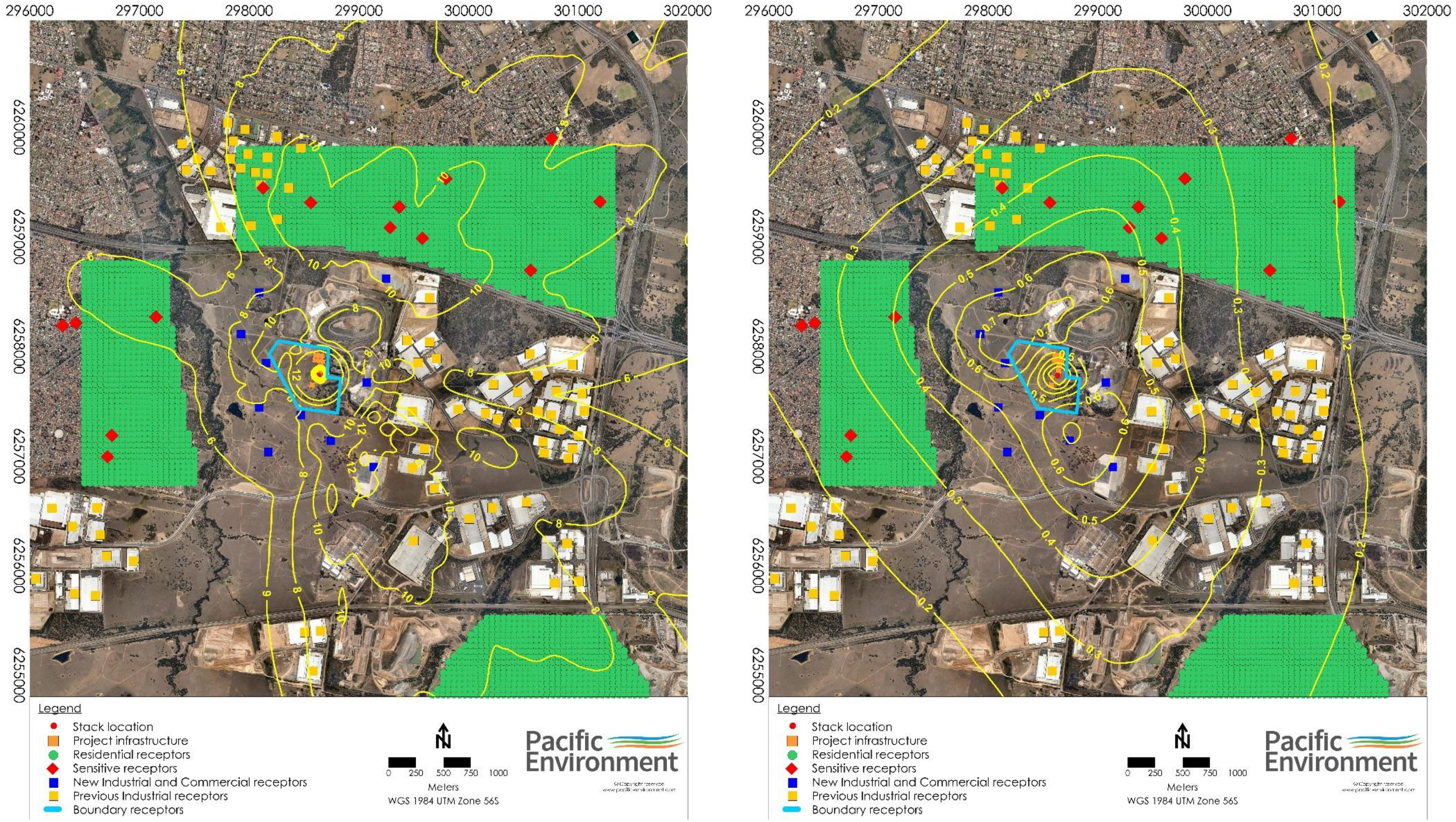
Figure 9-1: Maximum predicted Ground Level PM_{10} Concentration – µg/m^3



Maximum 24-Hour $PM_{2.5}$ (criterion = 25 µg/m³)

Annual Average $PM_{2.5}$ (criterion = 8 µg/m³)

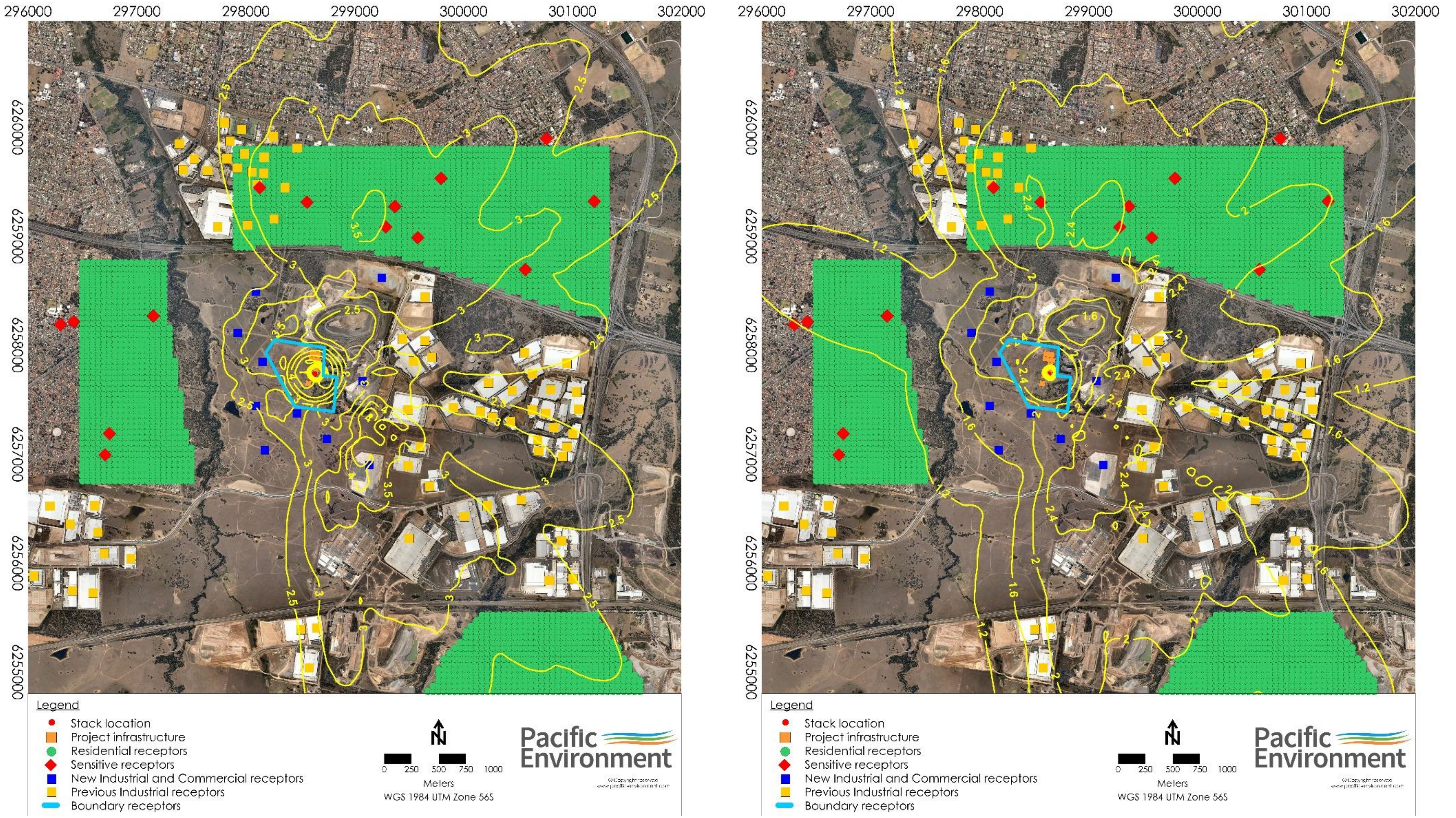
Figure 9-2: Maximum Predicted Ground Level $PM_{2.5}$ Concentration – µg/m³



Maximum 1-Hour NO$_2$ (criterion = 246 µg/m^3)

Annual Average NO$_2$ (criterion = 62 µg/m^3)

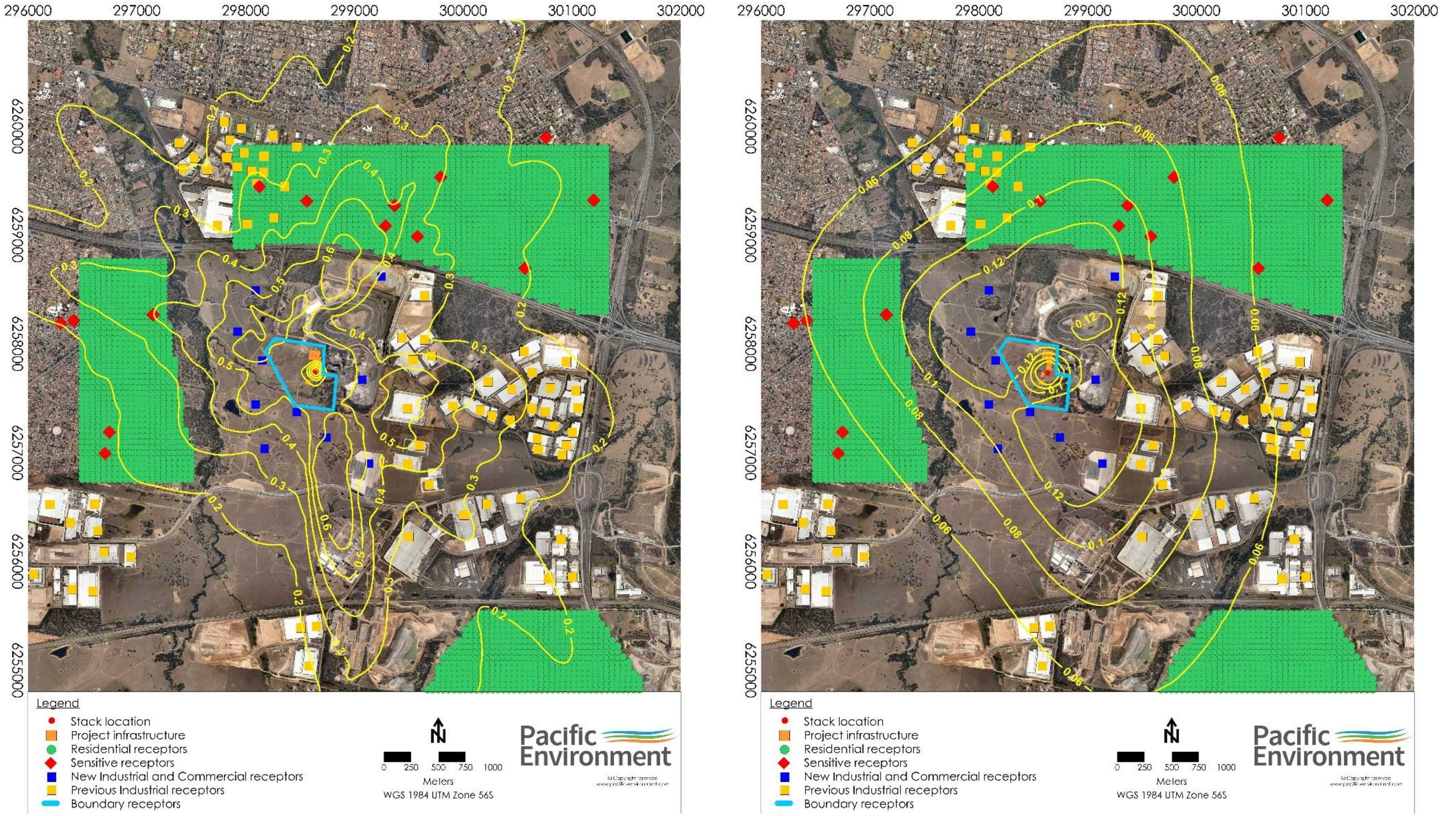
Figure 9-3: Maximum Predicted Ground Level NO$_2$ Concentration – µg/m^3



Maximum 10-Minute SO_2 (criterion = 712 µg/m^3)

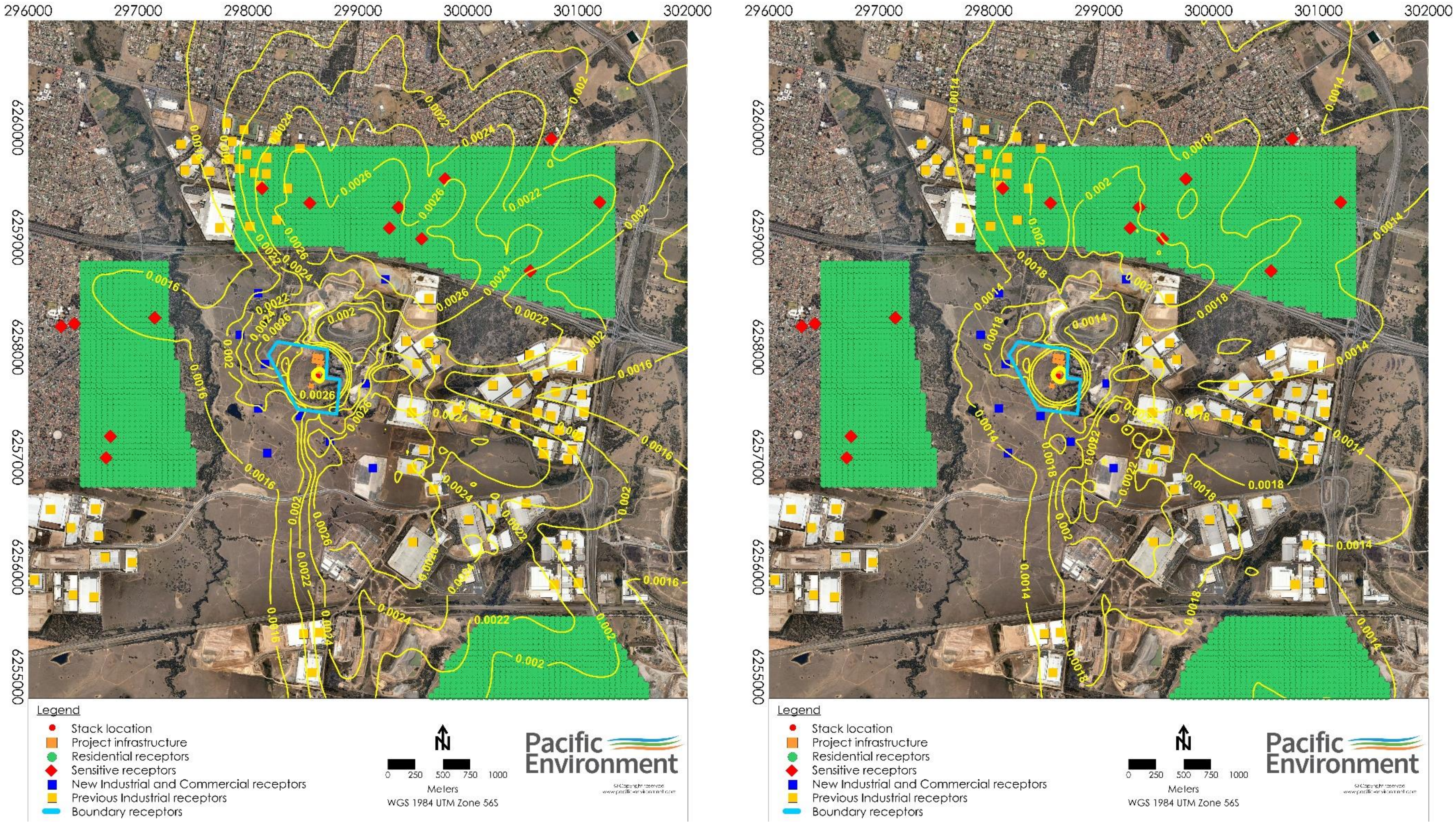
Maximum 1-Hour SO_2 (criterion = 570 µg/m^3)

Figure 9-4: Maximum Predicted Ground Level SO_2 Concentration – µg/m^3



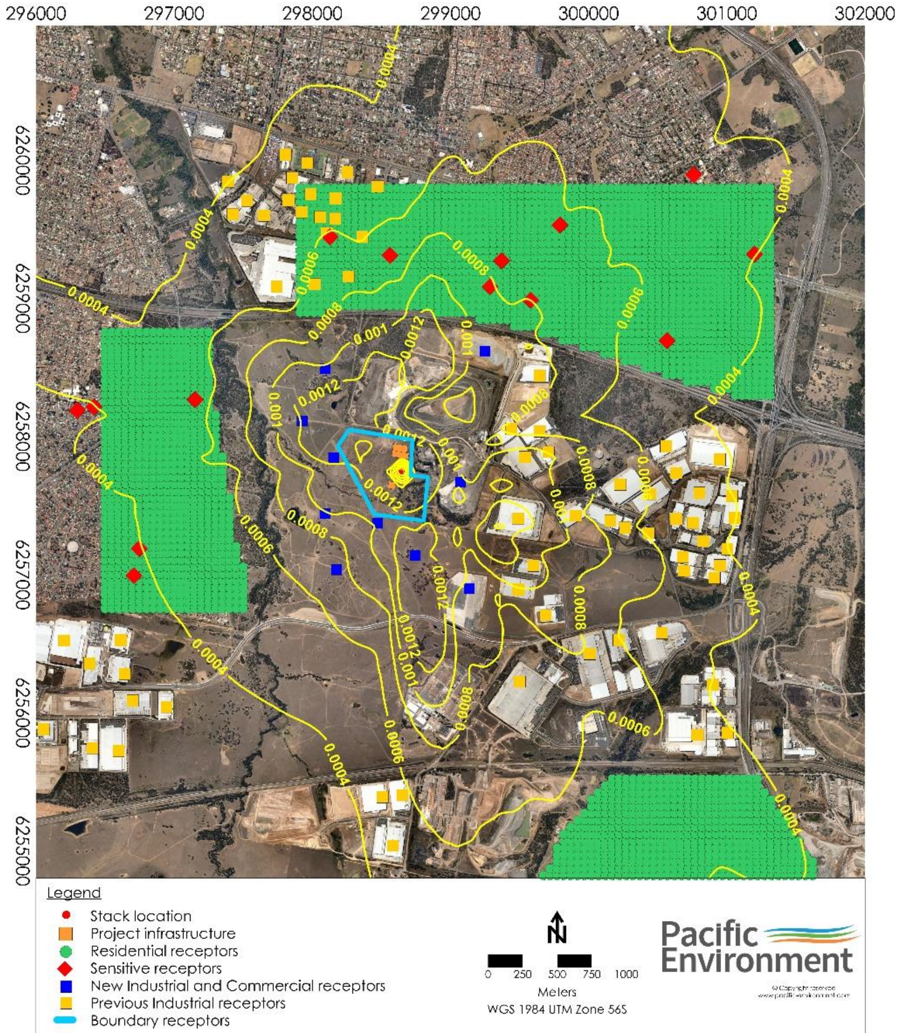
Maximum 24-Hour SO₂ (criterion = 228 µg/m³) **Annual Average SO₂ (criterion = 60 µg/m³)**

Figure 9-5: Maximum Predicted Ground Level SO_2 Concentration – µg/m³



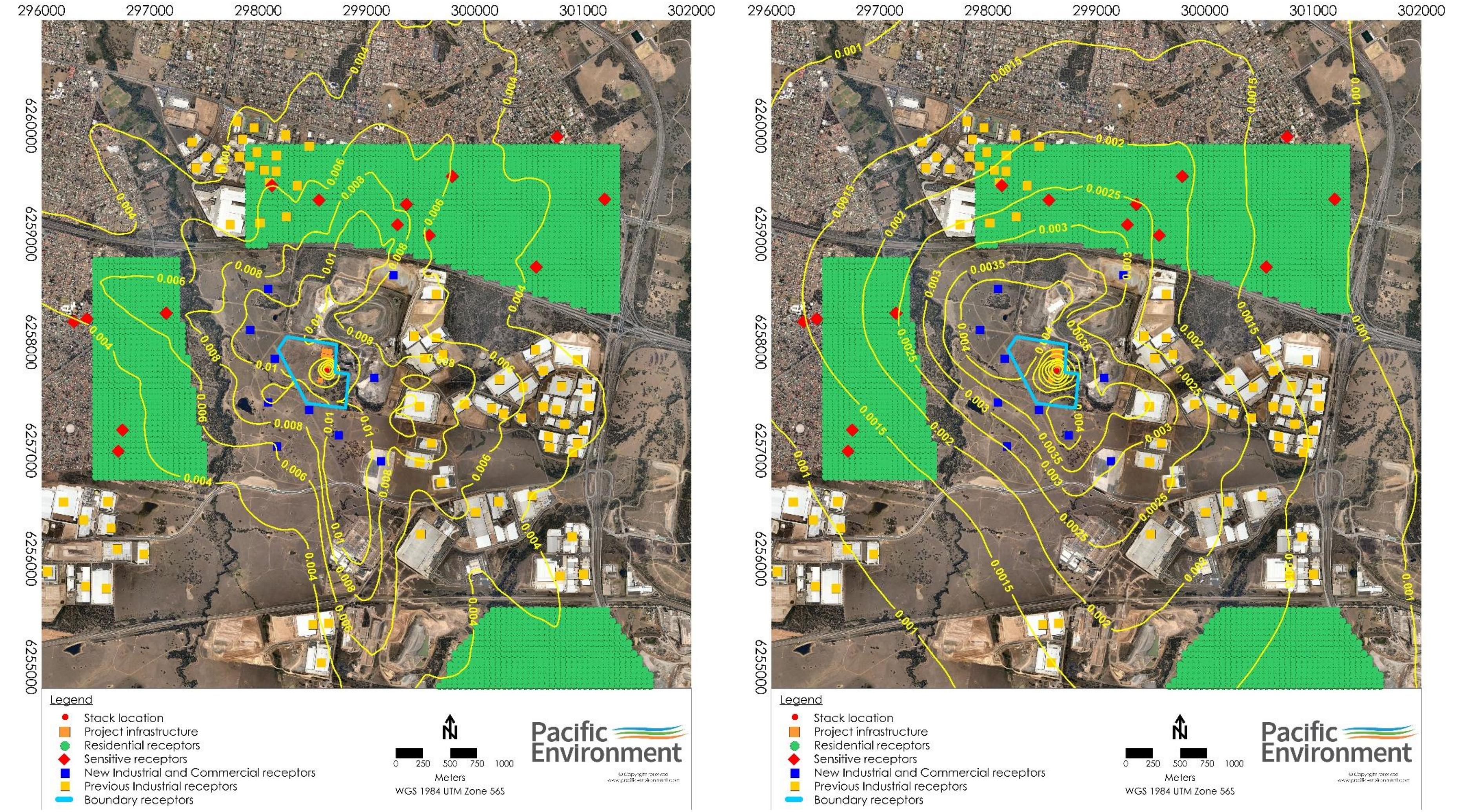
Maximum 15-Minute CO (criterion = 100 mg/m³) **Maximum 1-Hour CO (criterion = 30 mg/m³)**

Figure 9-6: Maximum Predicted Ground Level CO Concentration – mg/m³



Maximum 8-Hour CO (criterion = 10 mg/m^3)

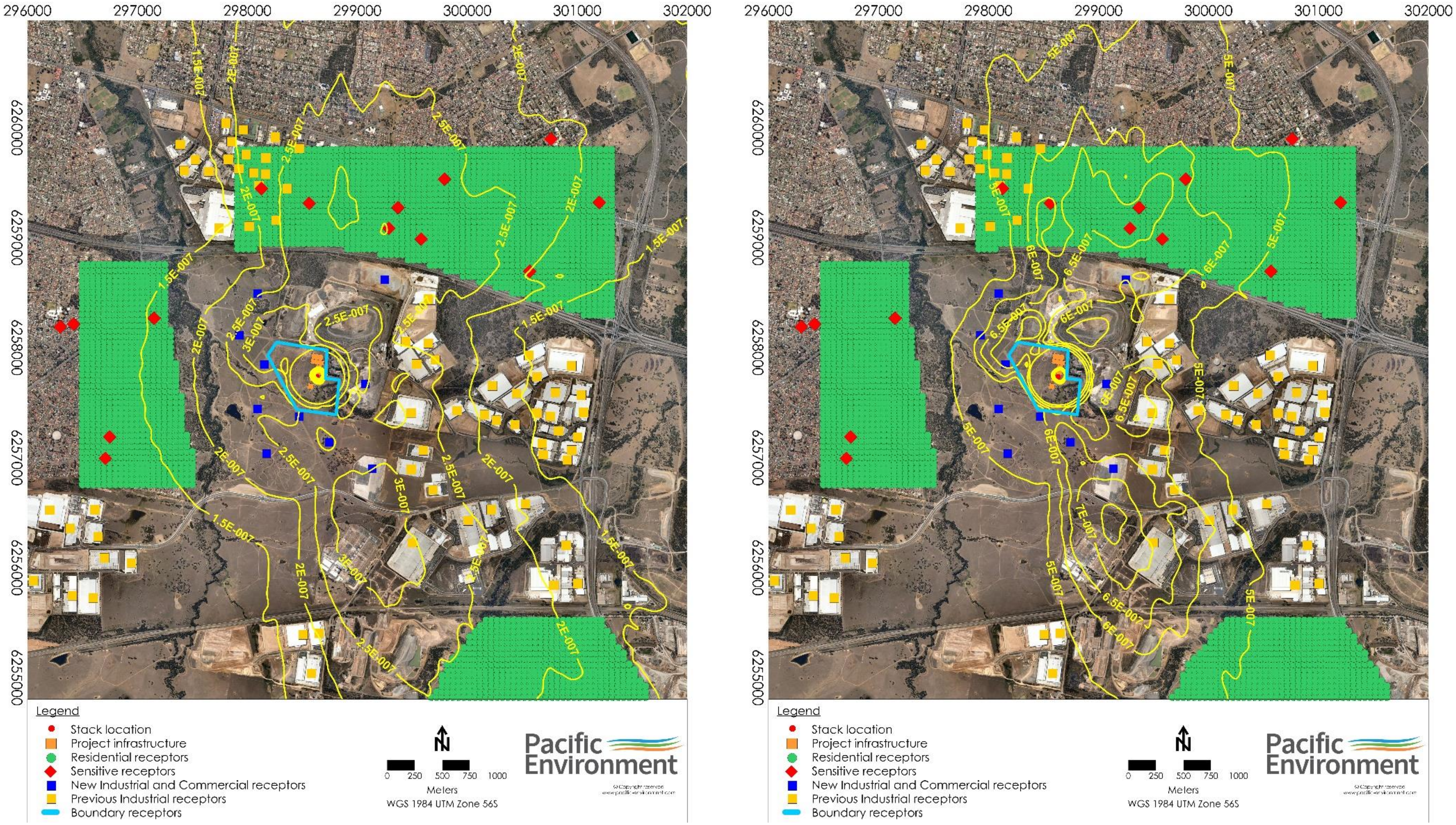
Figure 9-7: Maximum Predicted Ground Level CO Concentration – mg/m^3



Maximum 24-Hour HF (µg/m³) (criterion = 2.9 µg/m³)

Maximum 30 day HF (µg/m³) (criterion = 0.84 µg/m³)

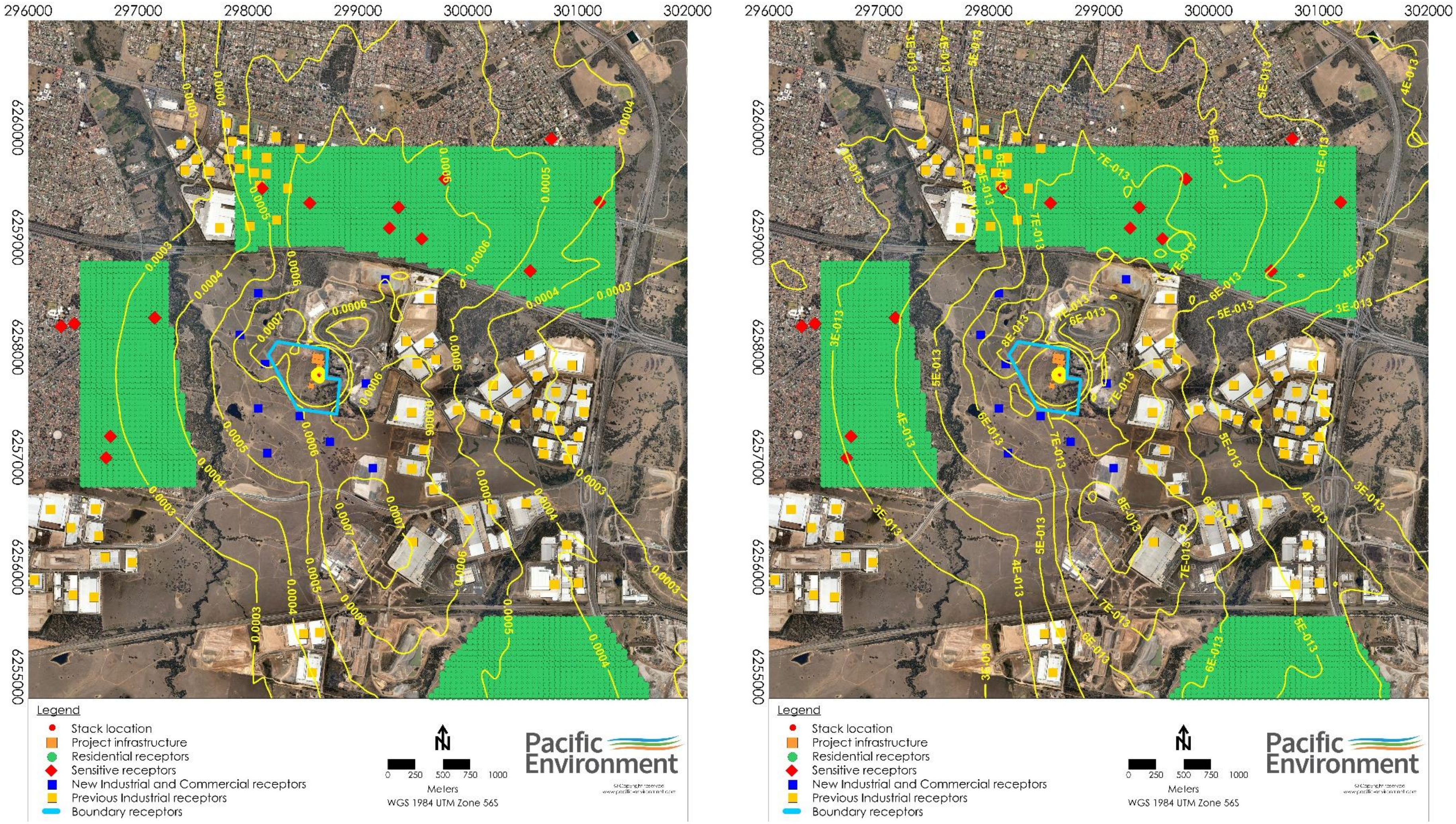
Figure 9-8: Maximum Predicted Ground Level HF Concentration



99.9th percentile 1-Hour Mercury (criterion = 0.0018 mg/m³)

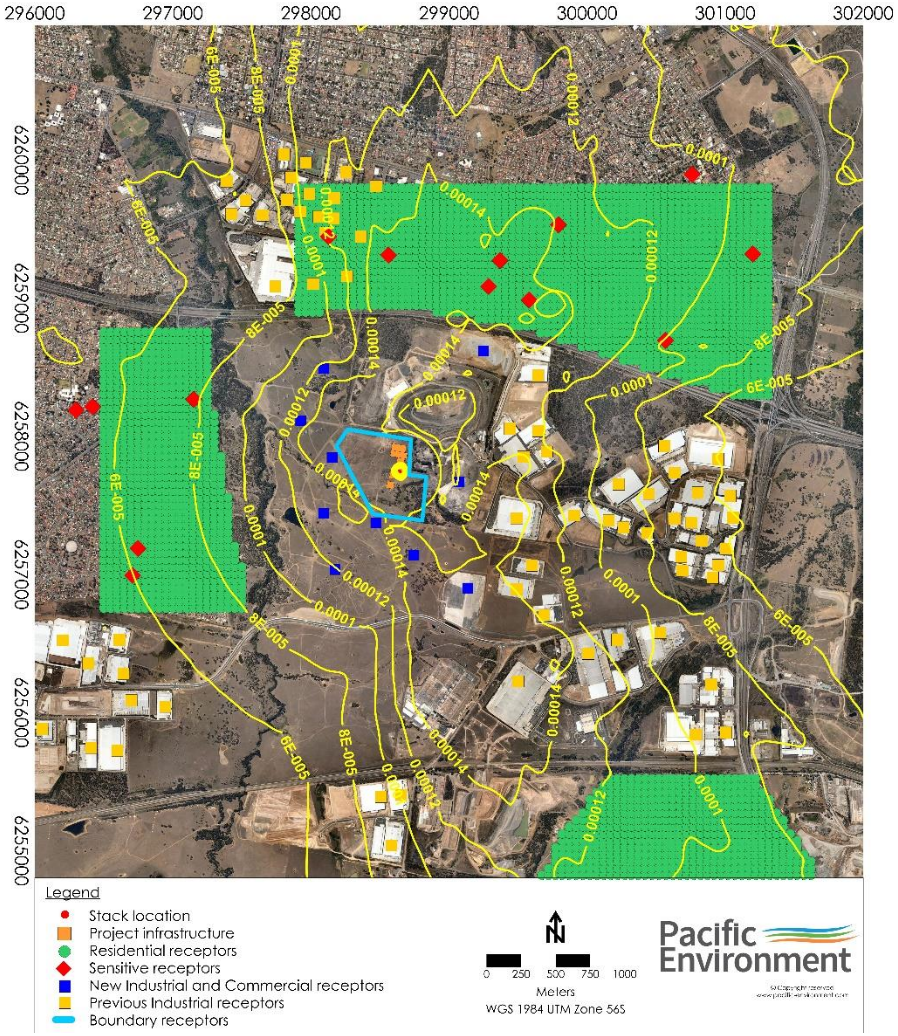
99.9th percentile 1-Hour Cadmium (criterion = 0.000018 mg/m³)

Figure 9-9: 99.9th Percentile Predicted Ground Level Metals Concentration – mg/m³



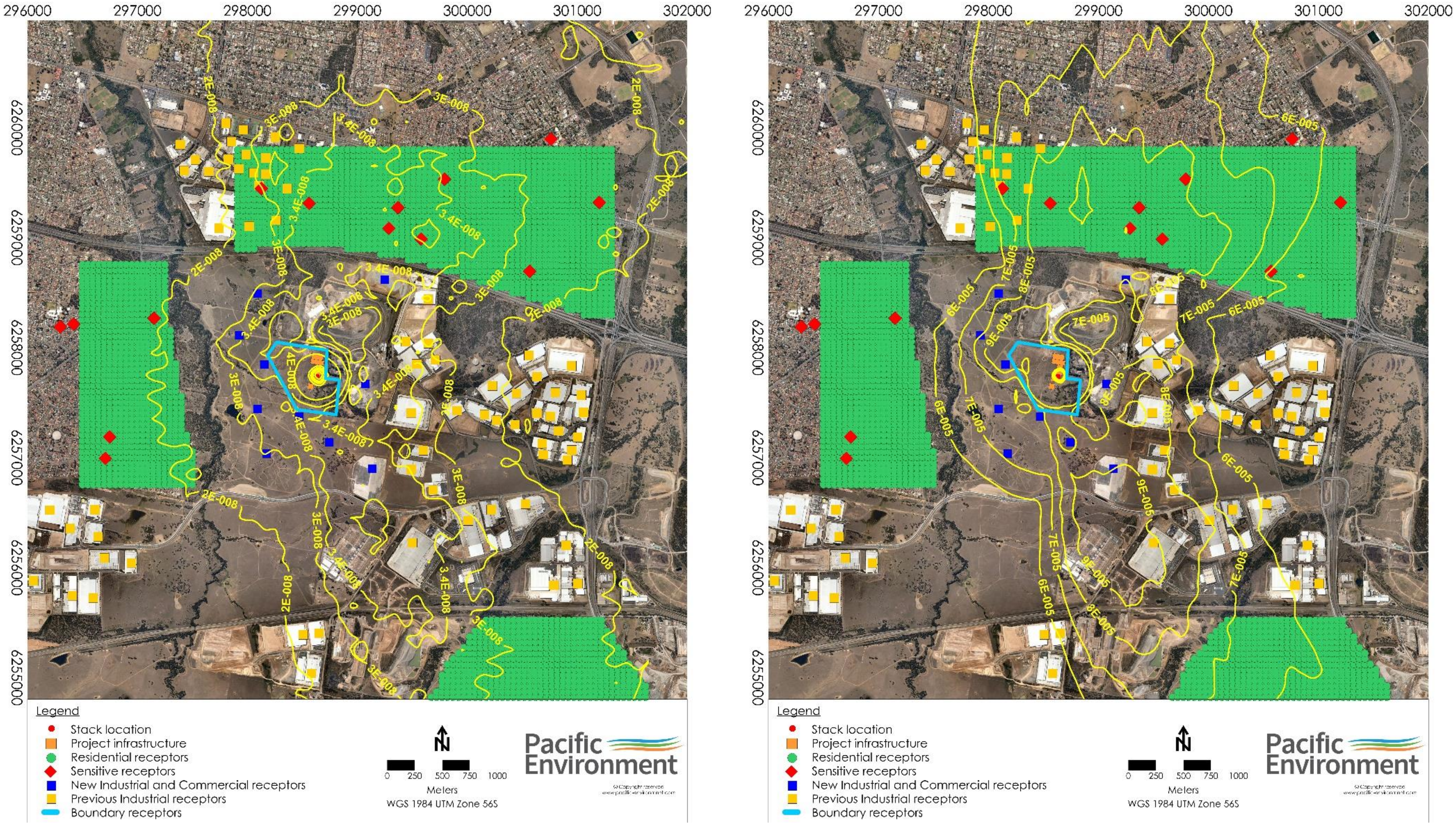
99.9th percentile 1-Hour HCl (criterion = 0.14 mg/m^3) **99.9th percentile 1-Hour Dioxins and Furans (criterion = 2.0x10^{-9} mg/m^3)**

Figure 9-10: 99.9th Percentile Predicted HCl and Dioxin/Furan Ground Level Concentration – mg/m^3



99.9th percentile 1-Hour NH_3 (criterion = 0.33mg/m^3)

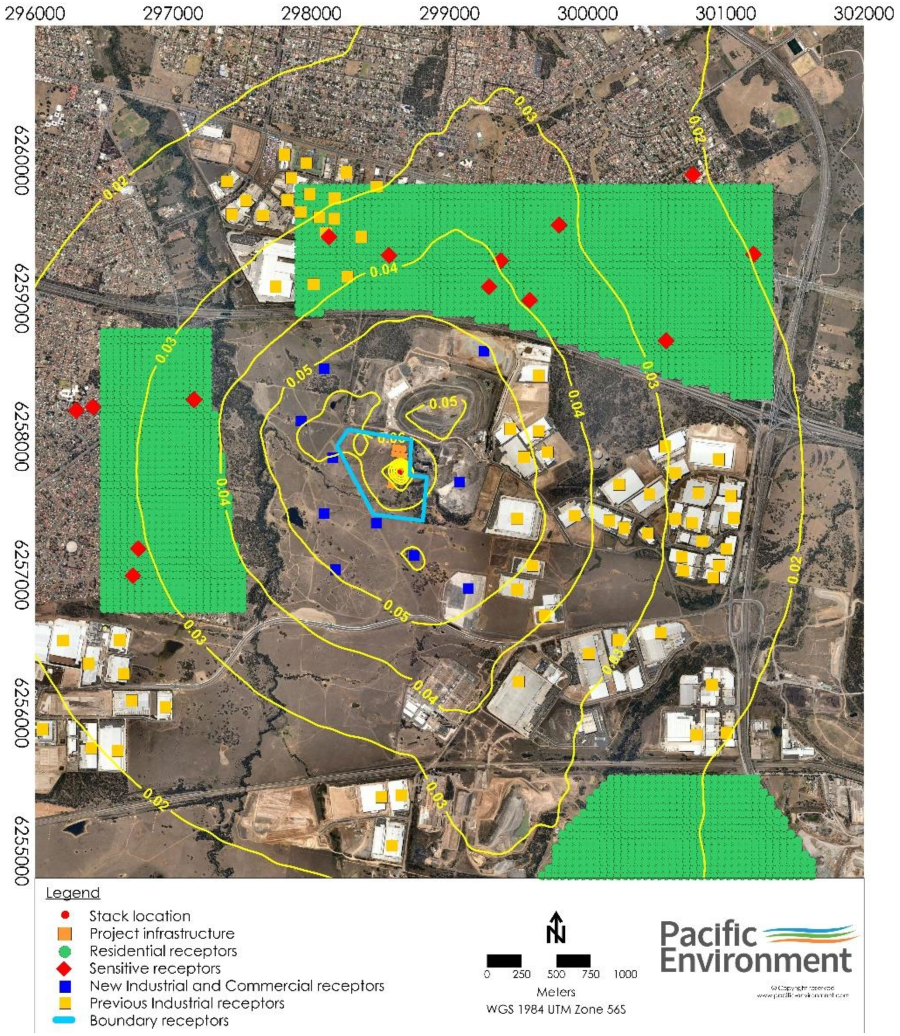
Figure 9-11: 99.9th Percentile Predicted Ammonia Ground Level Concentration



99.9th percentile 1-Hour PAH (as benzo(a)pyrene) (criterion = 0.0004mg/m^3)

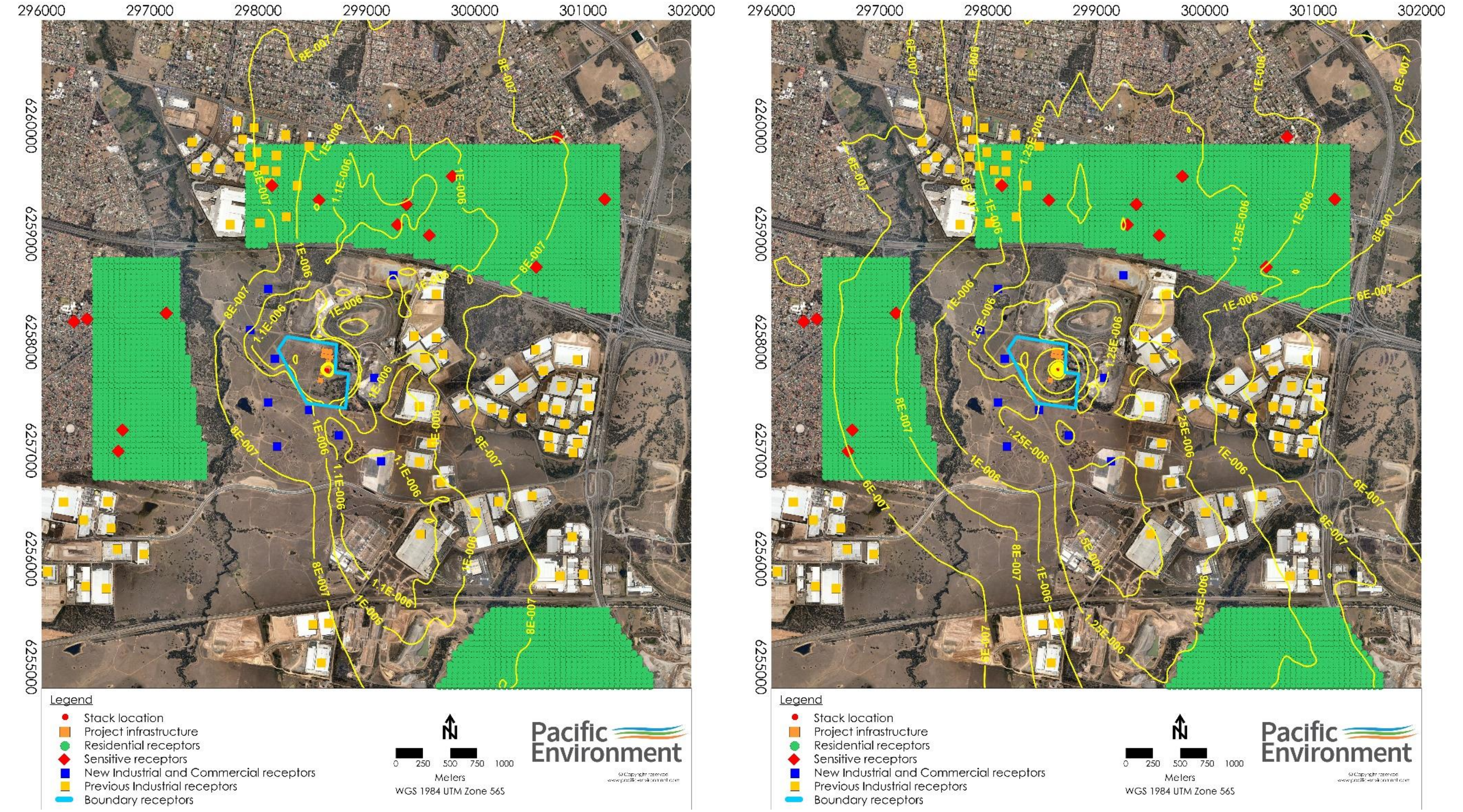
99.9th percentile 1-Hour VOC (benzene criterion = 0.029mg/m^3)

Figure 9-12: 99.9th Percentile Predicted PAH and VOC Ground Level Concentration



99th percentile 1-Hour H_2S (criterion = 1.38µg/m^3)

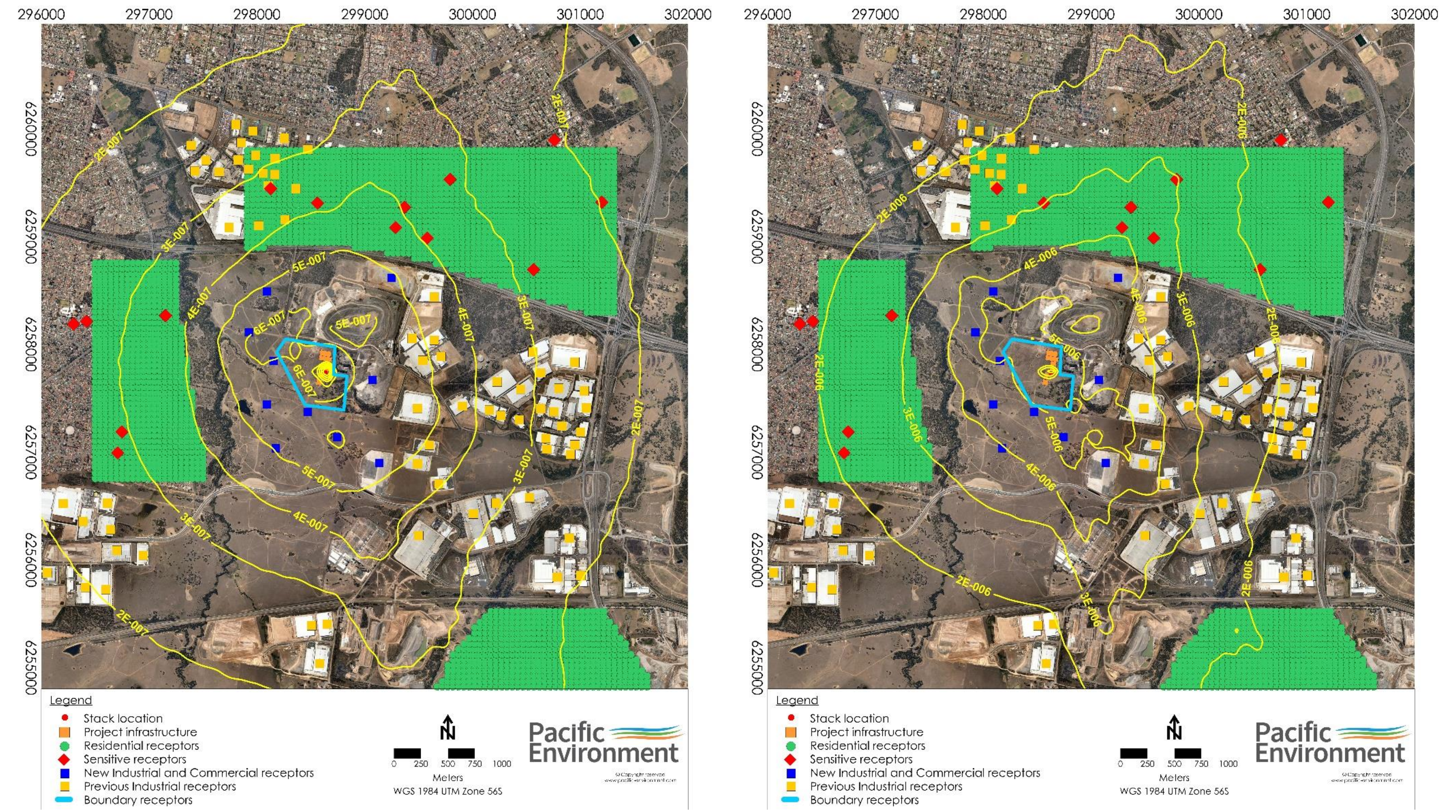
Figure 9-13: 99th Percentile Predicted Hydrogen Sulfide Ground Level Concentration



99.9th percentile 1-Hour Benzene (criterion = 0.029mg/m³)

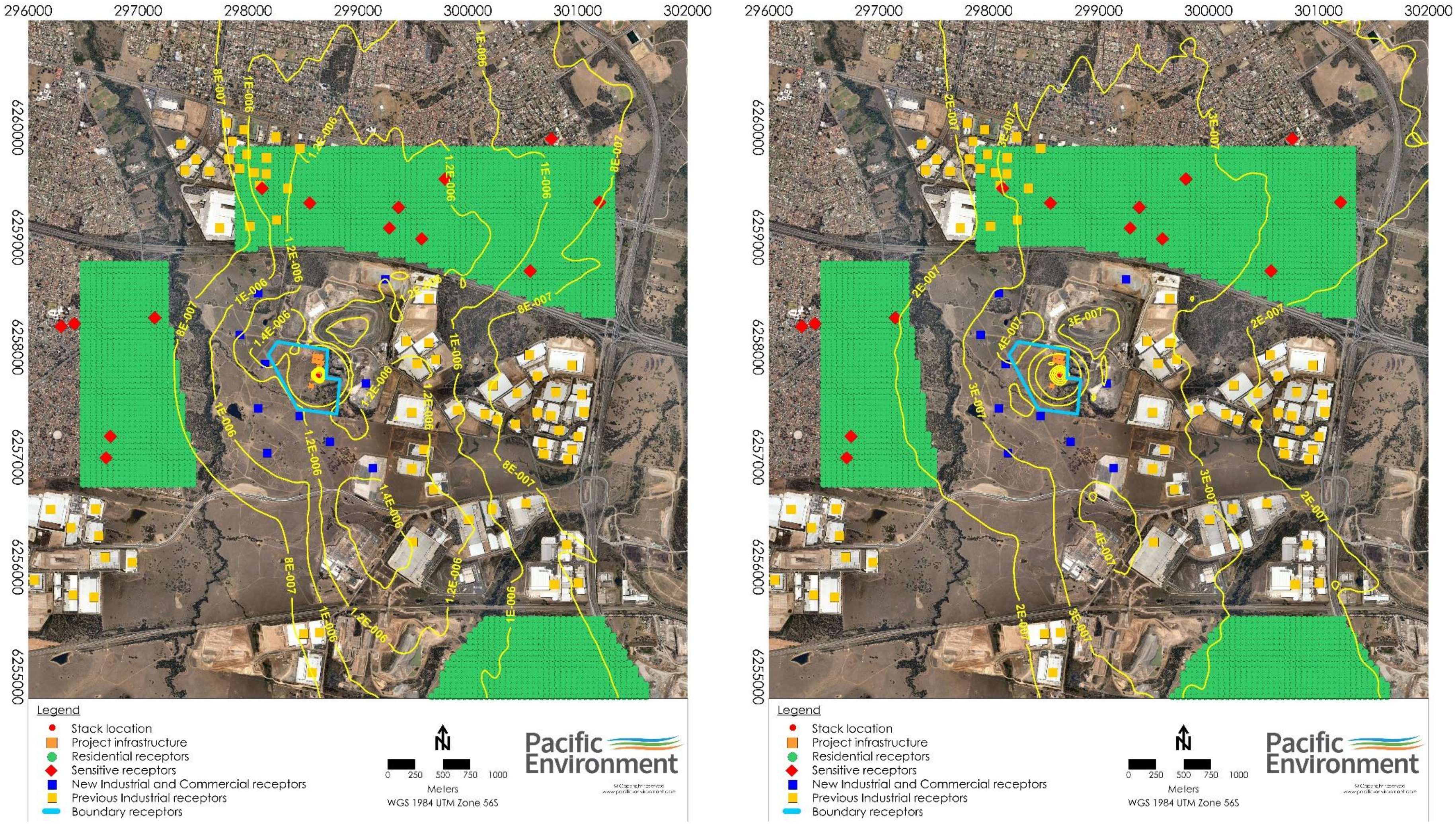
99.9th percentile 1-Hour Dichloro-methane (criterion = 3.19mg/m³)

Figure 9-14: 99.9th Percentile Predicted Benzene and Dichloro-methane Ground Level Concentration



99th percentile 1-Hour Xylene (criterion = 0.36mg/m³) **99th percentile 1-Hour Toluene (criterion = 0.19mg/m³)**

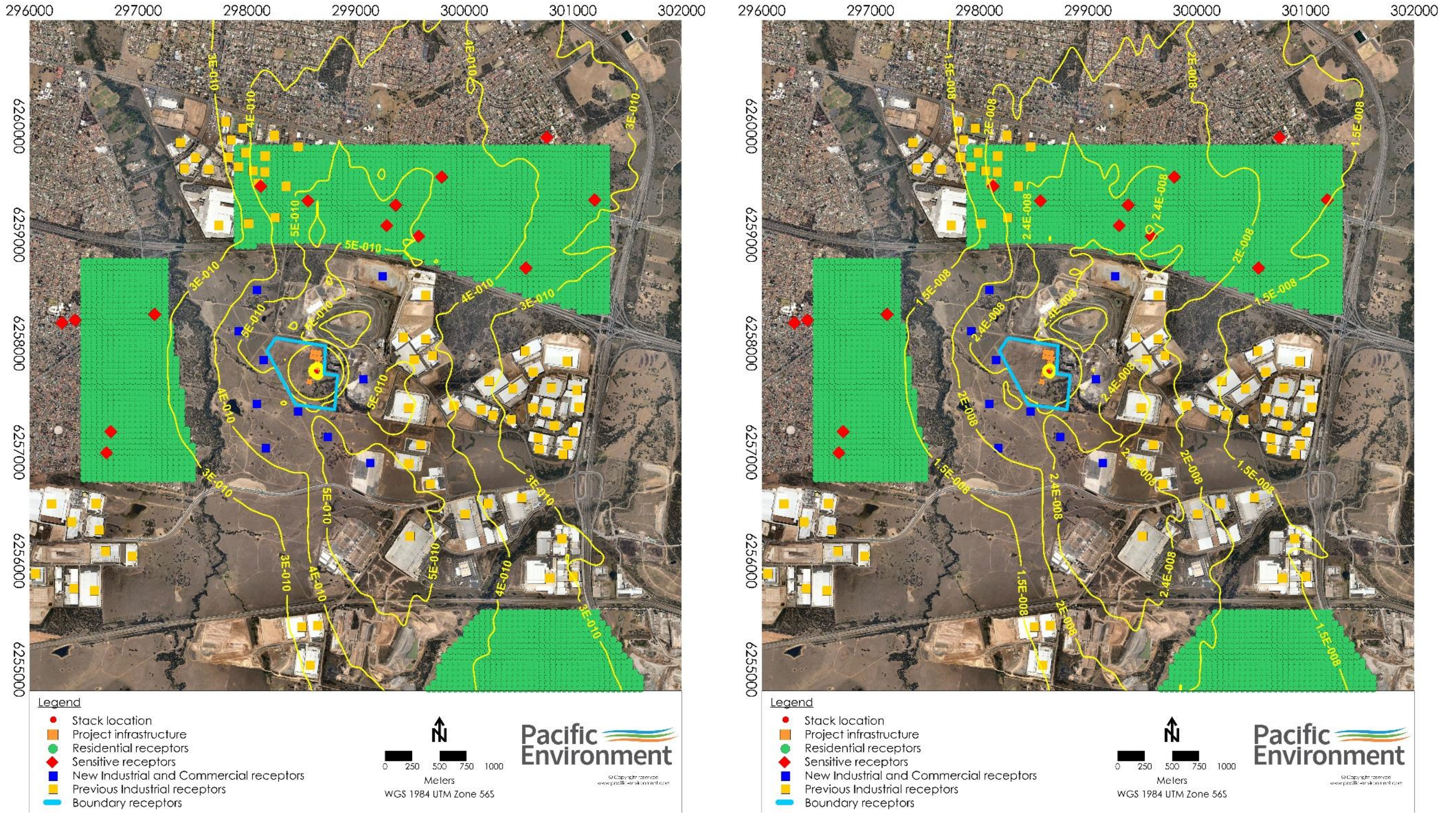
Figure 9-15: 99th Percentile Predicted Xylene and Toluene Ground Level Concentration



99.9th percentile 1-Hour Acetone (propanone) (criterion = 22mg/m³)

99.9th percentile 1-Hour Trichloro-ethylene (criterion = 0.5mg/m³)

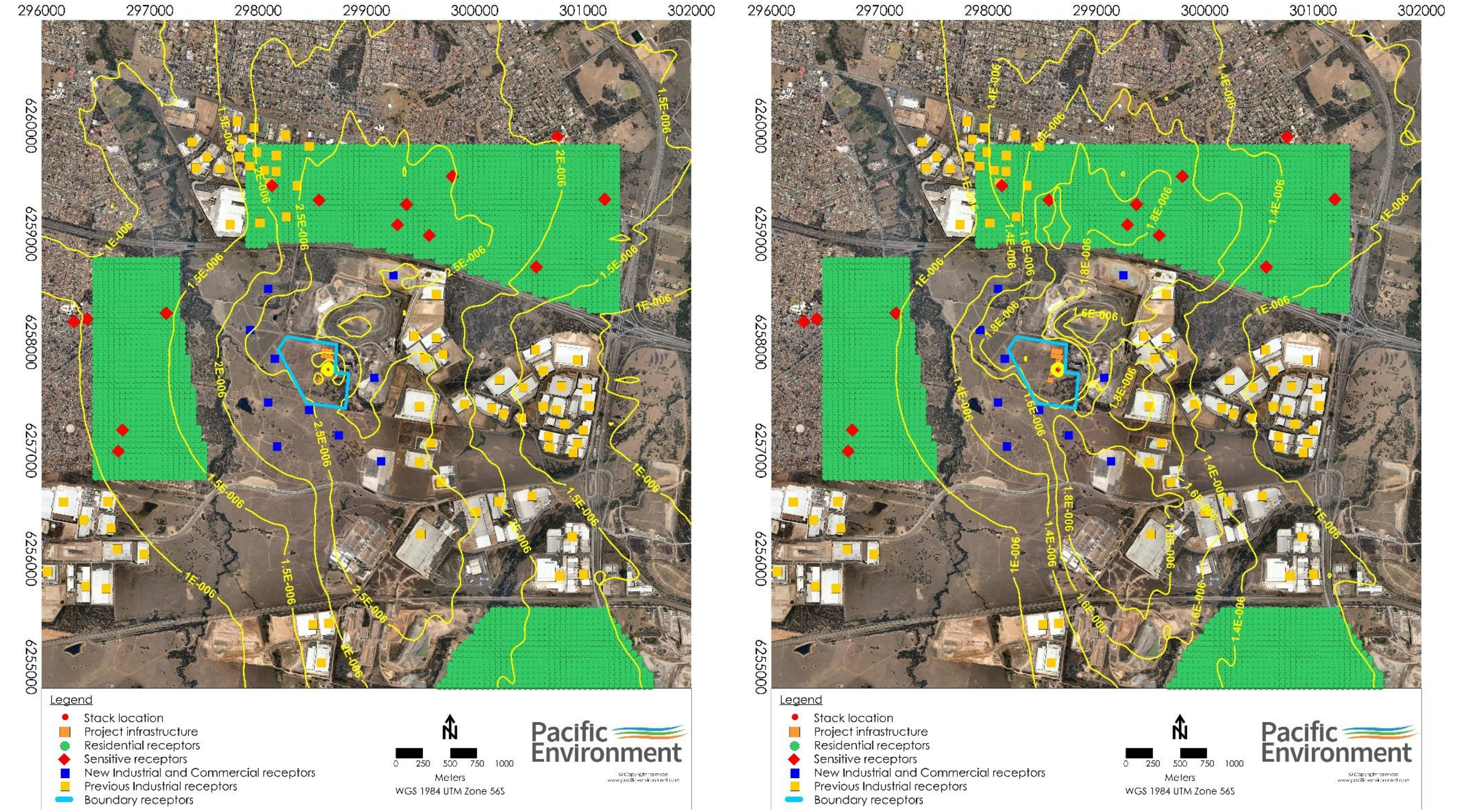
Figure 9-16: 99.9th Percentile Predicted Acetone (propanone) and Trichloro-ethylene Ground Level Concentration



99.9th percentile 1-Hour Be (criterion = 0.000004mg/m^3)

99.9th percentile 1-Hour Ag (criterion = 0.0018mg/m^3)

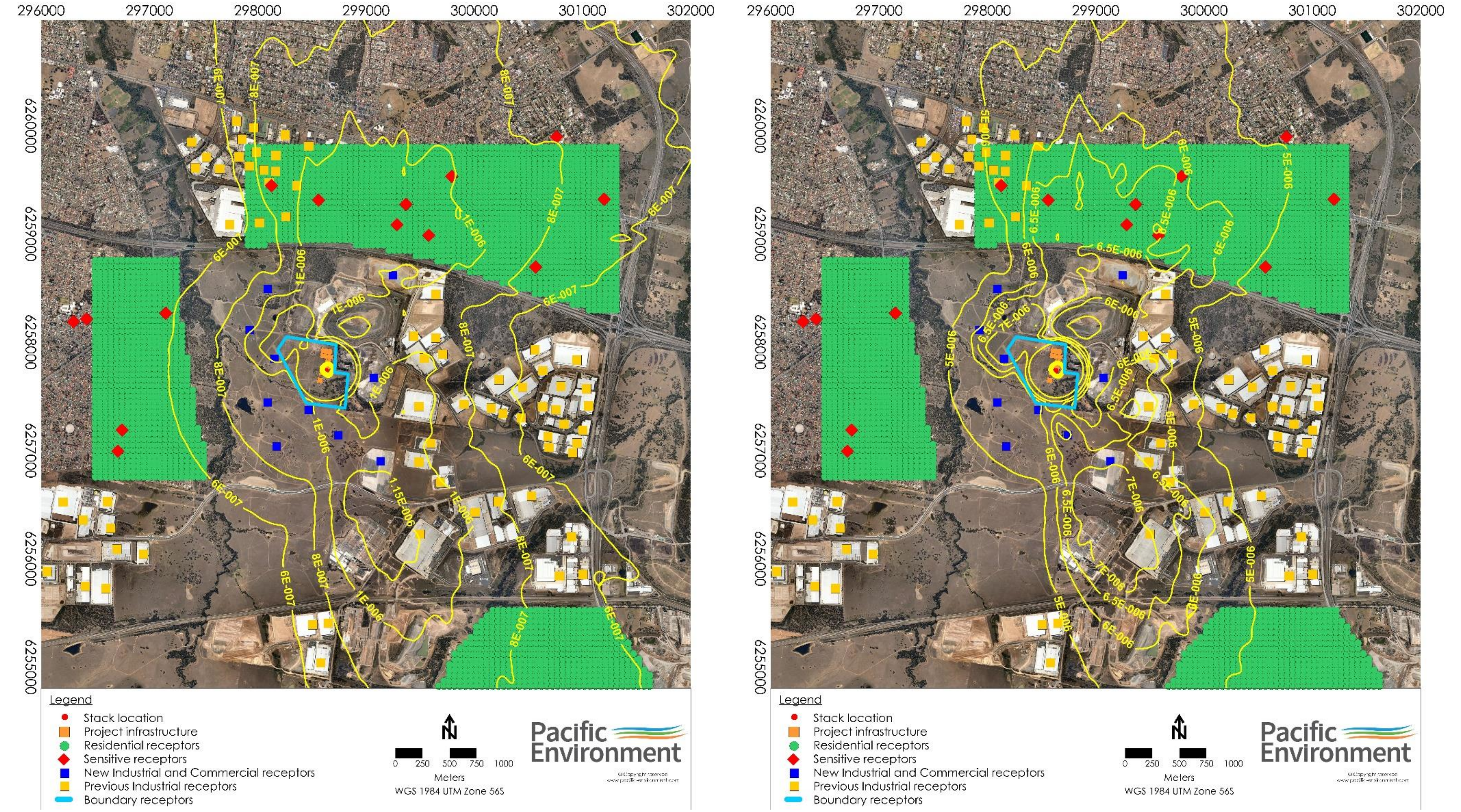
Figure 9-17: 99.9th Percentile Predicted Be and Ag Ground Level Concentration



99.9th percentile 1-Hour Zn (criterion = 0.09mg/m³)

99.9th percentile 1-Hour As (criterion = 0.00009mg/m³)

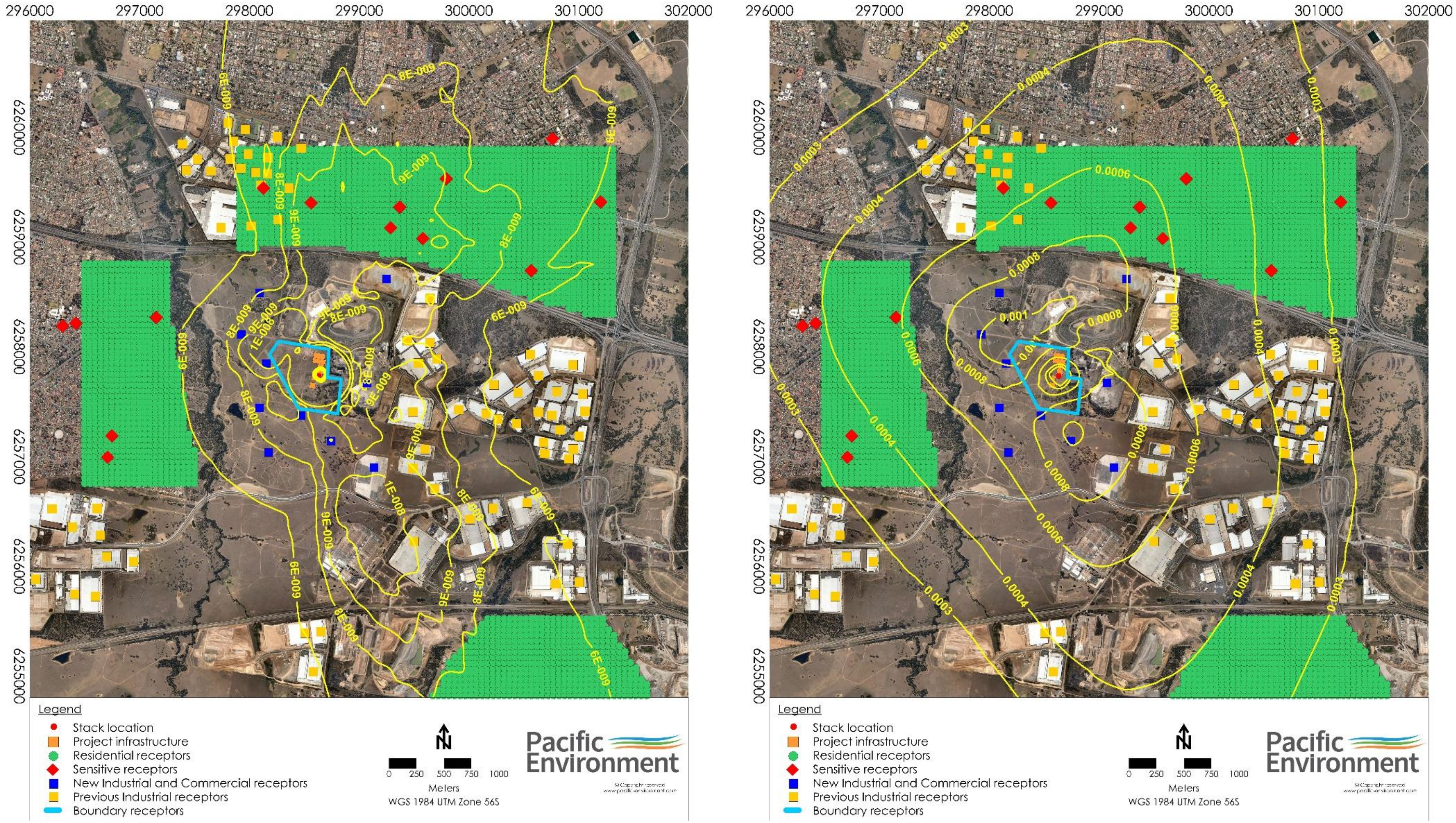
Figure 9-18: 99.9th Percentile Predicted Zn and As Ground Level Concentration



99.9th percentile 1-Hour Sb (criterion = 0.009mg/m³)

99.9th percentile 1-Hour Cr (III) (criterion = 0.009mg/m³)

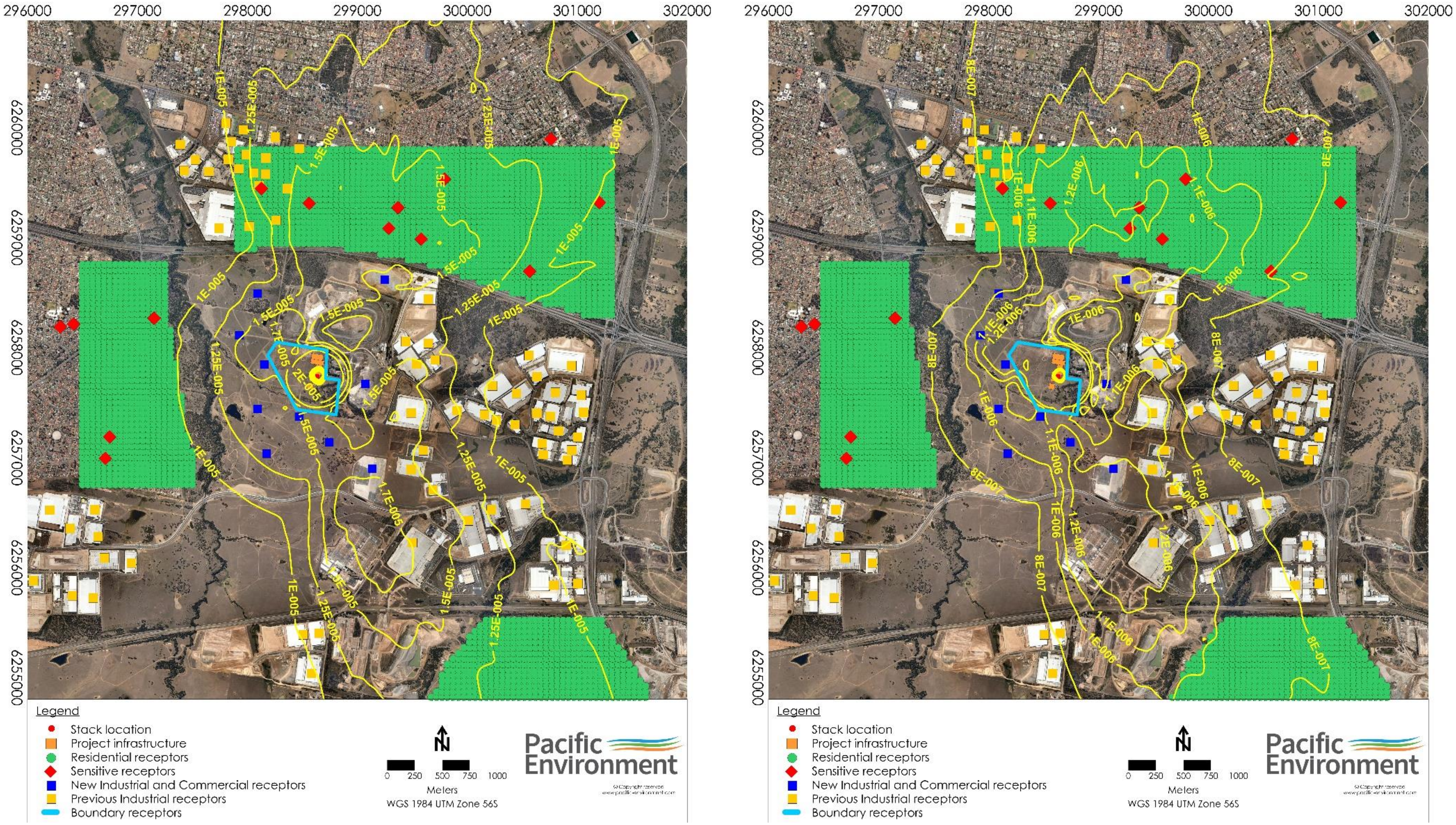
Figure 9-19: 99.9th Percentile Predicted Sb and Cr (III) Ground Level Concentration



99.9th percentile 1-Hour Cr (VI) (criterion = 0.00009mg/m^3)

Annual Pb (criterion = 0.5µg/m^3)

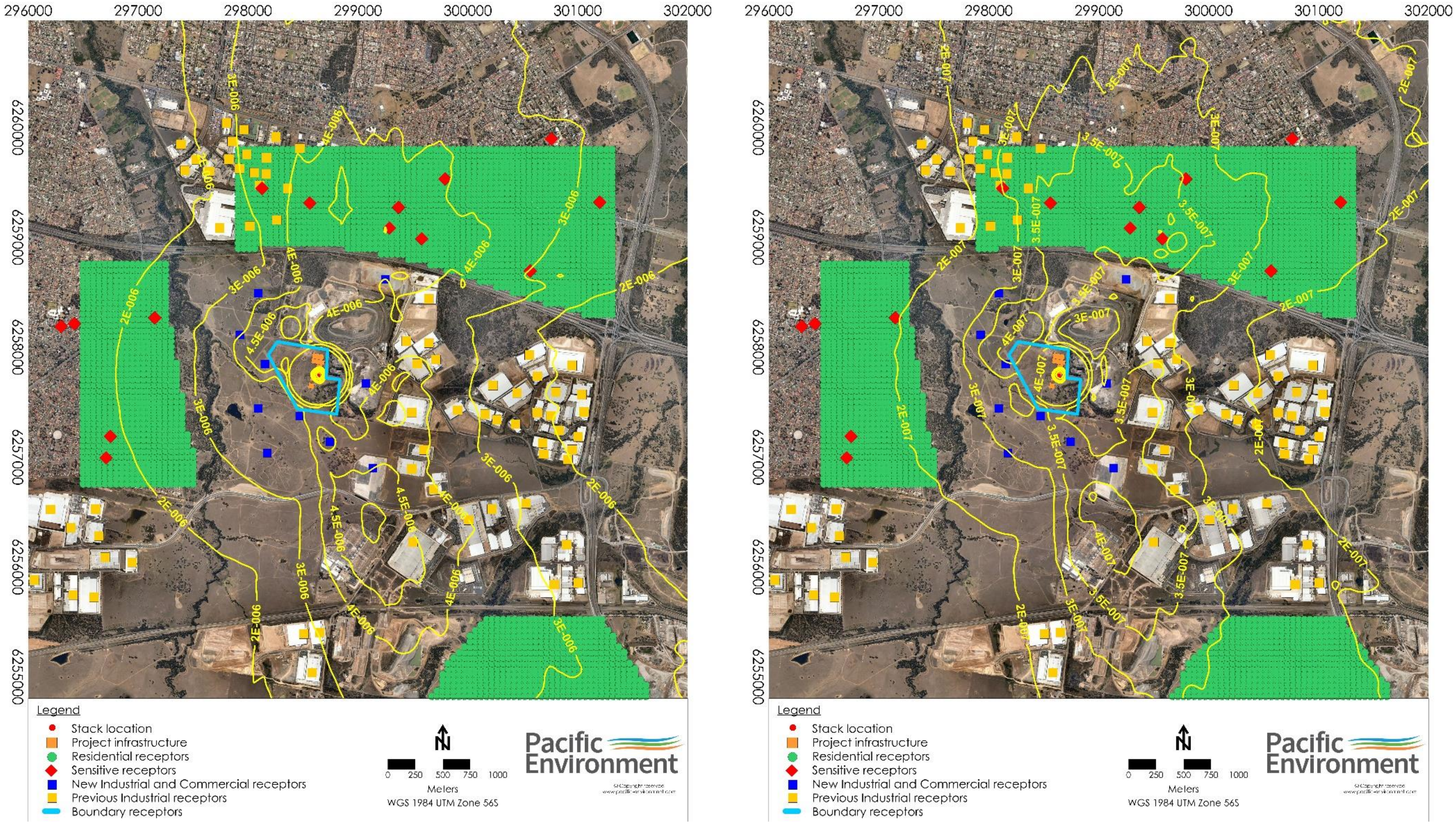
Figure 9-20: 99.9th Percentile Predicted Cr (VI) and 100th Percentile Annual Pb Ground Level Concentration



99.9th percentile 1-Hour Ni (criterion = 0.00018mg/m^3)

99.9th percentile 1-Hour Cu (dusts and mists) (criterion = 0.0037mg/m^3)

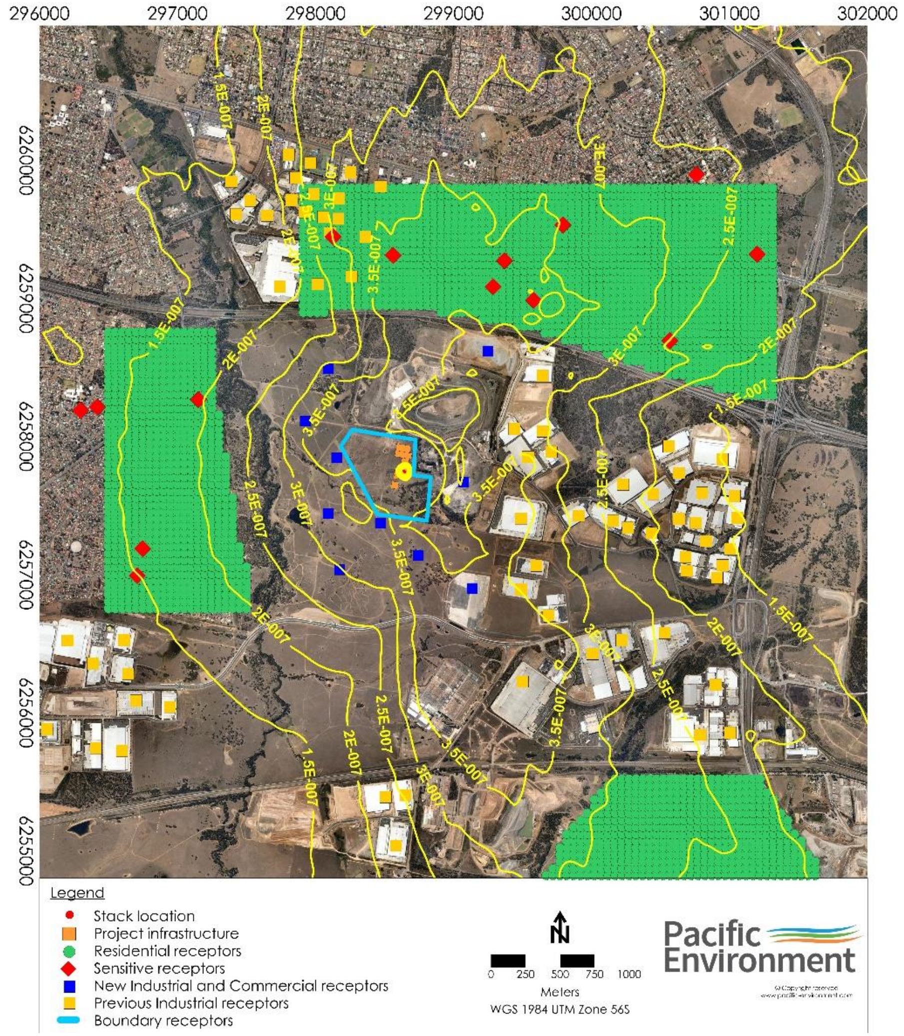
Figure 9-21: 99.9th Percentile Predicted Ni and Cu (dusts and mists) Ground Level Concentration



99.9th percentile 1-Hour Mn (criterion = 0.018mg/m^3)

99th percentile 1-Hour Phenol (criterion = 0.0037mg/m^3)

Figure 9-22: 99.9th Percentile Predicted Mn and 99th Percentile Phenol Ground Level Concentration



99.9th percentile 1-Hour Hexane (criterion = 0.018mg/m^3)

Figure 9-23: 99.9th Percentile Predicted Hexane

9.1.2 Scenario 2 - Regulatory (POEO Limits)

As noted in **Section 6.3.2**, to inform future Environmental Protection Licensing of the EfW facility, in addition to the expected and upset conditions, ground level concentrations resulting from a Regulatory scenario (in-stack concentrations at the POEO emission limits) have been presented.

A summary of the ground level concentrations (GLCs) for each pollutant when released at the POEO emission limits is presented in **Table 9-2**. GLCs are presented at and beyond the site boundary, as well as the maximum prediction at sensitive receptors. Predictions above the relevant NSW impact assessment criterion are shown in bold.

Table 9-2: Summary of predicted ground level concentrations at POEO emission limits

Pollutant	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
NO$_2$ (a)	1 hour	µg/m^3	246	47	37
	Annual	µg/ m^3	62	2.3	2.1
CO	15-minute	mg/ m^3	100	0.02	0.01
	1 hour	mg/ m^3	30	0.01	0.01
	8 hours	mg/ m^3	10	0.01	0.01
PM$_{10}$	24 hours	µg/ m^3	50	1.1	0.8
	Annual	µg/ m^3	25	0.2	0.2
PM$_{2.5}$	24 hours	µg/ m^3	25	1.1	0.8
	Annual	µg/ m^3	8	0.2	0.2
HF	24 hours	µg/ m^3	2.9	1.1	0.8
	7 days	µg/ m^3	1.7	0.5	0.4
	30 days	µg/ m^3	0.84	0.4	0.4
	90 days	µg/ m^3	0.5	0.3	0.3
Cd (b)	1 hour	mg/ m^3	0.000018	1.7E-05	1.1E-05
Hg (b)	1 hour	mg/ m^3	0.00018	1.7E-05	1.1E-05
Dioxins and furans (b)	1 hour	mg/ m^3	0.000000002	1.2E-11	8.0E-12
Be(b)	1 hour	mg/ m^3	0.000004	**8.6E-05**	**5.7E-05**
As(b)	1 hour	mg/ m^3	0.00009	8.6E-05	5.7E-05
Sb(b)	1 hour	mg/ m^3	0.009	8.6E-05	5.7E-05
Cr (III) (b)	1 hour	mg/ m^3	0.009	8.6E-05	5.7E-05
Cr (VI) (b)	1 hour	mg/ m^3	0.00009	8.6E-05	5.7E-05
Pb	Annual	µg/ m^3	0.5	4.6E-03	4.2E-03
Ni(b)	1 hour	mg/ m^3	0.00018	8.6E-05	5.7E-05
Mn(b)	1 hour	mg/ m^3	0.018	8.6E-05	5.7E-05
TVOC (as benzene)(b)	1 hour	mg/ m^3	0.029	6.1E-03	4.0E-03

Note: (a) based on the assumption of 100% conversion from NO$_x$ to NO$_2$ (b) Expressed as the 99.9th percentile of the dispersion modelling prediction

Modelling results for criteria pollutants are assessed against the maximum prediction at sensitive receptors. In summary, the modelling results show that when emitting at the POEO emission limits:

- The maximum predicted 1-hour NO$_2$ is 15% of the impact assessment criterion, assuming a conservative 100% conversion from NO$_x$ to NO$_2$

- The maximum predicted annual NO_2 is 3% of the impact assessment criterion.
- The maximum predicted 24-hour PM increment is 2% of the impact assessment criterion for PM_{10} and 3% of the impact assessment criterion for $PM_{2.5}$.
- The maximum predicted annual PM is 1% of the impact assessment criterion for PM_{10} and 3% of the impact assessment criterion for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 0.1% or less than the relevant impact assessment criterion.
- The maximum predicted 24-hour HF is 29% of the impact assessment criterion, for 7-day 26%, for 30-day HF, 42% and for 90-day, 57%.
- The annual average lead concentration is 0.8 % of the impact assessment criterion.

For the pollutants above it is also important to consider cumulative impacts due to existing background air quality. The cumulative predictions relevant to the Regulatory (POEO) Scenario are presented in **Section 9.2.2**. Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary and show that when emitting at the POEO emission limits:

- Cd is 96% the impact assessment criterion.
- Hg is 10% of the impact assessment criterion.
- dioxins and furans are 1% of the impact assessment criterion.
- Be is 2152% of the impact assessment criterion.
- As is 96% of the impact assessment criterion.
- Sb is 1% of the impact assessment criterion.
- Cr(III) is 1% of the impact assessment criterion.
- Cr(VI) is 96% of the impact assessment criterion.
- Ni is 48% of the impact assessment criterion.
- Mn is 0.5% of the impact assessment criterion.
- (assessed as benzene) is 21% of the impact assessment criterion.

In general there is a significant improvement in the ground level concentration predictions for the criteria pollutants compared with previous studies **(Pacific Environment, 2015; 2016; 2017c)**. This is attributed to there now being a single stack source and an effective halving of projected mass emission rates. However, for the metals assessed in this scenario, the significant reductions in ground level predictions has not directly followed through as a more conservative assumption has been adopted within the current assessment whereby the in-stack concentration has been set to the limit of 1 mg/Nm^3 for each individual metal rather than in aggregate, as previously assessed **(Pacific Environment, 2017c)**.

As shown in **Table 9-2** and noted above, there is one air quality metric (Be) that is predicted to exceed the NSW impact assessment criteria when the facility is operated under the POEO in-stack limits.

However, given that the IED limits investigated as part of Scenario 4 are more stringent, and are reflective of the facility's design specifications, it is suggested that these limits are adopted in the Environmental Protection Licence. As seen in **Section 9.1.4**, adoption of the IED limits for Be are anticipated to be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

9.1.3 Scenario 3 - Upset

A summary of the predicted maximum ground level concentrations for each pollutant is presented in **Table 9-3**. Ground level concentrations are presented at and beyond the site boundary, as well as the maximum prediction at sensitive receptors. Predictions above the relevant NSW impact assessment criterion are shown in bold.

Long term averaging periods (annual, 90 day, 30 day, 7 day and 1 day) have not been included. This is because any upset emission scenario is anticipated to last a maximum of a matter of hours (likely less). Therefore prediction over longer averaging periods is not relevant for this scenario. For this reason also, is it considered more appropriate to compare the 100th percentile results with the impact assessment criteria. This is considered a more statistically valid approach given the short-term and infrequent nature of any upset conditions (limited to a maximum of four hours) applying the Approved methods 99th or 99.9th percentile criteria would thus potentially under-state the predicted short-duration ground level concentration. For completeness, both the 100th percentile prediction, and the applicable percentile under the Approved Methods, are shown in **Table 9-3**.

Table 9-3: Summary of predicted ground level concentrations during upset conditions

Pollutant	Averaging period	Units	Criterion	Highest prediction at and beyond site boundary		Highest prediction at sensitive receptor	
				100th percentile	Approved Methods percentile	100th percentile	Approved Methods percentile
NO_2 (a)	1 hour	µg/m^3	246	53	53	41	41
SO_2	10-minute	µg/ m^3	712	94	94	74	74
	1 hour	µg/ m^3	570	66	66	52	52
CO	15-minute	mg/ m^3	100	0.1	0.1	0.1	0.1
	1 hour	mg/ m^3	30	0.1	0.1	0.1	0.1
	8 hours	mg/ m^3	10	0.04	0.04	0.03	0.03
HCl	1 hour	mg/ m^3	0.14	0.01	0.01	0.01	0.01
Cd	1 hour	mg/ m^3	0.000018	**5.9E-05**	**5.4E-05**	**4.6E-05**	**3.6E-05**
Hg	1 hour	mg/ m^3	0.00018	6.6E-05	6.0E-05	5.2E-05	4.0E-05
Dioxins and furans (b)	1 hour	mg/ m^3	0.000000002	1.3E-10	1.2E-10	1.0E-10	8.0E-11
Benzene	1 hour	mg/ m^3	0.029	2.0E-05	1.8E-05	1.5E-05	1.2E-05
Toluene	1 hour	mg/ m^3	0.19	3.9E-05	2.1E-05	3.1E-05	1.8E-05
Xylene	1 hour	mg/ m^3	0.36	1.3E-05	7.2E-06	1.0E-05	6.1E-06
NH_3	1 hour	mg/ m^3	0.33	2.6E-03	2.4E-03	2.1E-03	1.6E-03
H_2S	1 hour	µg/ m^3	1.38	1.3	0.7	1.0	0.6
PAH (as benzo(a)pyrene)	1 hour	mg/ m^3	0.0004	6.6E-07	6.0E-07	5.2E-07	4.0E-07
Dichloro-methane	1 hour	mg/ m^3	3.19	2.6E-05	2.4E-05	2.1E-05	1.6E-05
Acetone (propanone)	1 hour	mg/ m^3	22	2.4E-05	2.2E-05	1.9E-05	1.4E-05
Trichloro-ethylene	1 hour	mg/ m^3	0.5	6.6E-06	6.0E-06	5.2E-06	4.0E-06
Be	1 hour	mg/ m^3	0.000004	6.9E-08	6.3E-08	5.4E-08	4.2E-08
Ag	1 hour	mg/ m^3	0.0018	3.4E-06	3.1E-06	2.6E-06	2.0E-06
Zn (as ZnO)	1 hour	mg/ m^3	0.09	6.7E-04	6.1E-04	5.3E-04	4.1E-04
As	1 hour	mg/ m^3	0.00009	1.0E-05	9.6E-06	8.2E-06	6.3E-06
Sb	1 hour	mg/ m^3	0.009	1.6E-05	1.4E-05	1.2E-05	9.5E-06
Cr (III)	1 hour	mg/ m^3	0.009	8.9E-05	8.1E-05	7.0E-05	5.4E-05
Cr (VI)	1 hour	mg/ m^3	0.00009	1.7E-07	1.6E-07	1.3E-07	1.0E-07
Ni	1 hour	mg/ m^3	0.00018	1.6E-04	1.4E-04	1.2E-04	9.5E-05
Cu (dusts and mists)	1 hour	mg/ m^3	0.0037	7.8E-05	7.2E-05	6.1E-05	4.7E-05

Pollutant	Averaging period	Units	Criterion	Highest prediction at and beyond site boundary		Highest prediction at sensitive receptor	
				100th percentile	Approved Methods percentile	100th percentile	Approved Methods percentile
Mn	1 hour	mg/ m³	0.018	1.8E-04	1.6E-04	1.4E-04	1.1E-04
Phenol	1 hour	mg/ m³	0.0037	6.6E-06	3.6E-06	5.2E-06	3.1E-06
Hexane	1 hour	mg/ m³	0.018	6.6E-06	6.0E-06	5.2E-06	4.0E-06
TVOC	1 hour	mg/ m³	0.029	1.3E-02	1.2E-02	1.0E-02	8.0E-03

Note: (a) Based on the assumption of 100% conversion from NO_x to NO_2

(b) The Approved Methods percentile adopts

- the 100th percentile for criteria pollutants
- the 99.9th percentile for air toxics
- The 99th percentile for odorous compounds including H_2S, Toluene, Xylene and Phenol.

Modelling results for criteria pollutants are assessed against the maximum prediction at sensitive receptors. In summary, the modelling results show that during upset conditions:

- The maximum predicted 1-hour NO_2 is 17% of the impact assessment criterion, assuming 100% conversion from NO_x to NO_2.
- The maximum predicted 10-minute SO_2 is 10% of the impact assessment criterion, and for 1-hour 9%.
- The maximum predicted CO 15-minute, and 1-hour and 8-hour averaging periods are 0.3% or less than the relevant impact assessment criterion.

For the pollutants above it is also important to consider cumulative impacts due to existing "background" air quality, and other air quality impacts in the area. The cumulative predictions are presented in **Section 9.2.3**.

Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary. The individual odour compounds (H_2S, Toluene, Xylene and Phenol) are assessed against the 99th percentile prediction.

- HCl is 9% of the impact assessment criterion.
- Cd is 329% of the impact assessment criterion.
- Hg is 37% of the impact assessment criterion.
- dioxins and furans are 7% of the impact assessment criterion.
- benzene is 0.07% of the impact assessment criterion.
- toluene is 0.02% of the impact assessment criterion.
- xylene is 0.004% of the impact assessment criterion.
- NH_3 is 0.8% of the impact assessment criterion.
- PAH (as benzo(a)pyrene) is 0.2% of the impact assessment criterion.
- H_2S is 95% of the impact assessment criterion.
- dichloromethane is 0.001% of the impact assessment criterion.
- acetone is 0.0001% of the impact assessment criterion.
- trichloroethylene is 0.001% of the impact assessment criterion.
- Be is 1.7% of the impact assessment criterion.
- Ag is 0.2% of the impact assessment criterion.
- Zn is 0.7% of the impact assessment criterion.
- As is 12% of the impact assessment criterion.
- Sb is 0.2% of the impact assessment criterion.
- Cr(III) is 1.0% of the impact assessment criterion.
- Cr(VI) is 0.2% of the impact assessment criterion.
- Ni is 87% of the impact assessment criterion.
- Cu is 2.1% of the impact assessment criterion.

- Mn is 1.0% of the impact assessment criterion.
- phenol is 0.2% of the impact assessment criterion.
- hexane is 0.04% of the impact assessment criterion.
- TVOC (assessed as benzene) is 45% of the impact assessment criterion.

As already discussed, there is an overall improvement in the ground level concentrations predictions for the criteria pollutants and air toxics compared with previous studies **(Pacific Environment, 2015; 2016; 2017c)**. This is attributed to there now being a single stack source and associated reduction in mass emission rates.

As shown in **Table 9-3** and noted above, Cd is predicted to exceed the NSW impact assessment criterion under the upset scenario.

To assess these exceedances during upset conditions, a probabilistic approach has been adopted. As already discussed in **Section 2.5**, adopting a design to the requirements of the EU IED entails that such events shall under no circumstance occur for more than four hours uninterrupted where the emission values exceed the limits and no more than 60 hours per year. Thus, the probability that upset conditions will actually result in adverse air quality impacts at ground level is therefore a function of the maximum allowable hours of upset per year (60/8,760 = 0.68%) multiplied by the predicted frequency of exceedance per annum for each pollutant under upset emissions. The resultant probabilities are therefore:

- Cd – 0.012% probability (based on prediction of 159 hours of 8,760 hours predicted to be above 0.000018 mg/m^3 = 0.012%)

Based on the above it can be inferred that the probability of the above pollutants resulting in adverse air quality impacts at ground level due to upset conditions would be extremely low.

9.1.4 Scenario 4 – Regulatory (IED Limits)

To reflect the design specifications of the EfW facility (i.e. emission control system performance over and above the requirements of the NSW Clean Air Regulations), an alternative emission scenario is presented, based on plant performance to meet the requirements of the EU IED Limits (see **Section 4.3**).

As noted in **Section 6.3.4**, this scenario is presented to inform future Environmental Protection Licensing of the EfW facility.

A summary of the ground level concentrations (GLCs) for each pollutant when released at the IED emission limits is presented in **Table 9-4**. GLCs are presented at and beyond the site boundary, as well as the maximum prediction at sensitive receptors. Predictions above the relevant NSW impact assessment criterion are shown in bold.

Table 9-4: Summary of predicted ground level concentrations at IED emission limits

Pollutant	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
NO_2 (a)	1 hour	µg/m^3	246	52.6	41.3
	Annual	µg/ m^3	62	1.3	1.2
SO_2	10-minute	µg/ m^3	712	37.7	29.5
	1 hour	µg/ m^3	570	26.3	20.6
	24 hours	µg/ m^3	228	1.6	1.2
	Annual	µg/ m^3	60	0.3	0.3
CO	15-minute	mg/ m^3	100	0.02	0.01
	1 hour	mg/ m^3	30	0.01	0.01
	8 hours	mg/ m^3	10	0.004	0.003
PM_{10}	24 hours	µg/ m^3	50	0.32	0.24
	Annual	µg/ m^3	25	0.06	0.06
$PM_{2.5}$	24 hours	µg/ m^3	25	0.32	0.24
	Annual	µg/ m^3	8	0.06	0.06
HCl	1 hour	mg/ m^3	0.14	0.01	0.00
HF	24 hours	µg/ m^3	2.9	0.03	0.02
	7 days	µg/ m^3	1.7	0.01	0.01
	30 days	µg/ m^3	0.84	0.01	0.01
	90 days	µg/ m^3	0.5	0.01	0.01
Cd (b)	1 hour	mg/ m^3	0.000018	6.0E-06	4.0E-06
Hg (b)	1 hour	mg/ m^3	0.00018	6.0E-06	4.0E-06
Dioxins and furans (b)	1 hour	mg/ m^3	0.000000002	1.2E-11	8.0E-12
As(b)	1 hour	mg/ m^3	0.00009	6.0E-05	4.0E-05
Sb(b)	1 hour	mg/ m^3	0.009	6.0E-05	4.0E-05
Cr (III) (b)	1 hour	mg/ m^3	0.009	6.0E-05	4.0E-05
Cr (VI) (b)	1 hour	mg/ m^3	0.00009	6.0E-05	4.0E-05
Pb	Annual	µg/ m^3	0.5	3.2E-03	2.9E-03
Ni(b)	1 hour	mg/ m^3	0.00018	6.0E-05	4.0E-05
Cu (dusts and mists) (b)	1 hour	mg/ m^3	0.0037	6.0E-05	4.0E-05
Mn(b)	1 hour	mg/ m^3	0.018	6.0E-05	4.0E-05
TVOC(b)	1 hour	mg/ m^3	0.029	2.4E-03	1.6E-03

Note: (a) based on the assumption of 100% conversion from NO_x to NO_2[m]
(b) expressed as the 99.9th percentile of the dispersion modelling prediction

Modelling results for criteria pollutants are assessed against the maximum prediction at sensitive receptors. In summary, the modelling results show that when emitting at the IED emission limits:

- The maximum predicted 1-hour NO_2 is 17% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2

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[m] As discussed, we have conservatively assumed 100% conversion of NO_x to NO_2.

- The maximum predicted annual NO_2 is 2% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 4% of the impact assessment criterion, for 1-hour 4%, for 24-hour SO_2, 0.5% and for annual, 0.5%.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 0.03% or less than the relevant impact assessment criterion.
- The maximum predicted 24-hour PM increment is 0.5% of the impact assessment criterion for PM_{10} and 0.9% of the impact assessment criterion for $PM_{2.5}$.
- The maximum predicted annual PM is 0.2% of the impact assessment criterion for PM_{10} and 0.7% of the impact assessment criterion for $PM_{2.5}$.
- The maximum predicted 24-hour HF is 1% of the impact assessment criterion, for 7-day 2%, for 30-day HF, 3% and for 90-day, 5%.
- The annual average lead concentration is 0.3% of the impact assessment criterion.

For the pollutants above it is also important to consider cumulative impacts due to existing background air quality. The cumulative predictions relevant to Scenario 4 are presented in **Section 9.2.4**.

Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary and show that when emitting at the IED emission limits:

- HCl is 5% of the impact assessment criterion.
- Cd is 33% of the impact assessment criterion.
- Hg is 3% of the impact assessment criterion.
- dioxins and furans are 0.6% of the impact assessment criterion.
- As is 67% of the impact assessment criterion.
- Sb is 0.7% of the impact assessment criterion.
- Cr(III) is 0.7% of the impact assessment criterion.
- Cr(VI) is 67% of the impact assessment criterion.
- Ni is 34% of the impact assessment criterion.
- Cu is 1.6% of the impact assessment criterion.
- Mn is 0.3% of the impact assessment criterion.
- TVOC (assessed as benzene) is 8% of the impact assessment criterion.

As shown in **Table 9-4** and noted above, all air quality metrics are predicted to comply with the NSW impact assessment criteria when the facility is operated under the IED in-stack limits.

As already discussed, there is an overall improvements in the ground level concentrations predictions for the criteria pollutants compared with previous studies **(Pacific Environment, 2015; 2016; 2017c)**. This is attributed to there now being a single stack source and associated reduction in predicted emissions. However, the for the metals assessed in this scenario, the reductions in ground level predictions has not directly followed through as the in-stack concentration has, for this assessment, been conservatively set to the limit for each metal, rather than in aggregate, as previously assessed (**Pacific Environment, 2017c**).

Finally, it is noted that previous assessment of a two stack, four line facility (e.g. **Pacific Environment, 2017c**) proposed that an in-stack concentration limit for Cd of 0.04 mg/Nm^3 would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility, and this proposed emission limit would be captured within a statement of commitment for the Project. For consistency with previous commitments, it is assumed that this commitment is retained, notwithstanding that compliance with the POEO limit is now anticipated.

9.1.5 Scenario 5 - Diesel Generators

As noted in **Section 4.3**, the diesel generators would not operate for more than 200 hours per year and for a few hours during any one event, therefore the predicted ground level concentrations from these sources have been compared against the short term assessment criteria only.

The atmospheric dispersion model results attributable to operation of the emergency diesel generators, concurrent with stack emissions are conservatively estimated in **Table 9-5**. The predicted ground level concentrations for the most impacted sensitive receptor at or beyond the site boundary for NO_2, CO, PM_{10}, $PM_{2.5}$, benzene and SO_2 have been provided.

In addition to worst-case predictions associated with operation of the emergency diesel generators, **Table 9-5** also provides the predicted maximum ground level concentrations for the most impacted sensitive receptor during operation of the stack at or beyond the site boundary for NO_2, CO, PM_{10}, $PM_{2.5}$, benzene and SO_2. As shown, the predicted maximum concentration of the generators and stack in aggregate results in a concentration that is less than the respective criteria for the assessed pollutants. Note that this is a highly conservative assessment as it is not anticipated that the maximum concentrations from these two distinct sources would occur at either the same time or location, given the substantial difference in exit parameters between the sources.

Table 9-5: Conservative estimation of ground level concentrations during operation of emergency diesel generators

Parameter	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
NO_2	1 hour	µg/m³	246	170 (1)	177 (1)
CO	15-minute	mg/m³	100	5.8	4.6
	1 hour	mg/m³	30	4.4	3.5
	8 hour	mg/m³	10	2.6	2.1
PM_{10}	24 hour	µg/m³	50	1.4	0.2
$PM_{2.5}$	24 hour	µg/m³	25	1.4	0.2
Benzene (2,3)	1 hour	mg/m³	29	24	18
SO_2	10-minute	µg/m³	712	0.9	0.1
	1 hour	µg/m³	570	0.6	0.1
	24 hour	µg/m³	228	4.5E-07	0.007

Note 1: Nitrogen dioxide predictions have been made using the Ozone Limiting Method and as such, the values presented take account of contemporaneous background observations

Note 2: Consistent with Section 7.2.2 of **NSW EPA (2016)**, the predictions of benzene are compared against the ground level concentration criterion as increment only, at the 99.9th percentile.

Note 3: Benzene has been assumed to comprise 1% of the total VOC emission.

Table 9-5 indicates that predicted concentrations of all parameters are anticipated to be below the relevant NSW EPA ground level concentration criteria during operation of the emergency diesel generators.

9.2 Cumulative Assessment

To assess impacts against the relevant air quality criteria, it is necessary consider the existing background concentrations of the air quality metrics in question. The existing background air quality environment is described in **Section 5**.

9.2.1 Scenario 1 - Expected

The maximum predicted GLCs for products of combustion from the EfW facility are combined with maximum background levels and presented in **Table 9-6**. This provides a conservative estimate of cumulative impact as the probability of a maximum observed value occurring at the time of a maximum predicted value is very small.

Table 9-6: Cumulative assessment for criteria pollutants during expected operations

Pollutant	Averaging period	Units	Criteria	Maximum GLC at sensitive receptor	Maximum background	Cumulative concentration
NO_2 [(a)]	1 hour	µg/m³	246	12.4	100	112.4
	Annual	µg/ m³	62	0.71	23	23.71
SO_2	10-minute	µg/ m³	712	4.0	107	111.0
	1 hour	µg/ m³	570	2.8	57	59.8
	24 hours	µg/ m³	228	0.5	11	11.6
	Annual	µg/ m³	60	0.2	3.0	3.2
CO	15-minute	mg/ m³	100	0.003	8.0	8.003
	1 hour	mg/ m³	30	0.002	5.0	5.002
	8 hours	mg/ m³	10	0.001	3.0	3.001
PM_{10}	24 hours	µg/ m³	50	0.02	49	49.02
	Annual	µg/ m³	25	0.01	19	19.01
$PM_{2.5}$	24 hours	µg/ m³	25	0.02	24.8	24.82
	Annual	µg/ m³	8	0.01	7.0	7.01

Note: (a) based on the assumption of 100% conversion from NO_x to NO_2

Cumulative predictions are also presented for the criteria air quality metrics:

- The maximum predicted 1-hour NO_2 is 46% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 38% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 16% of the impact assessment criterion, for 1-hour 10%, for 24-hour SO_2, 5% and for annual, 5%.
- The maximum predicted 24-hour PM is 98% of the impact assessment criterion for PM_{10} and 99% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 76% of the impact assessment criterion for PM_{10} and 88% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 30% or less than the relevant impact assessment criterion.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

9.2.2 Scenario 2 - Regulatory (POEO Emission Limits)

The maximum predicted GLCs for products of combustion from the EfW facility are combined with maximum background levels and presented in **Table 9-7**.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background, with the exception of $PM_{2.5}$, which results in a cumulative concentration marginally above the 24-hour $PM_{2.5}$ criterion of 25 µg/m^3. However, this occurs on a day when the background $PM_{2.5}$ concentration is already high (at 24.8µg/m^3) and the probability of the EfW facility resulting in additional exceedances of the impact assessment criterion is considered to be low.

This is demonstrated in **Figure 9-24** which shows a time-series plot of the background 24-hour $PM_{2.5}$ concentration recorded at Liverpool with the EfW facility increment (from the most impacted sensitive receptor) stacked on top. The EfW facility clearly adds a very small increment to the existing background, however is predicted to result in one additional exceedances of the air quality goal. **Figure 9-24** indicates that these exceedances are a result of the high background $PM_{2.5}$ concentrations, rather than the incremental increase from the EfW facility. It is also noted that this assumes the facility operates at the POEO emission limit for PM continuously, which is not considered to be an operational reality.

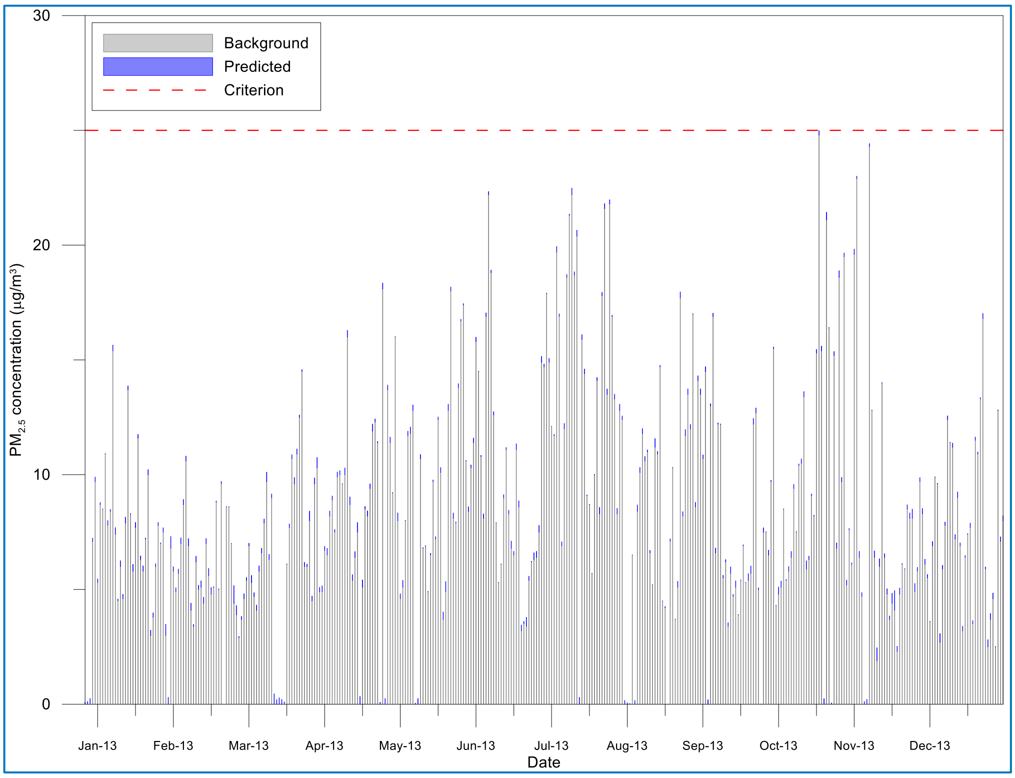

Figure 9-24: Predicted cumulative PM_{10} at most affected sensitive receptor adopting POEO Emission Limits

Table 9-7: Cumulative assessment for criteria pollutants while at POEO Emission Limits

Pollutant	Averaging period	Units	Criteria	Maximum GLC at sensitive receptor	Maximum background	Cumulative concentration
NO_2 [(a)]	1 hour	µg/m^3	246	37	100	137
	Annual	µg/ m^3	62	2.1	23	25.1
CO	15-minute	mg/ m^3	100	0.01	8.0	8.01
	1 hour	mg/ m^3	30	0.01	5.0	5.01
	8 hours	mg/ m^3	10	0.01	3.0	3.01
PM_{10}	24 hours	µg/ m^3	50	0.8	49	49.8
	Annual	µg/ m^3	25	0.2	19	19.2
$PM_{2.5}$ [(b)]	24 hours	µg/ m^3	25	0.8	Daily varying	25.0
	Annual	µg/ m^3	8	0.2	7.0	7.2

Notes (a) Based on the assumption of 100% conversion from NO_x to NO_2

(c) A contemporaneous assessment of predicted $PM_{2.5}$ concentrations was completed to assess cumulative impacts using data from Liverpool.

In summary, based on the information provided above and within **Section 9.1.2**, it is considered that application of the POEO emission limits within the Environmental Protection Licence for the facility would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

The exception to this is Be, where, as discussed in **Section 9.1.2**, it is proposed in any event that the more stringent IED regulatory limit be adopted for environmental protection licencing purposes.

It is noted that the proposed technology for the EfW facility is based on existing facilities in Europe and will incorporate best available technology (BAT) for flue gas treatment. The flue gas treatment is designed to meet the in-stack concentrations limits for waste incineration set by the EU IED. The IED emissions limits (**Table 4-3**) are generally more stringent that the Clean Air Regulation limits (**Table 4-2**). On the above basis, environmental licencing based on the IED limits (or hourly extrapolations of these performance standards) would also be a suitable alternative regulatory approach. Performance against in-stack emission limits reflective of the EU IED is presented within **Section 9.1.4** (incremental) and **Section 9.2.4** (cumulative).

9.2.3 Scenario 3 - Upset

The *maximum predicted* GLCs for products of combustion from the EfW facility during upset conditions are combined with *maximum observed (background) concentrations* and presented in **Table 9-8**. This again provides a highly conservative estimate of worst-case cumulative impact as the probability of a maximum observed value occurring at the time of a maximum predicted value (under upset conditions – maximum 60 hours per annum) is considered extremely small.

Table 9-8: Cumulative assessment for criteria pollutants

Pollutant	Averaging period	Units	Criteria	Maximum GLC at sensitive receptor	Maximum background	Cumulative concentration
NO_2 [(a)]	1 hour	µg/m^3	246	41	100	141
SO_2	10-minute	µg/ m^3	712	74	107	181
	1 hour	µg/ m^3	570	52	57	109
CO	15-minute	mg/ m^3	100	0.1	8	8.1
	1 hour	mg/ m^3	30	0.1	5	5.1
	8 hour	mg/ m^3	10	0.03	3	3.03

Notes (a) Based on the assumption of 100% conversion from NO_x to NO_2

9.2.4 Scenario 4 – Regulatory (IED Limits)

The maximum predicted GLCs for products of combustion from the EfW facility are combined with maximum background levels and presented in **Table 9-9**. This provides a conservative estimate of cumulative impact as the probability of a maximum observed value occurring at the time of a maximum predicted value is very small.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

Table 9-9: Cumulative assessment for criteria pollutants operating at IED limits

Pollutant	Averaging period	Units	Criteria	Maximum GLC at sensitive receptor	Maximum background	Cumulative concentration
NO_2 [(a)]	1 hour	µg/m^3	246	41.3	100	141.3
	Annual	µg/ m^3	62	1.2	23	24.2
SO_2	10-minute	µg/ m^3	712	29.5	107	136.5
	1 hour	µg/ m^3	570	20.6	57	77.6
	24 hours	µg/ m^3	228	1.2	11	12.2
	Annual	µg/ m^3	60	0.3	3.0	3.3
CO	15-minute	mg/ m^3	100	0.01	8.0	8.01
	1 hour	mg/ m^3	30	0.01	5.0	5.01
	8 hours	mg/ m^3	10	0.003	3.0	3.003
PM_{10}	24 hours	µg/ m^3	50	0.2	49	49.2
	Annual	µg/ m^3	25	0.1	19	19.1
$PM_{2.5}$	24 hours	µg/ m^3	25	0.2	24.8	25.0
	Annual	µg/ m^3	8	0.1	7.0	7.1

Note: (a) based on the assumption of 100% conversion from NO_x to NO_2 [n]

9.2.5 Scenario 5 – Diesel generators

The maximum predicted GLCs for products of combustion from the operations of the diesel generators combined with the EfW facility under expected operations (i.e. Scenario 1 emissions) and combined with maximum background levels and presented in **Table 9-10**. This provides a conservative estimate of cumulative impact as the probability of a maximum observed value occurring at the time of a maximum predicted value is very small.

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[n] As discussed, we have conservatively assumed 100% conversion of NO_x to NO_2.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

Table 9-10: Cumulative assessment for criteria pollutants for diesel generators

Parameter	Averaging period	Units	Criteria	Highest prediction at and beyond site boundary (diesel generators + EfW stack)	Highest prediction at sensitive receptor (diesel generators + EfW stack)	Maximum background	Highest prediction at and beyond site boundary	Highest prediction at sensitive receptor
NO_2 (a)	1 hour	µg/m^3	246	757 (b)	599 (b)	Hourly varying	170	177
CO	15-minute	mg/m^3	100	5.8	4.6	8	13.8	12.6
	1 hour	mg/m^3	30	4.4	3.5	5	9.4	8.5
	8 hour	mg/m^3	10	2.6	2.1	3	5.6	5.1
PM_{10}	24 hour	µg/m^3	50	1.4	0.3	Daily varying	49.0	49.0
$PM_{2.5}$	24 hour	µg/m^3	25	1.4	0.3	Daily varying	25.0	25.0
Benzene (c,d)	1 hour	mg/m^3	29	24	18	-	24	18
SO_2	10-minute	µg/m^3	712	5.1	4.0	107	112.1	111.0
	1 hour	µg/m^3	570	3.6	2.8	57	60.6	59.8
	24 hour	µg/m^3	228	0.6	0.6	11	11.6	11.6

Notes (a) Nitrogen dioxide predictions have been made using the Ozone Limiting Method and as such, the values presented take account of contemporaneous background observations

(b) NOx

(c) Consistent with Section 7.2.2 of **NSW EPA, 2016**, the predictions of benzene are compared against the ground level concentration criterion as increment only, at the 99.9th percentile.

(d) Benzene has been assumed to comprise 1% of the total VOC emission.

9.3 Mitigation

Community and stakeholder concern has been raised related to the ability of the waste receival hall to contain fugitive (principally odour) emissions when the facility is under shut-down conditions (i.e. air is not being drawn to the furnaces, and the area may not thus be under negative pressure).

The facility consists of two lines, each of them in operation for at least 8,000 hours/year. For routine maintenance only one line is shut down at a time, the other remains in operation. Therefore air is extracted from the waste receival hall all year round. Even in case of an unplanned shut-down only one line has to be stopped, and thus it is highly unlikely that a problem occurs on both lines at the same time. Even if this would be the case the air extraction continues in order to cool down the furnace.

In addition, during maintenance the air flow remains to keep a slight under pressure in the system in order to prevent dust to escape from furnace and air pollution control system. As a result there will be no situation where air is not extracted from the waste receival hall / bunker.

Finally, it is highlighted that, given the proposed waste stream is non-putrescible, and in the main C&I / C&D waste, it is neither highly odorous nor likely to have any toxic emission to air.

The facility has the ability to be sealed using operable doors and louvres, and it anticipated that under any condition where negative pressure is not present in the receival hall, and odorous material is being stored, the operational air quality management plan for the facility would dictate that the area be sealed until such conditions change.

Extensive information on the mitigation of emission from the stack is provided in **Section 6.1** and **Appendix C**.

9.4 NO_x Load to Air Shed

9.4.1 Impacts on Regional Air Quality

NO_x is a precursor to the formation of ozone and ozone concentrations in the Sydney region have exceeded the Ambient Air-NEPM ozone standards every year since 1994 (**DECCW, 2010**). The Sydney region is therefore considered an ozone non-attainment area and if the NO_x emission from a new facility exceeds a threshold of 90 tonnes/year, an ozone impact assessment may be required under the NSW EPA proposed ozone impact assessment framework.

Assuming the EfW facility emits NO_x at the EU IED in-stack concentration limit for 8,000 hours of the year, the annual NO_x load to the Sydney air shed would be approximately 800 tonnes/year, thereby triggering further assessment. The potential for regional photochemical smog / ozone impacts are investigated in a standalone study, submitted as part of the Environmental Assessment (**Pacific Environment, 2017b**).

Based on the outcomes of the regional ozone modelling the annual NO_X load was revised through optimisation of the facility's proposed Selective Non-Catalytic Reduction (SNCR) emission control system. The daily average NO_x emissions estimate was revised down to be a daily average of 120 mg/m^3 with a total annual NOx load of 294 tonnes per year (assuming 8,000 hours per year of operation). Further detail of this is provided within **Pacific Environment, 2016b**.

9.4.2 Load Based Licensing

As discussed in **Section 4.5** the NO_x load based licensing threshold is 2.5 tonnes/year. Based on the anticipated NO_x emissions of 294 tonnes/year the EfW exceeds this threshold and it is therefore anticipated that the EfW facility will be subject to a load based licence limit on total NO_x emissions, as well as summertime NO_x emissions, prescribed by EPA on issuance of the EfW facility's EPL.

10 GREENHOUSE GAS ASSESSMENT

10.1 Introduction

The World Resources Institute / World Business Council for Sustainable Development Greenhouse Gas Protocol (the GHG Protocol) originally documented the different scopes for greenhouse gas (GHG) emission inventories. The GHG Protocol is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. This corporate accounting and reporting standard is endorsed by the Australian Department of Climate Change and Energy Efficiency.

The GHG Protocol defines three scopes for developing inventories leading to reporting of emissions. These scopes help to delineate direct and indirect emission sources, improve transparency, and provide a degree of flexibility for individual organisations to report based on their organisational structure, business activities and business goals.

Three scopes of emissions (also shown in **Figure 10-1**) are defined in the GHG Protocol:

- 'Scope 1' emissions: direct GHG emissions occurring from sources owned or controlled by the company – for example vehicle fleet and direct fuel combustion. Any negative emissions (sequestration), for example from a plantation owned by the entity, would also be included in Scope 1.
- 'Scope 2' emissions: indirect GHG emissions from purchasing electricity or heat from other parties; and
- 'Scope 3' emissions: indirect emissions which occur due to the company's business activities, but from sources not owned or controlled by the company - for example emissions from employee business-related air travel.

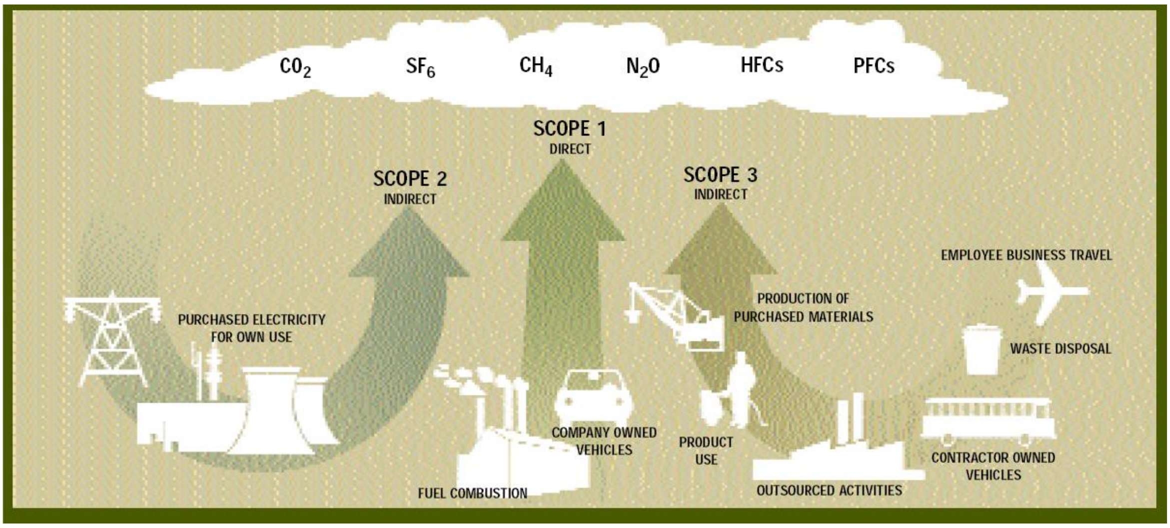


Figure 10-1: Overview of Scopes and Emissions across a Value Chain

A number of sources were considered for the greenhouse gas assessment of the facility. Emissions from the waste incineration were included. The reduction of greenhouse gases for substituting grid electricity and waste diverted from landfill were also included in the assessment. Scope 3 emissions, such as fuel consumption from transporting waste to site, were not included in the greenhouse gas assessment as they would be minor.

10.2 Reporting Guidelines

The GHG assessment is guided by, and makes reference to the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (the "NGER Measurement Determination") incorporating the National Greenhouse and Energy Reporting (Measurement) Amendment Determination 2012 (No. 1).

The National Greenhouse and Energy Reporting Regulations 2008 (the NGER Regulations) describe the detailed requirements for reporting under the NGER Act 2007. The National Greenhouse and Energy Reporting (Measurement) Technical Guidelines (the NGER Technical Guidelines) have been intended to support reporting under the NGER Act 2007. They have been designed to assist corporations in understanding and applying the NGER Measurement Determination.

The NGER Technical Guidelines outline calculation methods and criteria for determining GHG emissions, energy production, energy consumption and potential GHG emissions embodied in natural gas.

Under the NGER Act, Scope 1 and 2 emissions must be accounted for by the organisation. Reporting of Scope 3 is optional and has been addressed in this assessment qualitatively as the Scope 3 emissions would be minor. The EfW facility will have negligible Scope 2 emissions (of the site will be a net exporter of electricity) and the focus of this assessment is therefore on Scope 1 emissions.

10.3 Emission Estimates

10.3.1 Scope 1 GHG emissions from Waste Incineration

The calculation of GHG emissions for waste incineration is based on the maximum volume of material that will be combusted during any one year (see **Section 2.1**). The compositional data and chemical analysis used for these calculations are provided in **Appendix D** (**Ramboll, 2017**. It is noted that the precise composition of the waste may vary slightly such as the updated values presented in the Project Design brief (**Ramboll, 2017**). However, these minor changes would not have a material impact on the conclusions of the GHG assessment.

Combusted ash residue that is to be landfilled will not result in GHG emissions and therefore has not been considered. This is because the ash does not release methane as the available carbon has already been consumed during combustion (**US EPA, 2014**).

Part 5.5, Section 5.53 of the NGER Technical Guidelines outlines Method 1 for the calculation of carbon dioxide emissions from waste incineration, as follows:

$$E_i = Q_i \times CC_i \times FCC_i \times OF_i \times 3.664$$

where:
E_i is the emissions of CO_2 released from the incineration of waste type (*i*) measured in CO_2-e tonnes.
Q_i is the quantity of waste type (*i*) incinerated by the facility during the year, measured in tonnes.
CC_i is the carbon content of waste type (*i*).
FCC_i *is the proportion of carbon in* waste type (*i*) that is fossil origin (i.e. not biomass).
OF_i is the oxidation factor of waste type (*i*)

A range of GHG emissions from waste incineration were estimated based on different carbon contents for single waste streams. The average GHG emissions were also estimated. The estimated GHG emissions from waste incineration are presented in **Table 10-1**.

Table 10-1: Method 1 estimation of GHG emissions from waste incineration

	Waste (tpa) [1]	Carbon Content (%)	% carbon that is fossil origin[2]	Oxidation Factor [3]	CO_2-e (tpa)
Average	552,500	31.51% [4]	14.95%	1.0	95,362
Maximum	675,000	44.18% [5]	14.95%	1.0	163,353
Minimum	405,000	23.45% [6]	14.95%	1.0	52,023

1. Source (**Ramboll, 2017**)
2. Note: It is assumed that this includes plastic and components of **Appendix D**.
3. Oxidation Factor is not known, default oxidation factor of 1.0 for industrial waste applied (**IPCC, 2006**).
4. Average carbon content of the all waste streams. Source (**Ramboll, 2017**).
5. Maximum carbon content of a single waste stream (MRF Residual Waste) Source (**Ramboll, 2017**).
6. Minimum carbon content of a single waste stream (Floc Waste) Source (**Ramboll, 2017**).

10.3.2 Scope 2 GHG Emissions (substitution of grid electricity)

The facility is designed to have a total thermal input of 235.96 MW (117.98 MW for each combustion line) and an assumed net average annual electrical efficiency of 29.1% (**Ramboll, 2017**). Based on this information the EfW facility is designed to export 68.7 MWe (29.1% x 235.96 MW). As the auxiliary load for the EfW facility is 7.3 MW the EfW facility would therefore export to the main electricity grid, thus substituting a requirement for approximately 68.7 MW of more GHG emission intensive electricity generation.

An estimated of the GHG emissions that would be substituted from the grid is presented, based on an assumption that the EfW facility would operate for 8,000 hours per annum (**Ramboll, 2017**).

The GHG emissions from grid have been estimated as follows:

$$Y = Q \times \frac{EF}{1000}$$

Where:
Y is the Scope 2 emissions measured in CO_2-e tonnes.
Q is the quantity of electricity diverted (kilowatt hours).
EF is the scope 2 emission factor for NSW (*i*).

A scope 2 emission factor for NSW for 0.84 kg CO_2-e/kWh was used

Table 10-2: Estimation of GHG emissions (substitution of grid electricity)

Net Output (MW)[1]	Operational hours (per year) [1]	Electricity diverted from the grid (kWh per year)	Emission factor for grid electricity in NSW (kg CO_2-e/kWh) [2]	CO_2-e diverted from main electricity grid (tpa)
68.7	8,000	594,600,000	0.84	461,664

1. Source (**Ramboll, 2017**)
2. Latest estimate provided in Table 41 in the National Greenhouse Accounts Factors (**DEE, 2016**).

To account for the anticipated reduction for substitution of grid electricity for the facility over time a sensitivity analysis was performed. The scope 2 emission factor for grid electricity in NSW was plotted for the last 10 years of data presented in the National Greenhouse Accounts Factors (**DEE, 2016**). The data are presented in **Figure 10-2**. From this data, a percentage reduction of the scope 2 emission factor per year was calculated based on a linear trend (slope for this trend line is -0.0062).

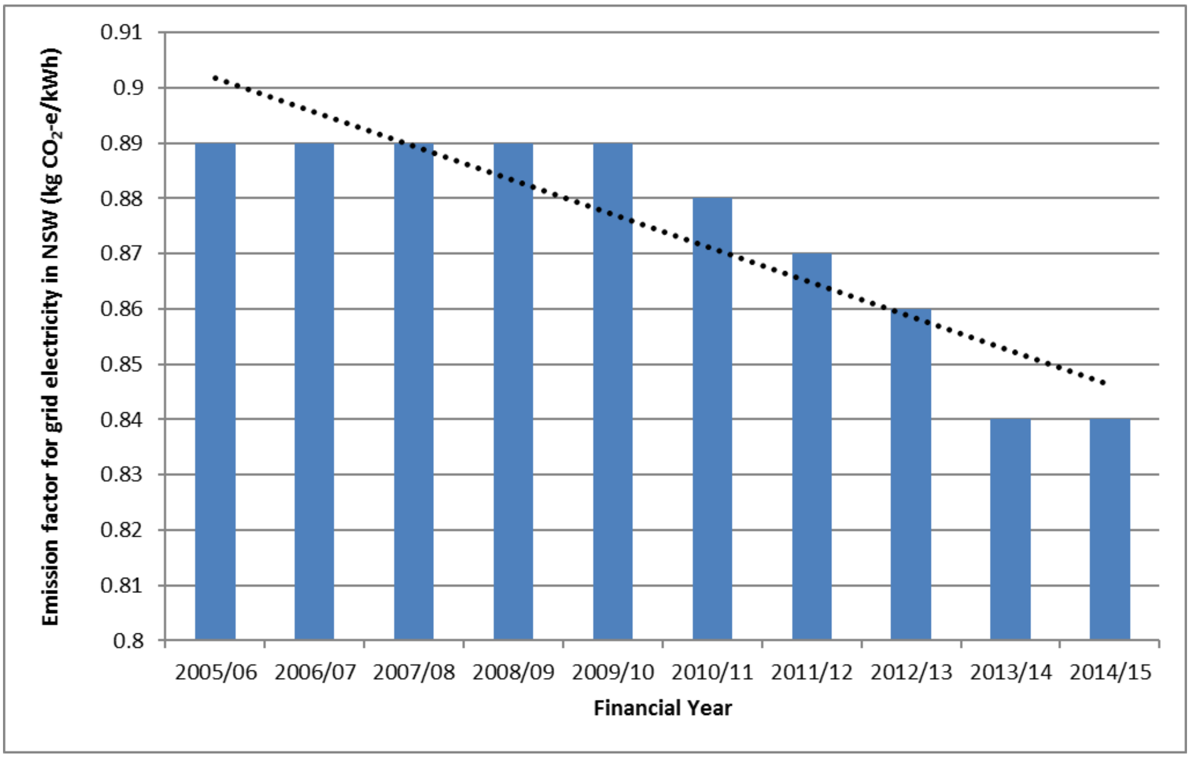


Figure 10-2: Emission factor for grid electricity in NSW from 2005/06 to present (DEE,2016)

Using a fixed and reducing scope 2 emission factor for grid electricity in NSW, the quantity of GHG emissions diverted from the NSW electricity grid were calculated assuming a 25 year life of facility as presented in **Figure 10-3**. The bars presented in the figure show the GHG emissions diverted calculated using the fixed scope 2 emission factor for grid electricity in NSW.

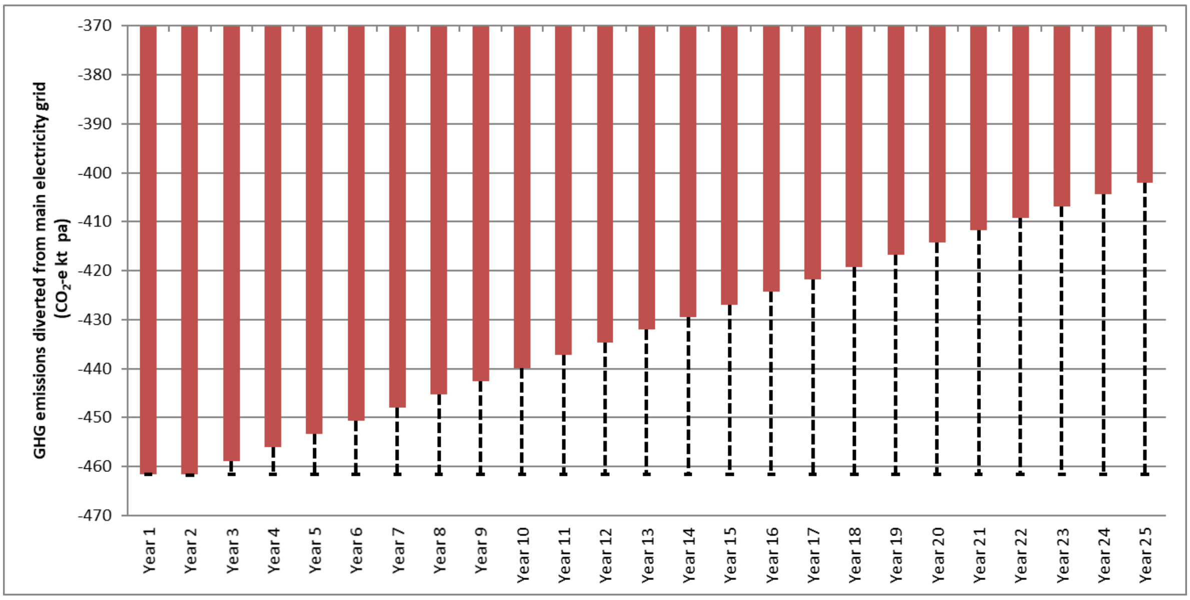


Figure 10-3: GHG emissions diverted from electricity grid

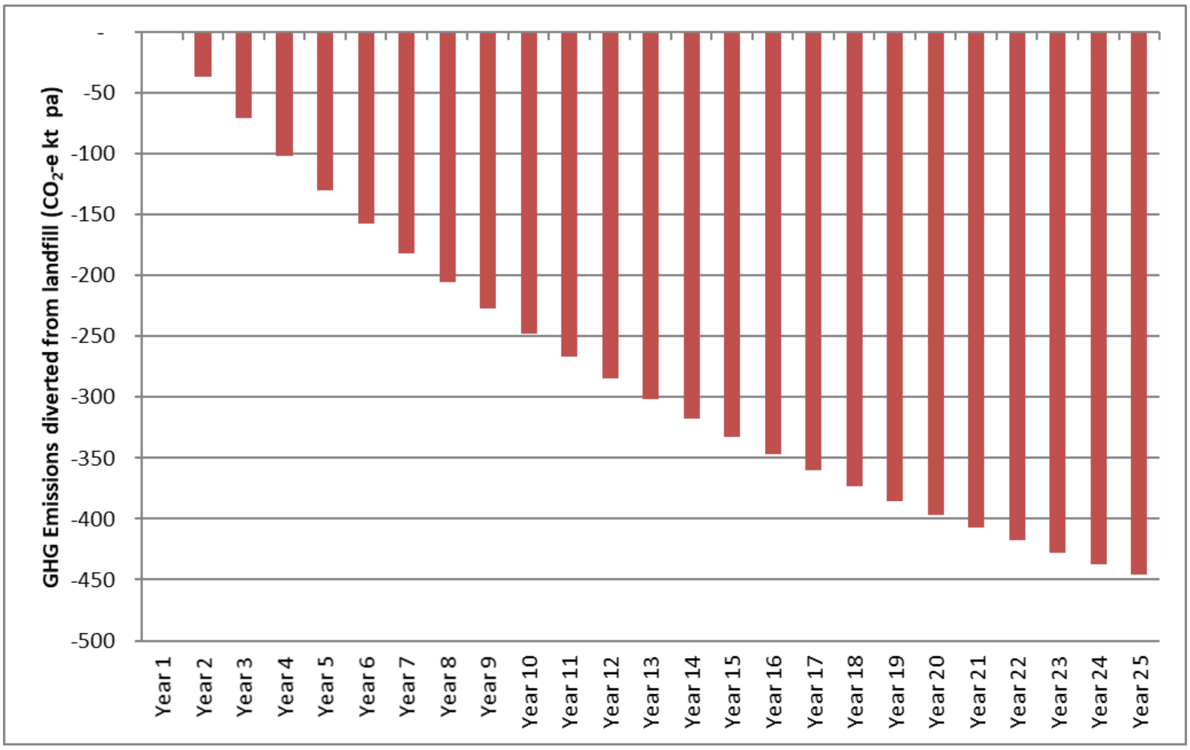
10.3.3 Scope 1 GHG Emissions Diverted from Landfilling

By removing biomass waste from the landfill, emissions of methane[o] from the decomposition of waste are eliminated. It is acknowledged that some landfills combust the methane via a flare or gas engine. However, this is not currently the case at the Genesis facility and would not form part of the future operations for the site and has therefore not been considered. The expected life of landfill project is expected to be 45 to 65 year **(ERM, 2008)**.

Emissions of methane from disposal of waste to landfill are estimated based on the NGER solid waste calculator 2015-16 (**NGER, 2016**).

The carbon content of the residual waste fuel is based on the information provided for the design fuel mix (**Ramboll, 2017**). For reference, the fuel composition data is provided in **Appendix D**[p].

The estimated GHG emissions that would be diverted from landfilling activities (assuming 552,500 tonnes landfilled per annum under the Business As Usual scenario) are presented in **Figure 10-4**.



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[o] Biomass emissions of CO_2 are considered to be climate neutral, and therefore not reported from either landfill or waste incineration. Emissions of methane are reported for landfilling and emissions of CO_2 for non-biomass (fossil origin) are reported for incineration.

[p] The individual compositions for food, paper and paper board, garden and park, wood and wood waste, textiles, nappies and rubber and leather were calculated from the information provided in Appendix D

Figure 10-4: Estimation of GHG emissions diverted from landfill

10.3.4 Scope 3 GHG Emissions

The Greenhouse Gas Protocol allows optional reporting of scope 3 emissions. If an organisation believes that scope 3 emissions are a significant component of the total emissions inventory, these can be reported along with scope 1 and scope 2 emissions. However, the Greenhouse Gas Protocol notes that reporting scope 3 emissions can result in double counting of emissions and can also make comparisons between organisations and/or products difficult (because reporting is voluntary). Double counting needs to be avoided when compiling national (country) inventories under the Kyoto Protocol. The Greenhouse Gas Protocol also recognises that compliance regimes are more likely to focus on the “point of release” of emissions (i.e., direct emissions) and/or indirect emissions from the purchase of electricity. As already noted in **Section 10.2**, scope 3 emissions are anticipated to be minor. Nevertheless, we have identified the following scope 3 emissions that would likely be released as a result of the EfW facility’s operations:

- Employees commuting to and from work.
- Employee business travel.
- Extraction, production and transport of purchased diesel fuel consumed.
- Fuel consumption transporting waste to the site.

10.3.5 Net GHG Emissions for EfW Facility

The emission intensity for electricity generated from waste incineration is lower than that derived from the NSW electricity grid (refer **Section10.4**) and therefore a net reduction in GHG emissions is achieved when electricity from this source is exported to the NSW grid.

Similarly, by removing biodegradable wastes from the landfill, significant emissions of methane from the decomposition of that waste are also avoided.

Figure 10-5 provides a representation of the net greenhouse gas emission (reduction) on an annual basis[q], assuming a 25 year facility life. The cumulative emission reduction over a 25 year period would thus be between 13.6 and 17.1 Mt CO_2-e. Based on average activity values the cumulative emission reduction is estimated as 15.3 Mt CO_2-e.

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[q] This figure shows the net GHG emissions based on average operations as well maximum and minimum conditions (shown as error bars in the figure).

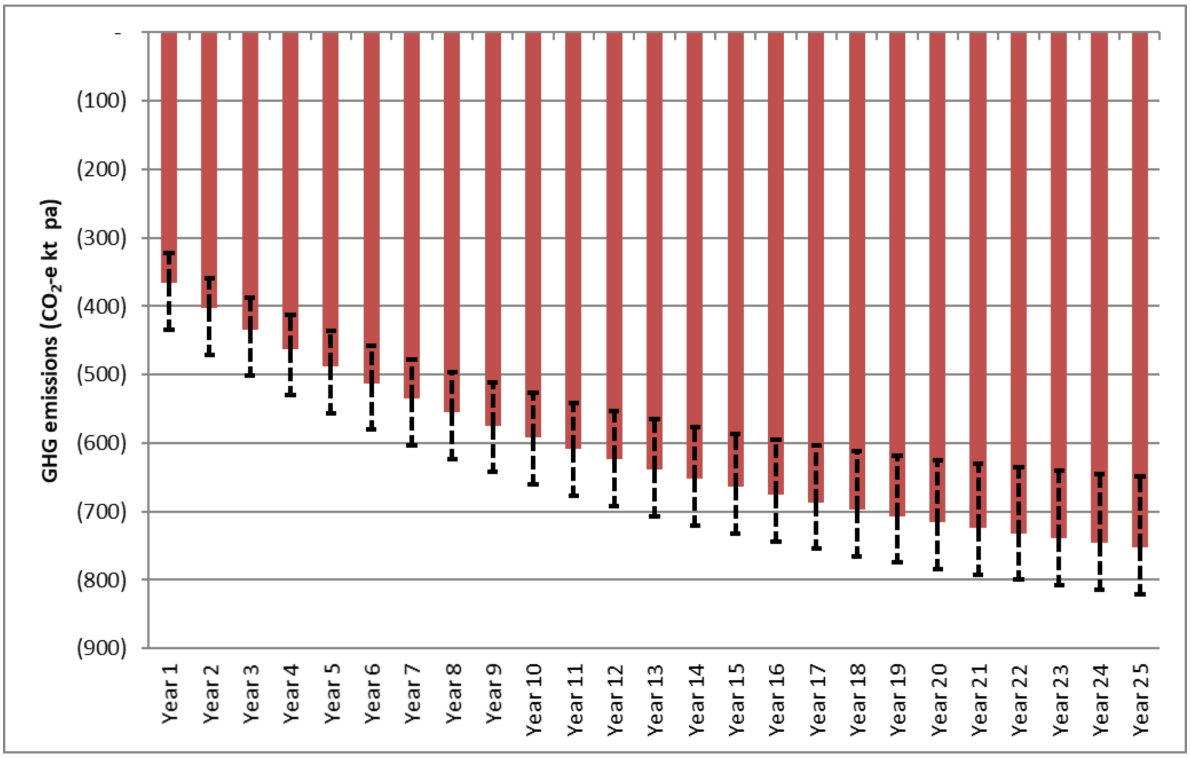


Figure 10-5: Estimation of net GHG emissions over a period of 25 years

10.4 Benchmarking GHG intensity

Emissions intensity of electricity generation is expressed as the rate of emissions (tonnes or kg of CO_2-e) per net unit of electricity produced (MWh or kWh).

The estimated emissions intensity for the proposed EfW facility is 0.17 tonnes CO_2-e/MWh generated. For 2014, the emissions intensity for the NSW grid was 0.93 tonnes CO_2-e/MWh generated (**AEMO, 2015**). Over time it is anticipated that the emission intensity for NSW would decrease through the introduction of less carbon intensive sources of energy.

The projected electricity consumption over the next 10 years for NSW is shown in **Figure 10-6**, along with the portion of total consumption that would be generated by the EfW facility. This contribution of the EfW facility to NSW electricity supply is approximately 2% for each financial year.

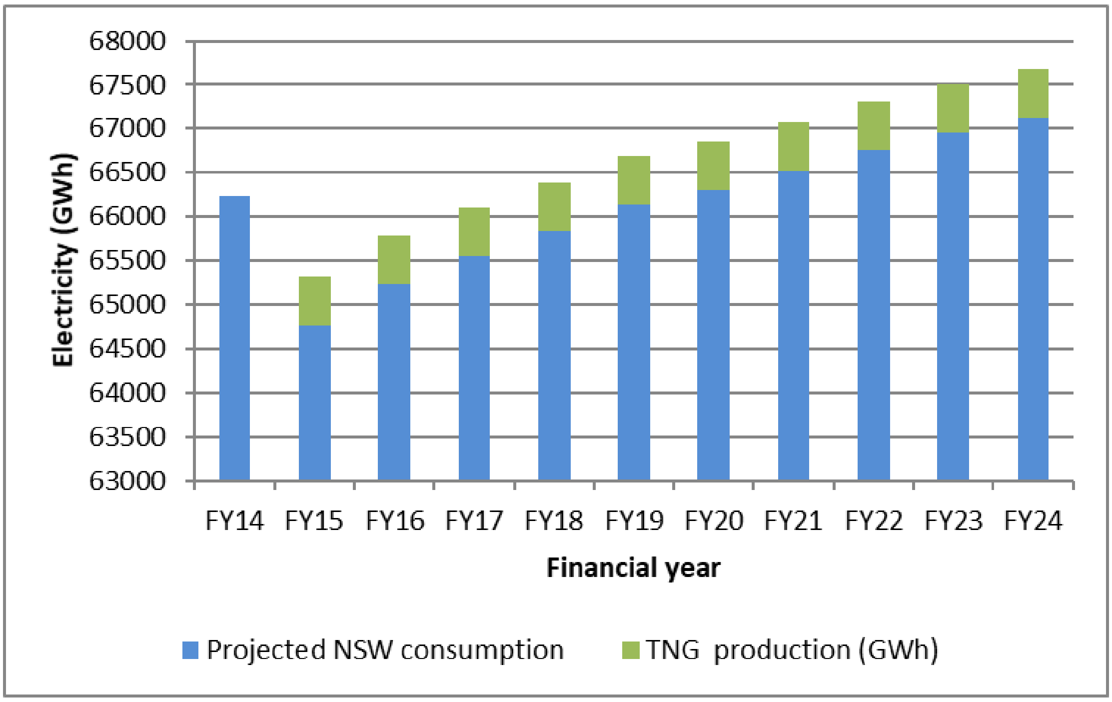
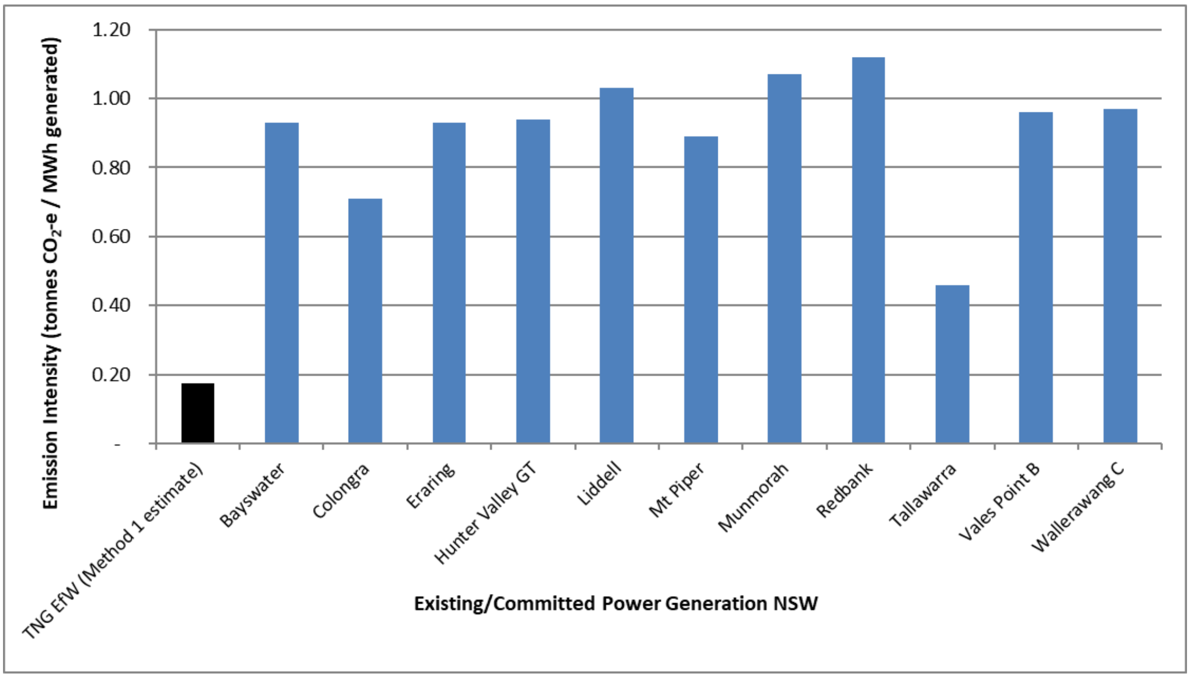


Figure 10-6: Projected NSW electricity consumption (AEMO, 2014)

A comparison has also been made with the emissions intensity measure of kg CO_2-e/$MWh_{\text{sent out}}$ based on data presented for major NSW generators in the ACIL Tasman report on *Fuel resources, new entry and generation costs in the NEM* (**Acil Tasman, 2009**). The data presented in **Figure 10-7** are based on Scope 1 emissions for fuel usage.



Data Source: **ACIL Tasman, 2009**

Figure 10-7: Emission intensity comparison for existing / committed NSW generators

11 CONCLUSION

Pacific Environment has been engaged by TNG NSW to prepare an Air Quality and Greenhouse Gas Assessment for the construction and operation of an Energy from Waste (EfW) facility. The proposed technology for the EfW facility is based on existing facilities in the UK and rest of Europe and will incorporate best available technology (BAT) for flue gas treatment, designed to meet the stringent in-stack concentrations limits for waste incineration set by the IEU Industrial Emissions Directive (IED).

The dispersion modelling completed as part of this assessment is now based on the evaluation of a single stack.

Dispersion modelling predictions have been based on the assumptions described in this report. The results are summarised as follows:

SCENARIO 1: EXPECTED

The incremental results are as follows:

- The maximum predicted 1-hour NO_2 is 5% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 1% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 0.6% of the impact assessment criterion, for 1-hour 0.5%, for 24-hour SO_2, 0.3% and for annual, 0.3%.
- The maximum predicted 24-hour PM is 0.05% of the impact assessment criterion for PM_{10} and 0.09% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 0.02% of the impact assessment criterion for PM_{10} and 0.07% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 0.01% or less than the relevant impact assessment criterion.
- The maximum predicted 24-hour HF is 0.4% of the impact assessment criterion, for 7-day 0.4%, for 30-day HF, 0.6% and for 90-day, 0.8%.
- The annual average lead concentration is 0.2% of the impact assessment criterion.

Modelling predictions for air toxics are assessed against the 99.9th percentile prediction, at and beyond the site boundary. The individual odour compound H_2S is assessed against the 99th percentile prediction.

In summary, the modelling results for these additional parameters show that the 99.9th percentile predicted:

- HCl is 1% of the impact assessment criterion.
- Cd is 6% of the impact assessment criterion.
- Hg is 0.3% of the impact assessment criterion.
- dioxins and furans are 0.1% of the impact assessment criterion.
- benzene is 0.006% of the impact assessment criterion.
- toluene is 0.001% of the impact assessment criterion.
- xylene is 0.0002% of the impact assessment criterion.
- NH_3 is 0.1% of the impact assessment criterion.
- PAH (as benzo(a)pyrene) is 0.02% of the impact assessment criterion.
- H_2S is 5.2% of the impact assessment criterion.
- dichloromethane is 0.0001% of the impact assessment criterion.
- acetone is 0.00001% of the impact assessment criterion.
- trichloroethylene is 0.0001% of the impact assessment criterion.
- Be is 0.02% of the impact assessment criterion.
- Ag is 0.002% of the impact assessment criterion.

- Zn is 0.005% of the impact assessment criterion.
- As is 3.3% of the impact assessment criterion.
- Sb is 0.02% of the impact assessment criterion.
- Cr(III) is 0.1% of the impact assessment criterion.
- Cr(VI) is 0.02% of the impact assessment criterion.
- Ni is 14.7% of the impact assessment criterion.
- Cu is 0.05% of the impact assessment criterion.
- Mn is 0.04% of the impact assessment criterion.
- phenol is 0.01% of the impact assessment criterion.
- hexane is 0.003% of the impact assessment criterion.
- TVOC (assessed as benzene) is 0.5% of the impact assessment criterion.

Cumulative predictions are also presented for the criteria air quality metrics:

- The maximum predicted 1-hour NO_2 is 46% of the impact assessment criterion, even assuming 100% conversion from NO_x to NO_2
- The maximum predicted annual NO_2 is 38% of the impact assessment criterion.
- The maximum predicted 10-minute SO_2 is 16% of the impact assessment criterion, for 1-hour 10%, for 24-hour SO_2, 5% and for annual, 5%.
- The maximum predicted 24-hour PM is 98% of the impact assessment criterion for PM_{10} and 99% for $PM_{2.5}$.
- The maximum predicted annual PM is less than 76% of the impact assessment criterion for PM_{10} and 88% for $PM_{2.5}$.
- The maximum predicted CO 15-minute, 1-hour and 8-hour averaging periods are 30% or less than the relevant impact assessment criterion.

There are no exceedances of the EPA criteria when the EfW contribution is added to maximum background concentration under expected operating conditions.

SCENARIO 2: REGULATORY (POEO LIMITS)

The modelling of the Regulatory (POEO Limits) scenario indicates that application of the POEO emission limits within the Environmental Protection Licence for the facility would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

However, given that the IED limits investigated as part of Scenario 4 are more stringent, and are reflective of the facility's design specifications, it is suggested that these limits are adopted in the Environmental Protection Licence.

For the cumulative assessment, there are no predicted exceedances of the EPA criteria when the EfW facility contribution is added to maximum background, with the exception of $PM_{2.5}$, which results in a cumulative concentration marginally above the 24-hour $PM_{2.5}$ criterion of 25 µg/m^3. However, this occurs on a day when the background $PM_{2.5}$ concentration is already high and the probability of the EfW facility resulting in additional exceedances of the impact assessment criterion is considered to be low.

SCENARIO 3: UPSET

The results of the modelling for Scenario 3 'Upset' conditions indicate that, under worst-case dispersion conditions Cd is predicted to exceed the NSW impact assessment criterion. A probabilistic approach has then been adopted, with results indicating that the probability of the above pollutant resulting in adverse ground level impacts (i.e. the potential for upset conditions to coincide with worst-case dispersion conditions) would be less than 0.012%.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

SCENARIO 4: REGULATORY (IED LIMITS)

Additional modelling of a Regulatory (IED Limits) scenario indicates that application of the IED emission limits within the Environmental Protection Licence for the facility would be sufficiently protective of health and environmental impacts while providing the facility with some operational flexibility.

In view of the more stringent emissions limits of the IED compared with those of the POEO Regulations, it is suggested that the EfW Facility be regulated to the IED limits within their Environmental Protection Licence.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

SCENARIO 5: DIESEL GENERATORS

The results of the dispersion modelling for the diesel generators scenario show that there would not be an exceedance of the relevant impact assessment criteria when the generators operate in isolation or combined with the EfW stack and background sources.

There are no exceedances of the EPA criteria when the EfW facility contribution is added to maximum background.

CONSTRUCTION

A semi-quantitative screening assessment of construction phase impacts identified human receptors within 350 m of the boundary of the site.

Various measures for limiting the impacts of construction dust have been recommended. Most of the recommended measures are routinely employed as 'good practice' on construction sites. At the EfW facility, particular attention should be paid to controlling dust generated by track-out due to the overall level of risk and the potential close proximity of track-out emissions to sensitive receptors.

GREENHOUSE GASES

The operation of the EfW facility would have a net positive GHG impact, potentially eliminating over a 25 year period between 13.6 to 17.1Mt CO_2-e. The emission intensity for electricity generated from waste incineration is significantly lower than that derived from the current NSW electricity grid.

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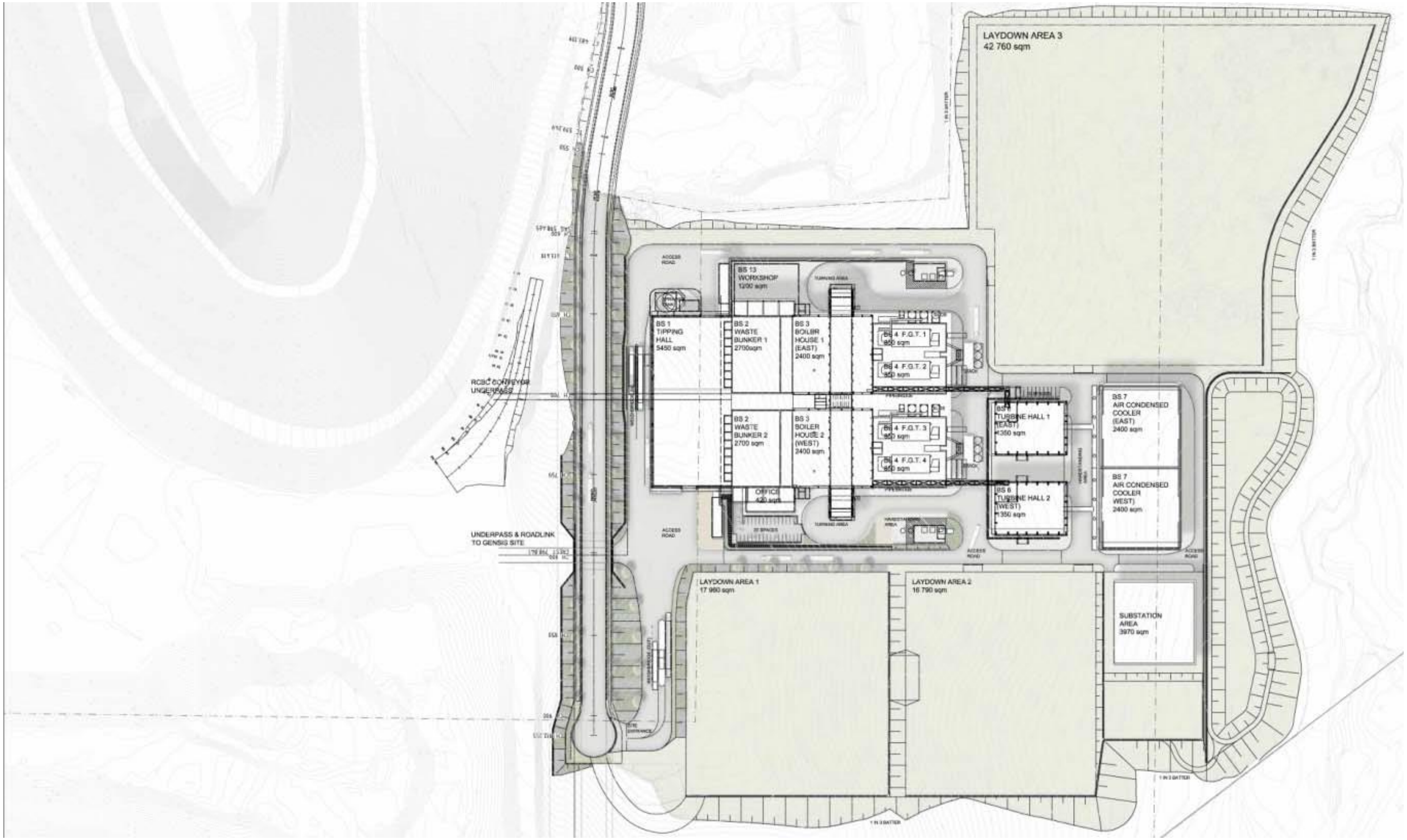
Appendix A GENERAL ARRANGEMENT OF EFW FACILITY


LAYDOWN AREA 3
42 760 sqm
BS 13
WORKSHOP
1200 sqm
TURNING AREA
ACCESS ROAD
BS 1
TIPPING
HALL
5450 sqm
BS 2
WASTE
BUNKER 1
2700sqm
BS 3
BOILER
HOUSE 1
(EAST)
2400 sqm
BS 4 F.G.T. 1
850 sqm
BS 4 F.G.T. 2
850 sqm
STACK
BS 2
WASTE
BUNKER 2
2700 sqm
BS 3
BOILER
HOUSE 2
(WEST)
2400 sqm
BS 4 F.G.T. 3
850 sqm
BS 4 F.G.T. 4
850 sqm
OFFICE
420 sqm
20 SPACES
BS 6
TURBINE HALL 1
(EAST)
1350 sqm
BS 6
TURBINE HALL 2
(WEST)
1350 sqm
BS 7
AIR CONDENSED
COOLER
(EAST)
2400 sqm
BS 7
AIR CONDENSED
COOLER
WEST)
2400 sqm
RCBC CONVEYOR
UNDERPASS
UNDERPASS & ROADLINK
TO GENSIS SITE
LAYDOWN AREA 1
17 960 sqm
LAYDOWN AREA 2
16 790 sqm
SUBSTATION
AREA
3970 sqm
1 IN 3 BATTER


Phase 1
Phase 2
BS 13
WORKSHOP
EAST AMENITIES
WATER TANK
PUMP ENCLOSURE
BS 1
TIPPING
HALL
BS 2
WASTE
BUNKER 1
BS 3
BOILER
HOUSE 1
(EAST)
BS 9
ASH
HANDLING
BS 11 ELECTRICAL
BS 4
F.G.T. 1
BS 4
F.G.T. 2
BS 5
STACK
BS 2
WASTE
BUNKER 2
BS 3
BOILER
HOUSE 2
(WEST)
CENTRAL
CORE
BS 4
F.G.T. 3
BS 6
TURBINE HALL 1
(EAST)
BS 7
AIR CONDENSED
COOLER
(EAST)
BS 6
TURBINE HALL 2
(WEST)
BS 7
AIR CONDENSED
COOLER
(WEST)
BS 12
OFFICE
WEST
AMENITIES
WEST
CORE
CAR PARKING
SUB
GROUND
CONVEYOR
UNDERPASS
FROM
GENESIS PLANT
B
OUT WEIGHBRIDGE
1:500
C
REFERENCE PLAN
1:2000
31000
58000
56900
40700
13700
12500
15800
39200
37200
51200
50400
63000
30800
9500
11800
16500
13100
20000
50500
39800
49200
46500
30500
45700

Appendix B ASSUMPTIONS

B.1 ASSUMPTIONS

General

The EfW facility will operate 24 hours a day, 7 days a week, with occasional offline periods for maintenance. Over the entire year, it is assumed that the EfW facility would be operational for 8,760 hours of the year.

The waste in total and as an average will not contain more than 1% chlorine **(Ramboll, 2017)**. This is further discussed in **Section 4.2**.

The flue gas treatment system includes:

- Selective Non-Catalytic Reduction (SNCR) for reducing emissions of oxide of nitrogen.
- Dry lime scrubbing for reducing emissions of acid gases, including hydrogen chloride (HCl) and Sulfur Dioxide (SO_2).
- Activated carbon injection for reducing emissions of dioxins and mercury.
- Fabric filters for reducing emissions of particles and metals.
- Following flue gas treatment, emissions will be dispersed via a 100m stack. Further details of the flue gas treatment are discussed in **Section 6**.

The EfW facility is designed to operate continuously, therefore start-up and shutdown are infrequent events and anticipated to be required during the facility's annual maintenance programme.

In accordance with the EU IED, such events shall under no circumstance occur for more than 4 hours uninterrupted where the emission values exceed the limits on no more than 60 hours per year.

To facilitate the safe shutdown and black start there will be two emergency diesel generators with one dedicated to each purpose. Each diesel generator will have a capacity of 2.4 MW that will provide sufficient power for the four waste lines. Emissions are based on engine specification for diesel generators that would be representative of the technology used. Routine maintenance and specific testing will occur for one hour, once a month.

Emissions

The primary emissions from the EfW facility, as defined by emission limits for waste incineration set by the EU IED, are as follows:

- Particulate matter (PM), assumed to be emitted as PM_{10} and $PM_{2.5}$[r].
- Hydrogen Chloride (HCl).
- Hydrogen Fluoride (HF).
- Carbon Monoxide (CO).
- Sulfur Dioxide (SO_2)
- Oxides of nitrogen (NO_x) (expressed as Nitrogen Dioxide (NO_2)).
- Heavy metals (including Mercury (Hg), Cadmium (Cd), Thallium (Tl), Antinomy (Sb)Arsenic (As), Chromium (Cr (III) and Cr (VI)), Lead (Pb), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V).
- Gaseous and vaporous organic substances (expressed as total organic carbon (TVOC)).
- Dioxins and furans (PCCD/F).

In addition to the emission identified in the EU IED, potential emissions also include:

- Benzoic Acid

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[r] Particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres respectively.

- Hexa-decanoic Acid
- Ethyl Benzoic Acid
- Toluene
- Phthalate
- Dichloro-methane
- Acetone (propanone)
- Tetra-decanoic Acid
- Benzene
- Acetonitrile
- Xylene
- Trichloro-phenol
- Methyl-hexane
- Trichloro-ethylene
- Heptane
- Hydrogen sulphide (H_2S)
- Ammonia (NH_3)
- Metals Beryllium (Be), Silver (Ag), Zinc (Zn), Tin (Sn), Molybdenum (Mo), Selenium (Se)
- Polychlorinated biphenyls (PCBs)
- Hexachlorobenzene (HCB)
- Polycyclic aromatic hydrocarbons (PAHs)
- Phenol
- Hexane
- Phthalate
- Hydrogen bromide (HBr)
- Brominated flame retardants (BFR)
- Total brominated dioxins.

In the main report, the 'Expected' and 'Upset' emission rates (g/s) adopted for modelling of each stack are derived from the in-stack concentrations provided by Ramboll in **Appendix G** and the flue gas flow rate per stack (Nm^3/s) shown in **Table 6-9**. A summary of the in-stack concentration estimates adopted is additionally documented within **Appendix G**.

Ammonia slippage from an SNCR system normally ranges between 1 to 10 mg/Nm^3, with an average of 4 mg of NH_3/Nm^3 **(European Commission, 2006)**. Ramboll have advised that an in-stack concentration of 2 mg/m^3 would be appropriate for the expected conditions. The effects of ammonia slip have been conservatively factored into the upset conditions emissions scenario, which assumes in-stack concentrations of ammonia of 20 mg/Nm^3.

Meteorology

The review identified 2013 as a representative year for dispersion modelling with no anomalous wind patterns compared to the other years examined and is therefore considered a representative year for dispersion modelling.

All calm conditions were replaced with a wind speed of 0.5 m/s.

Background used for cumulative assessment

A $PM_{2.5}$:PM_{10} ratio (0.35:1) has been applied to the PM_{10} data measured at St Marys and Prospect for the $PM_{2.5}$ background. The ratio is based on PM_{10} measurements from Richmond and Liverpool between 2009 and 2013.

Pollutant	Averaging period	Units	Criteria	Maximum background
NO_2	1 hour	µg/m^3	246	100
	Annual	µg/ m^3	62	23
SO_2	10-minute	µg/ m^3	712	107(a)
	1 hour	µg/ m^3	570	57
	24 hours	µg/ m^3	228	11
	Annual	µg/ m^3	60	3
CO	15-minute	mg/ m^3	100	8(a)
	1 hour	mg/ m^3	30	5
	8 hours	mg/ m^3	10	3
PM_{10}	24 hours	µg/ m^3	50	49(a)
	Annual	µg/ m^3	25	19
$PM_{2.5}$	24 hours	µg/ m^3	25	24.8
	Annual	µg/ m^3	8	7 (b)

Note: (a) Calculated background. See **Section 7.3**.

(b) Excludes days already over the 50 µg/m^3 criterion for PM_{10} and 25µg/m^3 criterion for $PM_{2.5}$.

Modelling

The stack temperature is taken from the technical specifications for a similar facility in the UK. A stack diameter of 3.1 m is chosen to achieve an exit velocity of greater than 15 m/s, based on the provided volumetric flow rates (**Ramboll, 2017**).

A stack height of 100m has been adopted as compliance with the NSW impact assessment criteria was demonstrated at this height.

AERMOD was chosen as a suitable dispersion model due to the source type, location of nearest receiver and nature of local topography.

Terrain data was sourced from NASA's Shuttle Radar Topography Mission Data (1 arc second [~30m] resolution) and processed to create the necessary input files.

Values of surface roughness, albedo and Bowen ratio were determined based on a review of aerial photography for a radius of 3 km centred on the EPA St Marys station. Default values for cultivated land and urban areas were chosen over two sectors across this area.

Building wake heights associated with the proposed on-site structures have been incorporated into the model.

For sub-hourly averaging periods, such as for CO and SO_2, predictions were based on the power-law formula from **EPA Victoria (2013)** to estimate short-term peak values from longer-term average concentrations. See **Section 7.3**.

Results

GLCs for NO_2 were based on the assumption of 100% NO_x to NO_2 conversion. Where the prediction does not meet the criterion using this highly conservative approach, the OLM Level 2 assessment methodology was adopted.

Longer term averaging periods (24-hour, annual, 90 day, 30 day and 7 day) have not been included for the upset conditions modelling scenario. This is because the upset conditions would last for a period of no more than four hours.

Assuming the EfW facility emits NO_x at the EU IED limit for 8,000 hours of the year, the annual NO_x load to the Sydney air shed would be approximately 440 tonnes/year, thereby triggering further assessment. The potential for regional photochemical smog / ozone impacts are investigated in a standalone study, submitted as part of the Environmental Assessment (**Pacific Environment, 2017b**).

Greenhouse Gas Assessment

Scope 2 emissions (purchase of electricity) is not required to be quantified (the EfW facility is a net exporter of electricity) and the focus of this assessment is therefore on Scope 1 emissions. Scope 3 is optional and has been addressed in this assessment qualitatively as the Scope 3 emissions would be minor.

The maximum volume of material that will be combusted during any one year is assumed to be 675,000 tonnes (**Ramboll, 2017**).

The minimum volume of material that will be combusted during any one year is assumed to be 405,000 tonnes (**Ramboll, 2017**).

The average volume of material that will be combusted during any one year is assumed to be 552,500 tonnes (**Ramboll, 2017**).The EfW facility is assumed to operate for 8,000 hours per year.

The EfW facility requires 7.3 MW of electricity to operate.

The carbon content of the residual waste fuel is based on the information provided for the design fuel mix (**Ramboll, 2017**).

Emissions of methane from disposal of waste to landfill are estimated based on the NGER solid waste calculator 2015-16 (**NGER, 2016**).

Appendix C RAMBOLL TECHNICAL MEMORANDA

RAMBØLL

ENERGY

MEMO

Job	**Response to Submissions: SD_6236:** **TNG Energy from Waste Facility, Eastern Creek,** **Dioxin in Energy from Waste facilities** **Reference:** **Australand, Air quality and** **Blacktown District Environment Group on Domestic Incineration**
Client	**DADI**
Memo no.	
Date	**10/08/2015**
To	**Ian Malouf, DADI**
From	**Tore Hulgaard**
Copy to	**Geert Stryg** **Martin Brunner**

Date 10/08/2015

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

1. Introduction

This memo is background memo elaborated with reference to "Consolidated Agency Submissions from 2015 Exhibition" (subsequently referred to as "2015 Exhibition") .

The memo describes general principles of dioxin destruction, formation and removal in Energy from Waste (EfW) facilities.

The dioxin emission and other dioxin containing outputs are described and put in perspective.

The dioxin related issues highlighted in the 2015-Exhibition are addressed, including the remarks of Australand under the heading of Air quality and Ozone; "

- The assumption that there will be no dioxins/furans leaving the primary secondary combustion chamber
- Absence of reference to, and compliance with, the Stockholm Convention

This memo also addresses dioxin emission from uncontrolled incineration, with reference to the note of the 2015-Exhibition under the heading Blacktown District Environmental Group, Domestic Incineration.

2. What is Dioxin?

Dioxin is not just one chemical substance. It is a group of substances that share a range of similarities, and most are toxic but to varying degrees. Reference is usually made to the most toxic of them, the so-called Sevoso dioxin or 2,3,7,8 TCDD (TCDD is tetrachlorodibenzo-para-dioxin).

Dioxins are of concern because they have been characterised as likely to be human carcinogens. Dioxins are solid substances at ambient temperatures and therefore deposit on land. Once deposited the destruction rate is low, why they are considered persistent.

Dioxin emissions and measurements in general are usually presented as toxicity equivalents (TEQ) of 2,3,7,8 TCDD which is a sum of around 20 selected dioxins and furans weighted according to their respective toxicities. Furans are dioxin like and therefore calculated together with dioxins.

In the EU Industrial Emissions Directive (IED) which is used as reference for the TNG EfW, 20 dioxins and furans are specified, and dioxin measurements according to IED are reported as international TEQ (I-TEQ)[1]. For instance the emissions of TNG EfW is reported as I-TEQ with a limit value of 0.1 ng/m³ (at reference conditions).

Dioxins are mainly formed in the course of combustion processes including waste incineration, metal production, landfill fires and other uncontrolled combustion. Dioxins could also be generated as byproducts of chemical production.

3. The Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants[2] (POPs) was adopted on 22 May 2001 in Stockholm, Sweden. The Convention entered into force on 17 May 2004.

The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or on the environment.

The convention includes originally 12 pollutants. The list has been expanded over the years and now includes around 23 pollutants. They are grouped into three categories: one banning production and use, one restricting production and use and one being the result of unintentional production. Dioxins and furans emissions from waste incineration are in the latter group (Annex C of the convention).

---

[1] Different organisations and norms operate with different number of dioxin and furans and slightly different weighting factor, which may give slightly different TEQ values for the same emission.

[2] Stockholm Convention on Persistent Organic Pollutants (POPs) as amended in 2009, available from http://chm.pops.int/Home/tabid/2121/Default.aspx

3.1 Does the facility comply with the provisions of the Stockholm Convention?

Annex C (section A of part V) of the Convention includes general consideration including “Improvements in waste management with the aim of the cessation of open and other uncontrolled burning of wastes, including the burning of landfill sites.”

The high level consequence of constructing the facility is that when waste is directed to the EfW-facility, less waste shall be available for open and other uncontrolled burning of waste, including unintended landfill fires. This is in agreement with the Stockholm Convention and it shall have a large beneficial impact on the dioxin pollution from waste management because emissions (in nanograms per tonne) from uncontrolled burning of waste is several orders of magnitude higher than the air emission from an EfW facility.

When it comes to facilities that may produce dioxins as unintended by-products, as described in Article 5, “Each Party” (meaning state that is bound by convention) shall promote the use of Best Available Techniques and Best Environmental Practices.

On the matter of dioxin abatement at the facility, it is specifically mentioned in the Convention the following to be considered in determining best available techniques; “Use of improved methods for flue-gas cleaning such as thermal or catalytic oxidation, dust precipitation, or adsorption”.

The EfW facility will be constructed using the Best Available Techniques (BAT) as described in the convention. It uses dust precipitation and adsorption in the flue gas treatment system, two of the techniques mentioned in the Convention. As described in Concept Design Report, each unit would be fitted with a flue gas treatment system including the addition of activated carbon as adsorbent to minimise the emissions of dioxins, and a bag filter to remove particulates. This technology is furthermore in agreement with provisions of the EU Best Available Techniques as described in the BAT reference note[3].

The technology ensures compliance with the EU air emission requirement of 0.1 ng/m^3 (ref. standard temperature and pressure, dry flue gas at 11% O_2).

When it comes to the solid outputs they are also in agreement with the Convention, because the dioxin concentrations in each of the residues is below the threshold for “low POP content”.

As stated in article 6, paragraph 2 (c), of the Convention, cooperation between the Parties and Basel Convention shall work to establish, as appropriate, the concentration levels of the chemicals listed in order to define the low persistent organic pollutant content. Wastes consisting of, containing or contaminated with POPs above the low POP content should, in accordance with article 6, paragraph 1 (d) (ii), be disposed of in such a way that the POP content is destroyed or irreversibly transformed or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option.”

---

[3] EU Commission 2006, Integrated Pollution Prevention and Control, Reference Document on the Best Available Techniques for Waste Incineration.

The “low POP content” threshold of wastes has been set at 15 µg/kg for dioxin (TEQ PCDD/F) as a provisional value[4]. All residue being bottom ash and flue gas treatment residue (including fly ash) are expected to be well below the “low POP content” threshold. Bottom ash is expected at a dioxin content (TEQ) around 0.001-0.030 µg/kg, and flue gas treatment residue around 1 µg/kg. This means that the Convention does not require further treatment of the residues prior to disposal when it comes to the dioxin content.

In conclusion all relevant paragraphs of the Stockholm Convention are considered and complied by the EfW facility.

---

[4] Basel Convention, Technical Guidelines for the Environmentally Sound Management (ESM) of Wastes Consisting of, Containing or Contaminated with Persistent Organic Pollutants (POPs), cf. http://www.basel.int/Implementation/POPsWastes/TechnicalGuidelines/tabid/2381/Default.aspx

4. Dioxin from EfW

An EfW facility may be illustrated as depicted in the figure below.

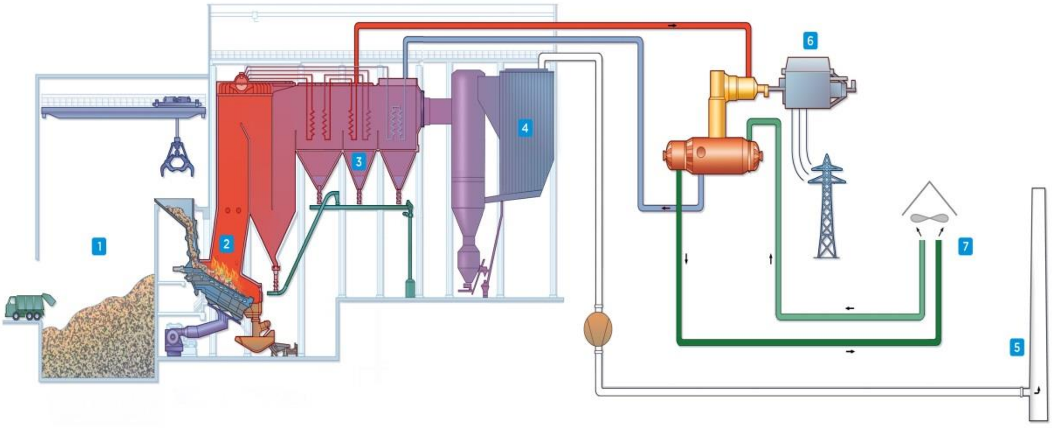

Figure 1 Typical Energy from Waste facility consisting of the main functions, 1) Waste bunker, 2) Furnace, 3)Energy recovery in a steam boiler, 4) Flue gas treatment, 5) stack, 6) electricity generation in turbine/generator set, 7) condensation of vapours in an air cooled condenser.

Waste is ignited and burnt on the grate in the furnace at temperatures around 1’100° C and the temperature of the flue gases is thereafter kept above 850 °C for at least 2 seconds in the afterburning chamber.

The flue gas treatment stage consists of a reactor with injection of lime and activated carbon for dioxin adsorption followed by a bag house filter for dust separation, including the activated carbon particles with dioxin adsorbed.

The flue gas treatment system ensures that the stack emissions comply with the emission requirement of 0.1 ng/m³ (at reference conditions) regardless the content in the raw, untreated flue gas within any realistic operational range.

4.1 Destruction and formation of dioxin in the furnace/boiler system

Input waste to the furnace contains dioxin. The content of dioxin is destroyed in the course of the combustion process where the gas temperature reaches above 1’000 °C and also in the afterburning chamber where the temperature is maintained at minimum 850 °C for minimum 2 seconds.

Dioxin is known to oxidise at high temperatures, for instance the Australian Department of Environment indicated thermal decomposition at 700 °C. [5] Also Vehlow[6] illustrated how the temperature affects the dioxin level, Figure 2.

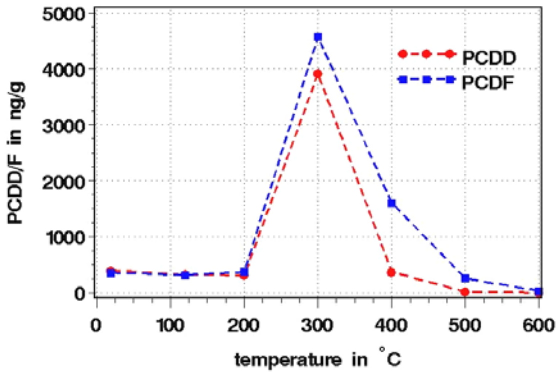

Figure 2 Formation of PCDD and PCDF in fly ashes from waste incineration during annealing in air atmosphere.

Also a report of US EPA[7] stated that 'a number of studies have provided evidence that most of the CDDs/CDFs present in the MSW are destroyed during combustion'.

The dioxin content in the raw, untreated flue gas originates mostly from formation on the boiler walls in the temperature range 250-400 °C.

The mass balance of dioxin is demonstrated by Vehlow. It indicates that the typical picture is that the dioxin content of the incoming waste grossly exceeds the sum of the outputs, so the EfW-facility is a net destructor of dioxin. The air emission is less than 1% of the content of the incoming waste. As mentioned previously the fly ash and flue gas treatment residue are disposed in a safe manner, outside reach of the environment.

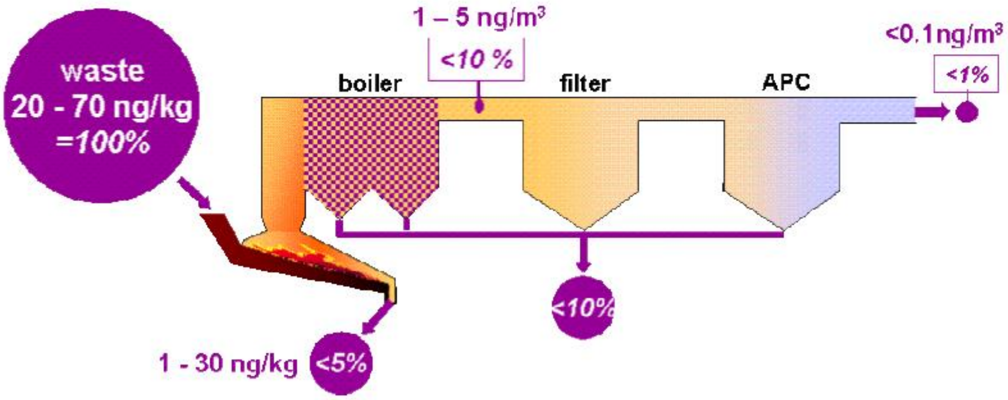

Figure 3 Dioxins (TEQ) in a state of the art EfW-facility. [Footnote 6]

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[5] http://www.npi.gov.au/resource/polychlorinated-dioxins-and-furans

[6] Jürgen Vehlow, Dioxins in Waste Combustion – Conclusions from 20 Years of Research, Bioenergy Australia, Melbourne, 2005.

[7] Mechanisms of formation of dioxin-like compounds during combustion of organic materials, Draft of May 2005. http://www.epa.gov/ncea/pdfs/dioxin/2k-update/pdfs/Dioxin_Chapter_2.pdf

5. Dioxin emission and inventory

The total dioxin emission in 2014 in Australia[8] is listed as around 300 g per year of TEQ dioxins of which more than half (170 g per year) originates from back yard incinerators.

The total dioxin emission from the TNG EfW facility is estimated as 0.7 g per year TEQ, emission if it operates at full capacity at the emission limit value of 0.1 ng/m³ (ref.) continuously. The typical emissions from EfW facilities are however around a factor 10 lower[9], causing the expected dioxin emission to be around 0.07 g per year TEQ or around 0.02% of the Australian inventory, and 0.05% of the contribution from back yard incinerators.

6. On domestic burning of waste

Blacktown District Environmental Group argues on domestic incineration, that “Local residents have been prevented from incinerating rubbish in their own backyard - unfair to now impose industrial incinerator on those same residents.”

The ban on domestic incineration appears to be in agreement with the provisions of the POP convention to reduce dioxin emissions, as cessation of open burning of waste is specifically mentioned in the convention Annex C (section A of part V), cf. section 3.1 above.

Transfer of waste from domestic incineration to the industrial EfW facility will save the environment for large amounts of dioxin, which is particularly important for the local community where domestic incineration happens.

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[8] Total national facility emissions for the substance: Polychlorinated dioxins and furans (TEQ) http://www.npi.gov.au/npidata/action/load/summary-result;jsessionid=26410198AE95A174F96749000E3FE4F9/criteria/substance/73/destination/ALL/source-type/ALL/substance-name/Polychlorinated%2Bdioxins%2Band%2Bfurans%2B%2528TEQ%2529/subthreshold-data/Yes/year/2014

[9] Emissions from decentralised chp plants 2007 - energinet.dk environmental project no. 07/1882, Appendix 3, listing an emission factor of 5 ng/GJ (TEQ) and considering a flue gas flow rate 550 m³/GJ (ref.).

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

Ramboll AG
Hardturmstrasse 132
CH-8005 Zürich
Schweiz

T +41 44 500 35 80
F +41 44 500 35 89

info@ramboll.ch
www.ramboll.com

Attachments

Memos 1 - 5

RAMBOLL ENERGY

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)**

Date 13/09/2015

Ramboll
Hardturmstrasse 132
CH-8005 Zürich
Switzerland

T +41 44 500 35 80
F +41 44 500 35 89
www.ramboll.com/energy

1. Reference and basis

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)

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%O2, dry gas		Operation condition	
		normal	upset
Beryllium	mg/Nm3	7.00E-06	5.25E-04
Silver	mg/Nm3	3.40E-04	2.55E-02
Cobalt	mg/Nm3	4.00E-03	4.00E-02
PCB (WHO TEQ humans/mammal)	mg/Nm3	1.60E-08	1.60E-07
PAH (WHO TEQ humans/mammal)	mg/Nm3	5.00E-04	5.00E-03
Zinc	mg/Nm3	3.70E-02	5.09E+00
Tin	mg/Nm3	3.33E-03	2.50E-01
Molybdenum	mg/Nm3	2.20E-05	2.63E-03
Selenium	mg/Nm3	2.12E-03	2.12E-02
HCB	mg/Nm3	8.21E-06	8.21E-05

3. Table 2: Overestimated COPC

Compound All values at 11%O2, dry gas		Operation condition	
		normal	upset
Mercury	mg/Nm3	0.004	0.013
Cadmium	mg/Nm3	0.009	0.090
Thallium	mg/Nm3	0.001	0.009
Nickel	mg/Nm3	0.021	0.208
PCDD/F TEQ (WHO humans/mammal)	ng/Nm3	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 (Nm3/s)	57.4	114.8	229.6
Gas Exit Flow Rate (Am3/s)	82.6	165.2	330.5
Gas Exit Velocity (m/s)	21.7		
Flue Gas Flow (Nm3/s) @ 11% O2	63.5	127.0	254.0
Flue gas composition (v/v)			
H2O	15.90%		
O2	6.60%		
N2	67.80%		
CO2	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)** **Lesley Randall (AECOM)** **Amanda Lee (AECOM)** **Damon Roddis (Pacific Environment)** **Phill Andrew (Savills)** **Rachael Snape (Urbis)**

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.

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.

The COPC's chosen where 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.

Date 19/10/2016

Ramboll
Hardturmstrasse 132
CH-8005 Zürich
Switzerland

T +41 44 500 35 80
F +41 44 500 35 89
www.ramboll.com/energy

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, SO_2, NOx, 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, SO_2)
- 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/Nm^3 (Nm^3 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/Nm^3 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 (SO_2)
- Oxides of nitrogen (NOx)
  (expressed as Nitrogen Dioxide (NO_2)).
- 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 (H_2S).
- Chlorine (Cl_2).
- Ammonia (NH_3).
- 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/m³
Identified single components	0.53 mg/m³
Not identified aliphatic hydrocarbons	56% of TOC

Main Components (µg/m³)	
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/m^3	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/m^3	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/m^3	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/m^3	0	0	-	-	0	-	-								1
Sulphur dioxide (SO$_2$)	mg/m^3	2	1	27	11	7.5	18	18	0	0	5	4	2	15	11	50
Oxides of nitrogen (expressed as NO$_2$)	mg/m^3	188	188	183	185	180	174	176	175	175	175	55	38	60	68	200
Mercury (Hg)	µg/m^3	4	23	1	0	3	0.3	0.1								50
Carbon monoxide (CO)	mg/m^3	23	23	6	7	12.5	8	8				2.5	5	2.5	2.5	50
Ammonia (NH$_3$)	mg/m^3	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

			Riverside			Newhaven		Cleveland	Evreux	Ingolstadt	Average	EU
Metal	**Symbol**	**Unit**	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**		see note		IED
Mercury	**Hg**	**mg/m^3**	**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/m^3**	**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/m^3**	**0.11**	**0.049**	**0.097**	**0.35**	**0.015**	**0.092**			**0.12**	**< 0.5**
Dioxins and Furanes	**PCDD/F TEQ** (WHO humans/mammal)	**ng/m^3**	**0.004**	**0.004**	**0.001**	**0.0015**	**0.0004**				**0.0022**	
Dioxin-like PCB's	**PCB** (WHO TEQ humans/mammal)	**ng/m^3**	**0.016**	**0.011**	**0.014**	**0.00001**	**0.00001**				**0.008**	
Hexachlorbenzol	**HCB**	µg/m3								< 0.0012	0.001	
Benzo(a)pyren	**B(a)P**	µg/m3							0.002	< 0.0013	0.002	
PAH's	**PAH** (WHO TEQ humans/mammal)	**µg/m^3**				**0.4**	**0.5**				**0.45**	

all concentrations in gas ref. to STP and 11% O_2 dry

note: Ingolstad 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_2O	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	-	-
Formaldehyde	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 CH_4.

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)** **Phill Andrew (Savills)** **Rachael Snape (Urbis)** **Damon Roddis (Pacific Environment)**

Date 19/10/2016

Ramboll
Hardturmstrasse 132
CH-8005 Zürich
Switzerland

T +41 44 500 35 80
F +41 44 500 35 89
www.ramboll.com/energy

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).

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% O_2, 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/Nm^3 and a mean of 0.010 mg/Nm^3 (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/Nm^3 and a mean of 0.011 mg/Nm^3 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/Nm^3 (1% of 0.052 mg/Nm^3) and an average of 0.00005 mg/Nm^3 (0.5% of 0.010 mg/Nm^3) 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/Nm^3 and a mean value of 0.000035 mg/Nm^3.

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/m^3
- Nickel – 20 ng/m^3
- Chromium (VI) – 0.2 ng/m^3

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/m^3 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/m^3). 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/m^3 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)
Damon Roddis (Pacific Environment)

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 where 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.

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

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.

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[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 extend 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 ration 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/Nm^3.

The other CMA are mostly expressed as the sum of compounds with identical number of chlorine atoms (dichlorobenze, trichlorobenzene, dichlorphenol, etc.). The measured values for such a group are in the range of below 1 up to max. 10 ng/Nm^3. For any assessment a concentration of max. 10 ng/Nm^3 per group during normal operation and 100 ng/Nm^3 (tenfold 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/Nm^3. For any other group of compound (as sum of compounds with identical number of chlorine atoms) a concentration of 10 ng/Nm^3 during normal operation and 100 ng/Nm^3 (tenfold value) during upset operation can be assumed.

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

Christopher A. Ollson [a,*], Loren D. Knopper [a], Melissa L. Whitfield Aslund [a], Ruwan Jayasinghe [b]

[a] Intrinsik Environmental Sciences, 6605 Hurontario Street, Mississauga, ON L5T 0A3, Canada
[b] Stantec, 675 Cochrane Dr, Markham, ON L3R 0B8, Canada

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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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.

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.

[*] Corresponding author at: Intrinsik Environmental Sciences Inc., 6605 Hurontario Street, Suite 500, Mississauga, ON L5T 0A3, Canada. Tel.: +1 905 364 7800x232, +1 416 456 1388 (mobile).
E-mail address: collson@intrinsik.com (C.A. Ollson).

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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.
	Baseline Traffic	Offsite vehicle traffic emissions prior to the start-up of the Facility.
Construction	Construction	Construction and commissioning of the Facility.
Operation	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.
	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	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 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
Exposure Pathway							
Direct Inhalation	✓	✓	✓	✓	✓		
Soil Ingestion	✓	✓	✓	✓	✓		
Dermal Contact – Soil	✓	✓	✓	✓	✓		
Dermal Contact – Water						✓	
Incidental Surface Water Ingestion						✓	
Garden Produce	✓	✓					
Fish							✓
Breast Milk	✓	✓					
Wild Game							✓
Agriculture		✓					
Life stage considered for threshold (non-carcinogenic) COPC							
Infant (0 to 6 mo)	✓	✓					
Toddler (7 mo to 4 yr)	✓	✓	✓	✓	✓	✓	✓
Life stage considered for non-threshold (carcinogenic) COPC							
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 (SO_2), Nitrogen Oxides (NOx), Carbon Monoxide (CO), Ozone (O_3), 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 LRASA) 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 SO_2 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 x 1) + (0.05 x 10) = 1.45], with the exception of SO_2 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 x 1) + (0.20 x 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 $\mu g/m^3$ 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):

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

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 (μg/m^3) for that duration and $RfC_{duration}$ represents the selected (duration specific) reference concentration (μg/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):

$$HQ = \frac{\sum Exp}{RfD} \tag{2}$$

Where $\sum Exp$ represents the chronic exposure estimate resulting from the sum of multiple exposure pathways (μg/kg/day) and RfD represents the selected chronic reference dose (μg/kg/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):

$$ILCR = [Air]_{project\ \ alone}\ \mathrm{x}\ UR \tag{3}$$

$$LCR = [Air]_{all\ \ sources}\ \mathrm{x}\ UR \tag{4}$$

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

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):

$$ILCR = \sum LADD_{project\ \ alone} \mathrm{x}\ CSF \tag{5}$$

$$LCR = \sum LADD_{all\ \ sources}\ \mathrm{x}\ CSF \tag{6}$$

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

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 NO_2, SO_2, $PM_{2.5}$, and PM_{10}) 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 3.1×10^{-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
1-Hour										
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	-	-	-	-	-
24-Hour										
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
Annual										
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 LRASA. 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 Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project	Baseline	Project Alone	Project	Process Upset	Process Upset Project
Metals	0.04	0.03	0.04	0.25	0.27	0.03	0.01	0.04	0.14	0.16	0.12	0.003	0.12	0.004	0.12
Chlorinated Polycyclic Aromatics	0.001	0.0003	0.001	0.003	0.004	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	0.002	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	0.0002	0.07	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	0.002	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
PAHs										
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
PCBs										
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**
VOCs										
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
Chlorinated Monocyclic Aromatics										
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
Inorganics										
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**
Dioxins/Furans and Lead										
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
PAHs										
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
PCBs										
Aroclor 1254 (Total PCBs)	**117.5**	0.004	**117.5**	0.01	**117.5**	**4.2**	0.0001	**4.2**	0.0004	**4.2**
VOCs										
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
Chlorinated Monocyclic Aromatics										
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**
Inorganics										
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**
Dioxins/Furans and Lead										
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
PAHs										
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
PCBs										
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**
VOCs										
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
Chlorinated Monocyclic Aromatics										
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
Inorganics										
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**
Dioxins/Furans and Lead										
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
PAHs										
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
PCBs										
Aroclor 1254 (Total PCBs)	**0.67**	0.002	**0.67**	0.006	**0.68**	**1.20**	0.002	**1.20**	0.006	**1.20**
VOCs										
Maximum observed	–	6.2E-09	–	1.7E-08	–	0.03	6.2E-09	0.03	1.7E-08	0.03
Chlorinated Monocyclic Aromatics										
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
Inorganics										
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**
Dioxins/Furans and Lead										
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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ENERGY

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.

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
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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 Br_2) was reported to be < 2,2 mg/Nm^3 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/Nm^3, in case of the Energos Plant (Ranheim) <5 ng/Nm^3. 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/Nm^3, BFR below 5 ng/Nm^3 and total brominated dioxins far below 0,05 ng/Nm^3.

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

TemaNord 2005:529

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Phone (+45) 3396 0200
Fax (+45) 3396 0202

Nordic Council
Store Strandstræde 18
DK-1255 Copenhagen K
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Environmental co-operation is aimed at contributing to the improvement of the environment and forestall problems in the Nordic countries as well as on the international scene. The co-operation is conducted by the Nordic Committee of Senior Officials for Environmental Affairs. The co-operation endeavours to advance joint aims for Action Plans and joint projects, exchange of information and assistance, e.g. to Eastern Europe, through the Nordic Environmental Finance Corporation (NEFCO).

Nordic Co-operation

Nordic co-operation, one of the oldest and most wide-ranging regional partnerships in the world, involves Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland and Åland. Co-operation reinforces the sense of Nordic community while respecting national differences and similarities, makes it possible to uphold Nordic interests in the world at large and promotes positive relations between neighbouring peoples.

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.

Content

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 Assosiation (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 (tetrabrombisphenol) was respectively 3,5 and 8 ng/Nm^3.

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 weightbromine. 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/Nm^3. During sampling at the FREVAR Plant average CO-levels were approximately 50 mg/Nm^3. 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

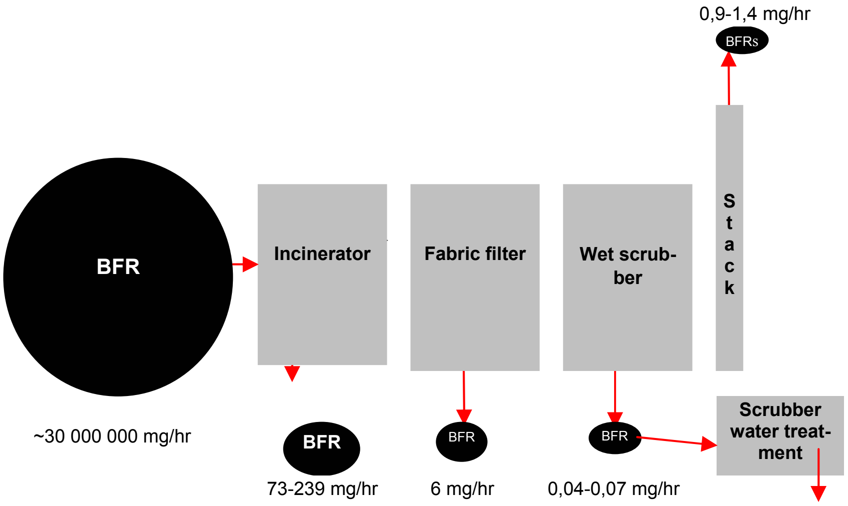
Measured results for gaseous bromine in untreated flue gas during incineration of normal waste mix indicates a bromine content equal to or lower than what is common for waste from households and the commercial sector.

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/Nm^3. 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/Nm^3.

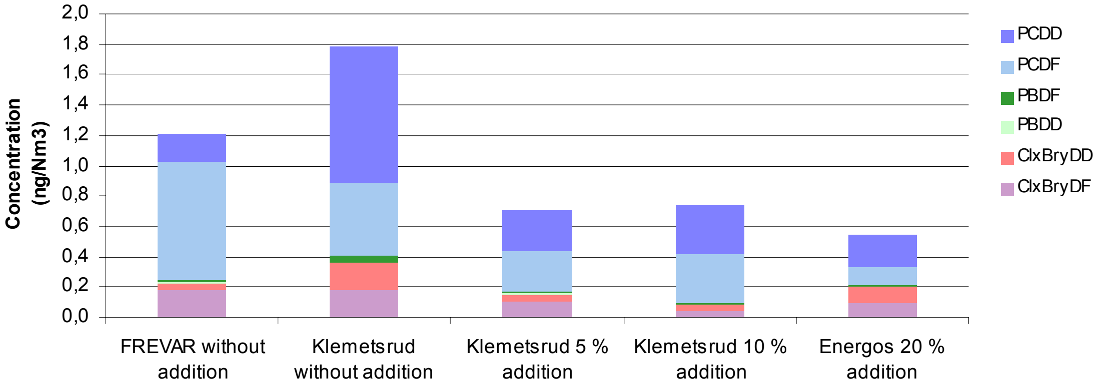
The concentration of BFRs in bottom ash from the tests at Klemetsrud Plant (Oslo) shows levels far below the threshold value stated in the Hazardous Waste Directive.

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)

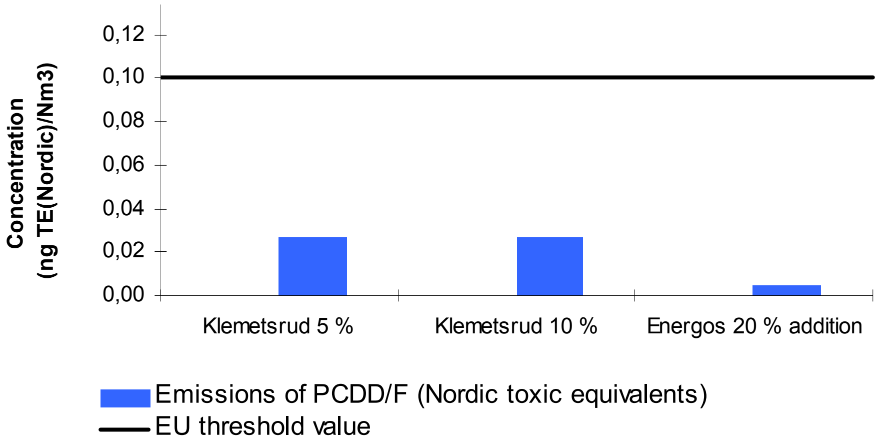
The figure below shows emissions of chlorinated, brominated and chlorinated/brominated dioxins without any addition of brominated waste, and with the addition of 5 % by weight, 10 % by weight and 20 % by weight bromine containing waste.

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

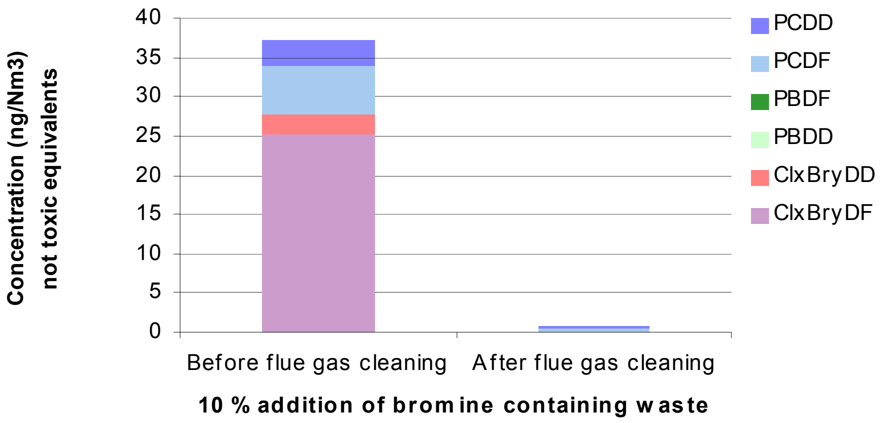
- The emission levels for chlorinated dioxins, reported as Nordic toxic equivalents, are low compared to emission threshold value in the EU-directive for incineration of waste. The reported emission levels were 0,03 ng/Nm^3 and 0,006 ng/Nm^3 respectively for the Klemetsrud Plant (Oslo) and Energos Plant (Ranheim), and the EU threshold value is 0,1 ng/Nm^3.
- 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/Nm^3, which was three times the concentration of chlorinated dioxins. After cleaning the concentration was approximately 0,1 ng/Nm^3. 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.

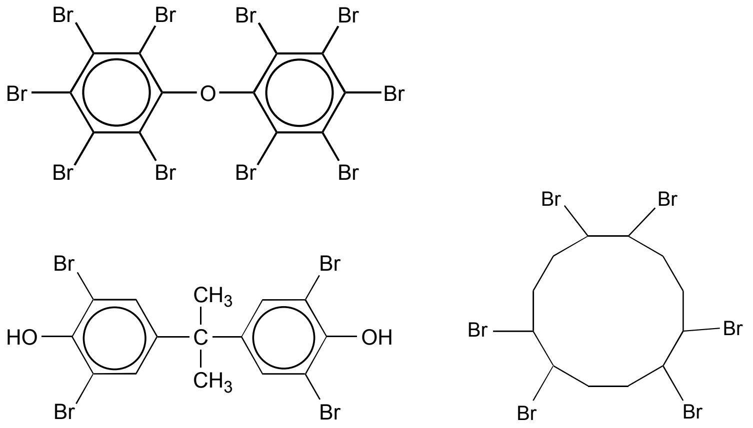
The largest amount of plastics will however be found in the so-called shredderfluff, with an amount of approximately 4400 tons/year. Shredderfluff is the waste fraction from wrecked car/scrap metal fragmenting plants, and it contains (among other things) a mix of plastics, rubber, wood, concrete, and 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 compunds tetrabromobisphenol A (TBBPA) og hexabromocyclododecane (HBCD).

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

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



Decabromodiphenyl ether (DeBDE) *Tetrabromobisphenol A (TBBPA)*
Hexabromocyclododecane (HBCD)

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 plychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Chlorinated dioxins and furans are often referred to as ”dioxins”.

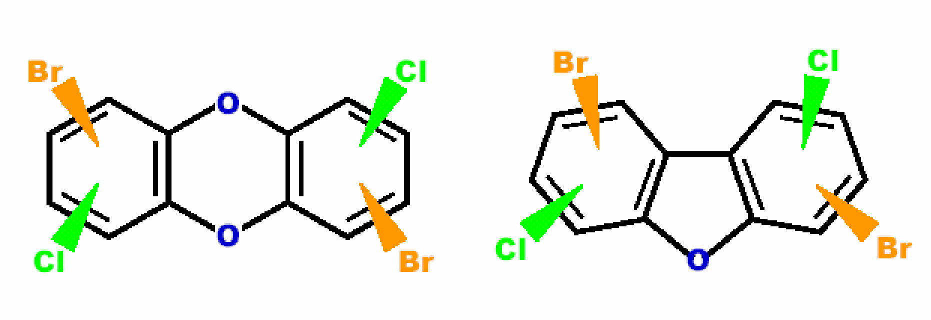
Brominated dioxines is a collective term for the corresponding 210 organic compounds substituted with bromine instead of chlorine. These are normally also reffered to as PBDD og PBDF (polybrominated dibenzo-p-dioxins og polybrominated dibenzofurans).

Brominated/chlorinated dioxins includes dibenzo-p-dioxins and dibenzofurans with both bromine and clorine 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).

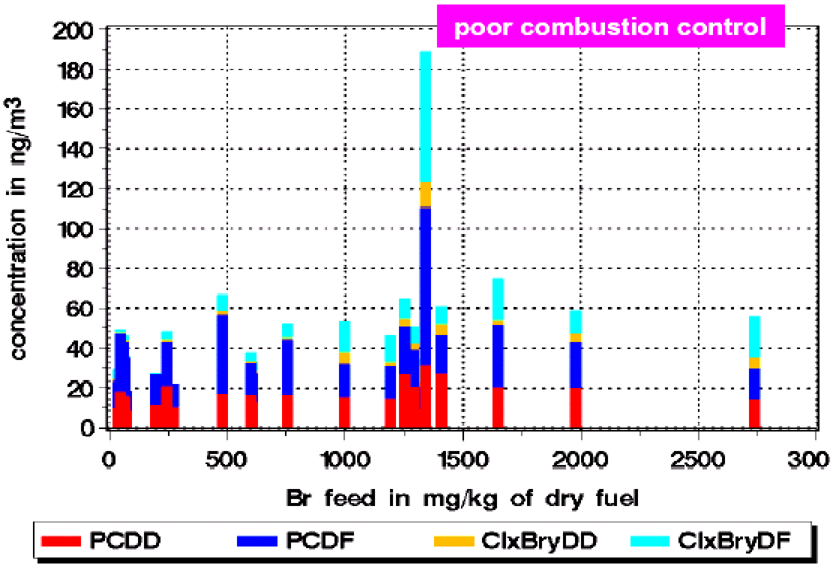
The incineration temperature was ranging from 850 to 950 ºC. The additional inputs of bromine during the tests were ranging up to 6 times the original bromine content in the household waste.

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.

Figuer 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 ºC.

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 Br_2 and HBr, which again is substantially different from the ratio between Cl_2 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).

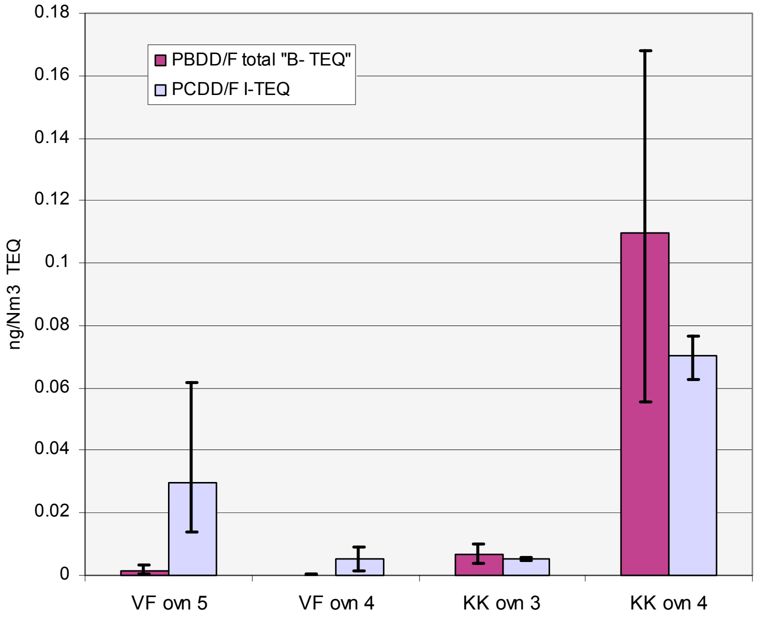
It was found 0,003 ng/Nm^3 tetrabrominated dibenzo-p-dioxins. Concentrations of other single compounds were lower than the detection limit, i.e. than 0,0001-0,02 ng/Nm^3. Note that the concentrations is given as actual measured values, not as toxic equivalents (Energos ASA, 2002).

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/Nm^3 in 1999). The emissions of brominated dioxins were lower than the detection limit for the measurements, i.e. < 0,05 ng/Nm^3 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/Nm^3. (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 [% by weight]	Bromine content in waste [% by weight]
TAMARA			
Polystyrene- and polyurethanefoam + waste from housholds and small industry/ businesses	1-3	2,2-4,2	0,02-0,08
TAMARA Plastics from EE-waste + waste from housholds and small industry/ businesses	3-12	0,4-1,5	0,01-0,18
Umeå University			
Waste from housholds 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 housholds and small industry/ businesses				
TAMARA Plastics from EE-waste + waste from housholds and small industry/ businesses	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 Waste from housholds and small businesses added different BFRs	Bromine, chlorine and flame-retardants [2]	Cl_2, HCl, Br_2, HBr, PXDDs/Fs[3]		
Uppsala Energi,Renova Waste from housholds and small industry/businesses			PXDDs/Fs	
Vestforbrænding Waste from housholds and small industry/businesses			PXDDs/Fs	PXDDs/Fs in residue from flue gas cleaning
KommunekemiHazardous waste			PXDDs/Fs	PXDDs/Fs in residue from flue gas cleaning

0) PXDDs/Fs: Dioxins containing bromine and/or chlorine
PBB, PBDE, TBBA
DeBDE, TBBP-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/Nm^3. Air emission of PBDE and TBBPA was 3,5 and 8 ng/Nm^3 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 congenere 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 congenere 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 inestigations 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 HBCD TBBPA	0,0005-0,09 <0,0001-0,08 0,001-0,044	
Bottom ash from incinerator, Japan	PBDE TBBPA	0,3 0,02	
Fly ash from incinerator, Japan	PBDE TBBPA	0,47 0,0013	
Air emissions from incinerator, Japan	PBDE TBBPA		3,5 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 *before* cleaning	Analysed parameters in flue gas *after* 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 BFRs	Bromine, Chlorine and BFRs in bottom ash, fly ash, flue gas, scrubberwater
FREVAR Plant	Waste from households and small industry/businesses Hospital waste	HCl, Cl_2, HBr, Br_2	Chlorinated, brominated and chlorinated / brominated dioxins	-
Energos Plant	Industrial waste	HCl, Cl_2, HBr, Br_2	Chlorinated and brominated dioxins	-
	Industrial waste + 20 % by weight brominated waste	HCl, Cl_2, HBr, Br_2	Chlorinated, brominated and chlorinated / brominated dioxins HCl, Cl_2, HBr, Br_2 BFRs	Bromine, Chlorine and BFRs in bottom ash

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 Klemetsrud 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).

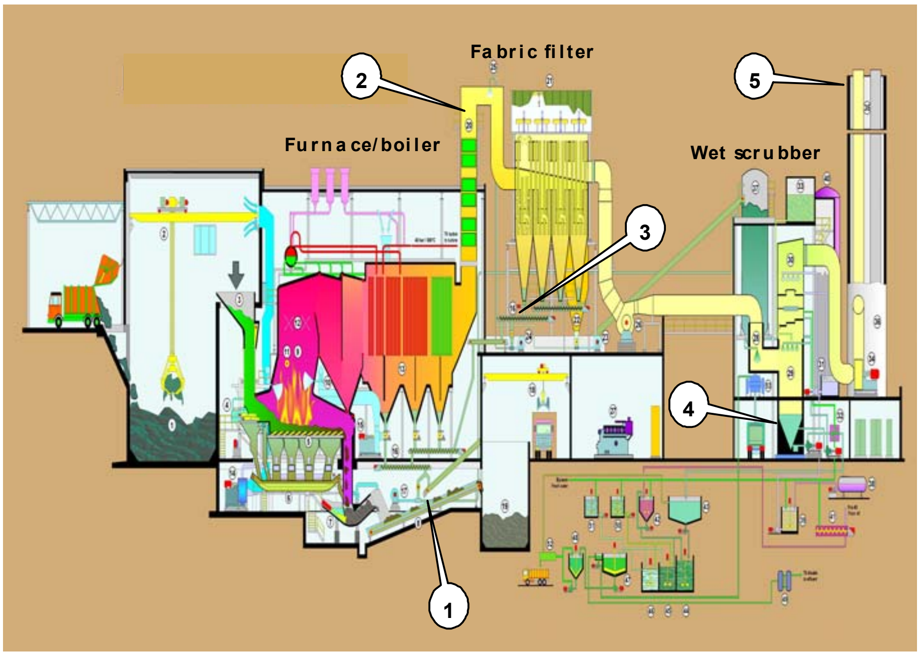
5.3 Description of plants and sampling points

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:

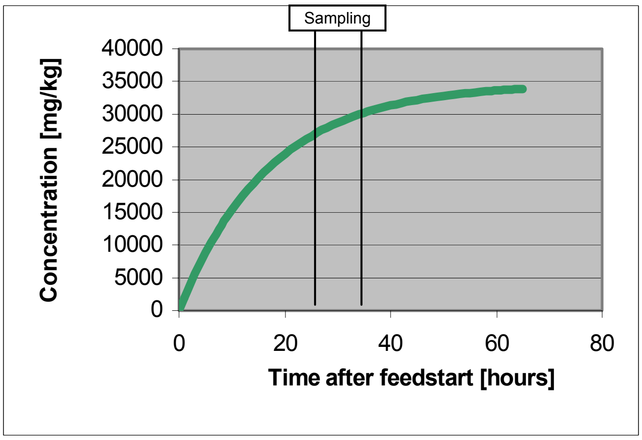
- Low addition: 5 % by weight addition of bromine containing waste. This mixture gives a feed rate for bromine containing waste of approx. 0,5 tons/hr, i.e. slightly above 5 % by weight. The resulting bromine feed rate was approx. 5 kg bromine/hr.
- High addition: 10 % by weight addition of bromine containing 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.

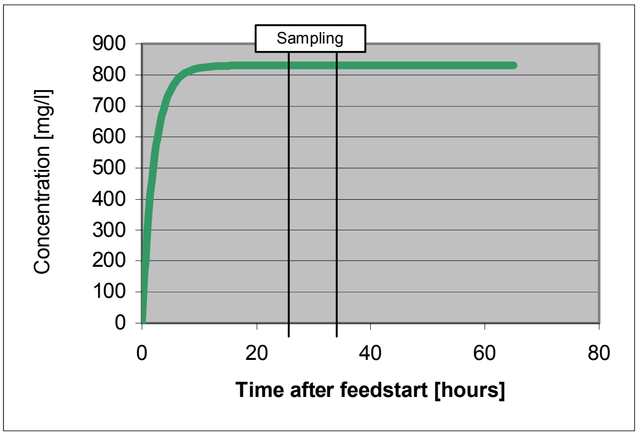
In order to maintain stable concentrations in output flows from the process, feeding of bromine containing waste to the incinerator has to start in due time before sampling.

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

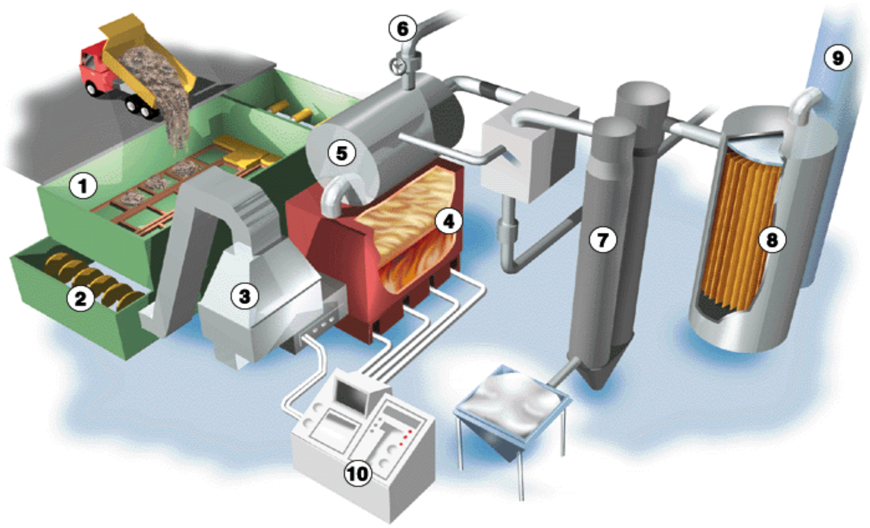
The Energos Plant at Ranheim incinerates annually approx. 10 000 tons of waste. The plant has approx. 4 MW thermal output, and a steamproduction of approx. 25 GWh/year, supplied to a neighbouring industrial plant, Peterson Linerboard Ranheim (PLR). The waste is a mixture of waste from PLR and other industries.

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.

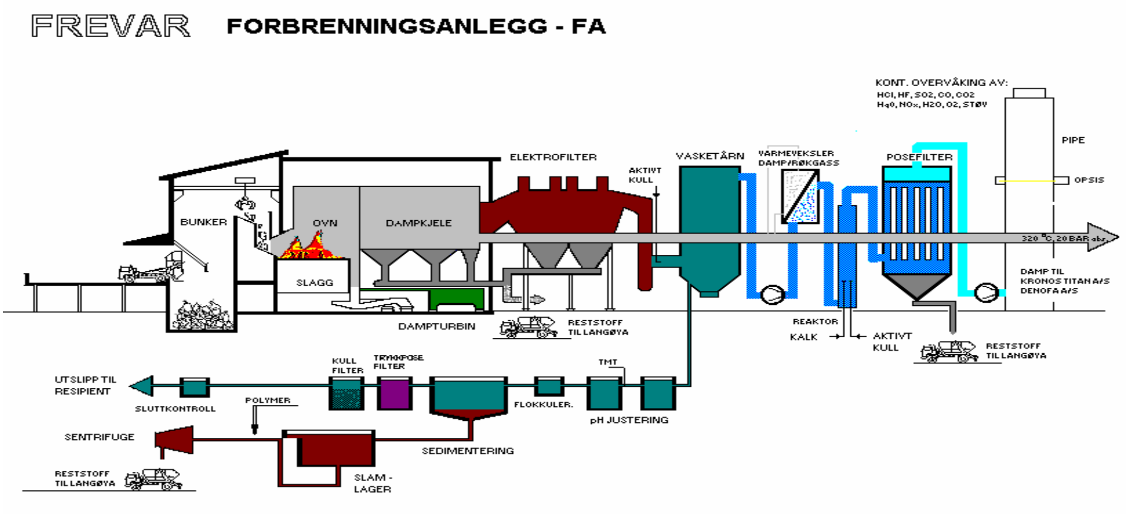
The flue gases from the two furnaces are led in to the same duct before the scrubber, and let out trough a joint stack.

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/Nm^3. CO-levels during sampling at FREVAR Plant were approx. 50 mg/Nm^3. 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/Nm^3, 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).

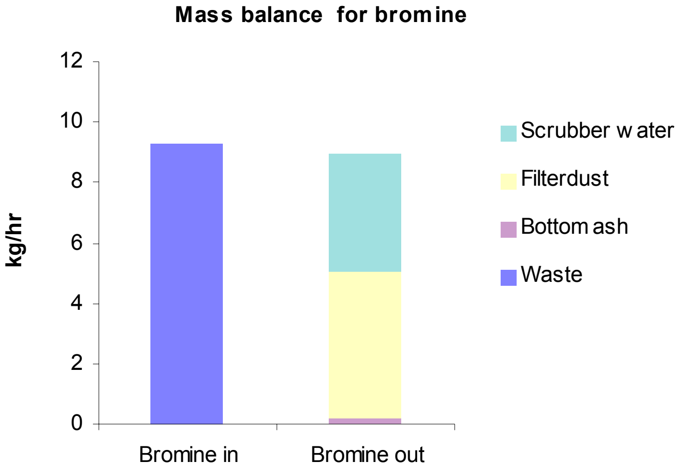
Results from measurements during addition of bromine containing waste, shows a clear increase in the HBr-concentration in uncleaned flue gas, compared to results from measurements with no brominated waste.

At the Energos Plant, gaseous bromine was also measured after the filter. The concentration was < 2,2 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

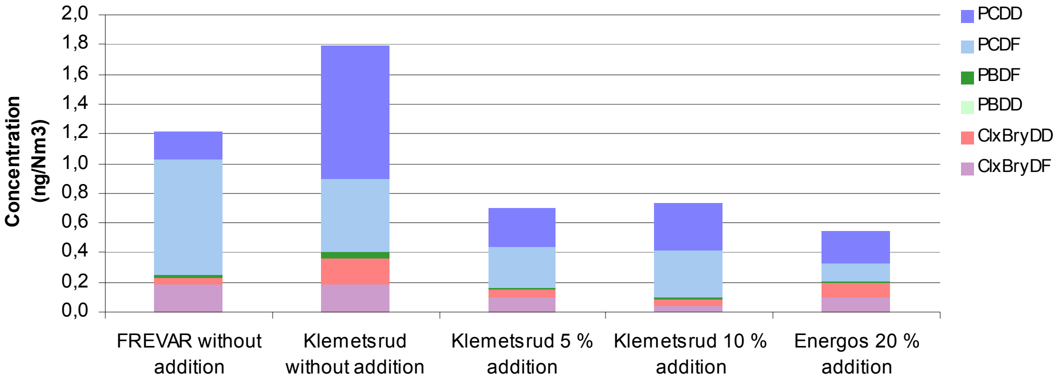
During the approximately 12 hours of sampling and measurement, the bromine content in flue gas before filter varied between approximately 1-2 kgs/hr, with the highest level during the last measurement. According to Energos, it is very likely that the adsorption-/desorption-processes in the boiler system 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/Nm^3 with no addition of brominated waste, and approx. 0,5 ng/Nm^3 with 5 % and 10 % by weight of bromine containing waste. At the FREVAR Plant, the emissions of chlorinated dioxins were approx. 1 ng/Nm^3 (with no addition of bromine containing waste). The Energos Plant had an emission concentration of approx. 0,3 ng/Nm^3 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.

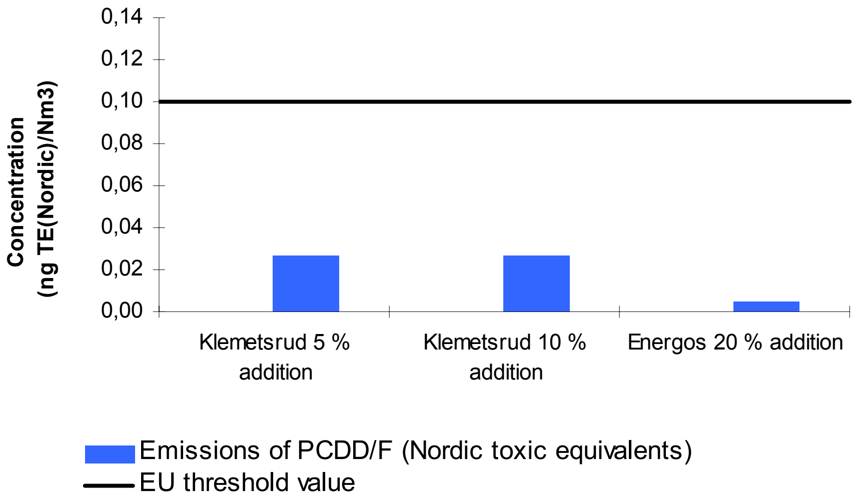
The emissions of *brominated/chlorinated dioxins* (ClxBryDDs+Clx BryDFs) with no addition of brominated waste (Klemetsrud and FRE-

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/Nm^3 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/Nm^3 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/Nm^3.

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

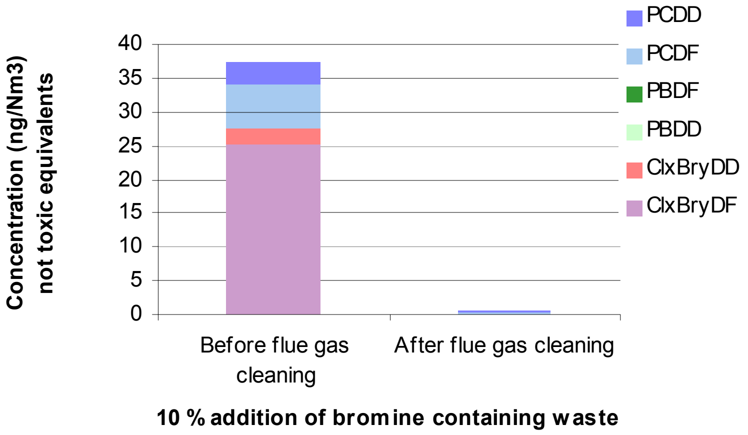
> EU-directive for incineration of waste. The reported emission levels were 0,03 ng/Nm^3 and 0,006 ng/Nm^3 respectively for the Klemetsrud Plant (Oslo) and Energos Plant (Ranheim), and the EU threshold value is 0,1 ng/Nm^3.

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 form 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.

		Level of BFRs	
	Unit	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/Nm^3. 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/Nm^3.

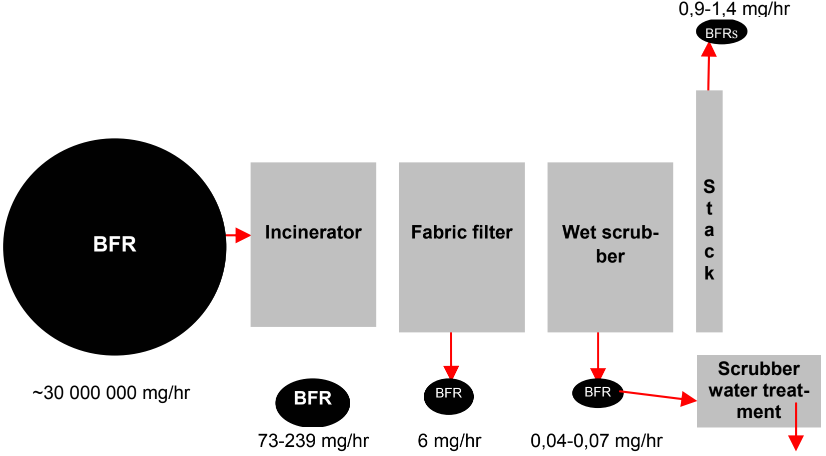
The concentration of BFRs in bottom ash from the tests at Klemetsrud Plant (Oslo) shows levels far below the emission limit value of 0,25 % by weight stated in the Hazardous Waste Directive.

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

MEMO

Job	**TNG Energy from Waste Facility, Eastern Creek, References Facilities**
Date	**2016-10-26**
From	**Ahmet Erol, Martin Brunner**

Background

TNG has been requested to provide further information on the capacity of the technology to process/handle the proposed volume (approx. 50%) of C&D waste. Ramboll has been asked to identify such plants and supply information on the operational experience of such plants.

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

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Results

We acknowledge that it has not been possible to identify an EfW plant (neither with comparable nor with alternative technology) processing a documented input of 50% C&D waste. The main reason is the fact, that any EfW plant treating primarily pre-processed waste (as this is the case for TNG) receives these pre-processed waste streams from different sorting/pre-processing plants. Once waste has been pre-processed it “looses” its waste declaration/identification and cannot be tracked back to its origin. Therefore it is not possible neither to declare the initial origin of the waste nor the exact composition concerning C&D, C&I, etc.

Nevertheless when taking in to account the relevant aspects for the design of an EfW plant (mainly the physical and chemical waste composition) it is possible to demonstrate that TNG operates well within the range of comparable facilities, namely the listed reference plants.

Reference facilities

The information on reference facilities provided in February 2016 (attached) provides details on the capacity, technology type and fuel mix including the chemical analysis of the design fuel of these plants.

The reference plants are treating big variation in the feedstock, which shows that the technology can be used on a broader level. There variation in the feedstock profile of all of the reference facilities combined is evidence to demonstrate a technological capacity to withstand a wide range of variance. The provided technology with moving grate technology and semi dry flue gas treatment is able to run with the waste composition of TNG.

Following several key design parameters are listed and discussed in relation to the design parameters of TNG.

Plant capacity

The mechanical throughput of TNG is comparable with the plant in Grossräschen (DE) and Ferrybridge (UK). While the plant capacity of TNG seems higher than these plants the thermal capacity (throughput x CV) – the most important design parameter – is identical. TNG therefore is in no way an exceptionally large plant

Calorific value

The calorific value defines the combustion characteristics of the waste. Generally it can be said that - except for very low CV below 8 MJ/kg - the higher the CV, the more difficult to maintain an ideal combustion process. With a CV of 12.3 MJ/kg TNG falls in the medium range between i.e. Knapsack with 15 MJ/kg or Riverside with 9.6 MJ/kg.

Chemical waste composition

Within the waste composition the most important parameters are:

- Moisture (limits the controlled ignition of the waste)
- Inert (ash) content (limits homogenous combustion and burnout)
- The larger of Chlorine or Sulphur content (is the limiting factor for the APC system)
- C/O ratio (high C/O ratio is an indicator for high plastic content which limits homogenous combustion and burnout)

For all these aspects TNG is well within the range of all the reference plants.

Summary

None of the listed reference facilities is an exact replica of the TNG fuel profile, however all relevant design parameters of TNG are well within comparable plants which are successfully in operation. As a result it can be said that the technology option pursued, being moving grate technology with semi dry flue gas treatment, was selected based on its capacity to handle a wide range of fuel types and variation of feed stock.

Appendix A Reference Facilities

Key Plant Parameters

Facility / Location	Country	Commission year	Capacity t/a	Fuel mix	Furnace / Boiler	Supplier Furnace / Boiler	APC	Supplier APC
TNG	AU	-	4 x 276'250	C&I, C&D	Grate	HZI	Semi dry (lime)	-
Grossräschen	DE	2008	1 x 246'000	C&I, C&D	Grate	AEE*	Semi dry (lime)	LAB
Heringen	DE	2009	2 x 148'500	C&I, C&D, some MSW	Grate	AEE*	Semi dry (lime)	LAB
Premnitz	DE	2008	1 x 150'000	C&I, C&D	Grate	AEE*	Semi dry (lime)	Lühr
Hannover	DE	2005	2 x 140'000	C&I, C&D, some MSW	Grate	AEE*	Semi dry (lime)	LAB
Knapsack	DE	2009	2 x 150'000	C&I, C&D	Grate	AEE*	Semi dry (lime)	Lühr
Ferrybridge	UK	2015	2 x 256'500	C&I, C&D, some MSW, waste wood	Grate	HZI	Semi dry (lime)	HZI
Riverside	UK	2011	3 x 195'000	MSW, C&I	Grate	HZI	Semi dry (lime)	HZI

* up to 2010 HZI was part of the AEE Group

Appendix B Reference Facilities

Chemical Analysis Design Fuel

		TNG	Grossräschen	Heringen	Premnitz	Hannover	Knapsack	Ferrybridge	Riverside
Carbon (C)	%	31.44	35.20	n.a.	28.50	n.a.	n.a.	35.60	26.63
Hydrogen (H)	%	4.07	1.88	n.a.	3.96	n.a.	n.a.	5.20	3.78
Nitrogen (N)	%	0.26	3.80	n.a.	0.32	n.a.	n.a.	0.60	0.54
Sulphur(S)	%	0.43	0.37	n.a.	0.18	n.a.	<0.8	0.20	0.10
Chloride (Cl)	%	0.88	0.70	n.a.	0.54	n.a.	1.20	0.50	0.70
Oxygen (O)	%	18.06	14.25	n.a.	19.50	n.a.	n.a.	25.10	17.79
Water (H_2O)	%	23.38	25.00	n.a.	22.00	n.a.	18.00	20.00	30.76
Ash	%	21.49	18.80	n.a.	25.00	n.a.	19.00	12.80	19.70
Total	%	100.00	100.00	-	100.00	-	-	100.00	100.00
NCV	MJ/kg	12.30	12.50	12.6	13.00	13.5	15.00	13.50	9.60

Percentage of wood (estimation based on chemical analysis of waste)

		TNG	Grossräschen	Heringen	Premnitz	Hannover	Knapsack	Ferrybridge	Riverside
Wood	%	30.24	23.86	n.a.	32.65	n.a.	n.a.	42.03	29.79

Chloride range of fuel (average)

		TNG	Grossräschen	Heringen	Premnitz	Hannover	Knapsack	Ferrybridge	Riverside
Cl	%	< 1	<1	n.a.	0.2-1.5	n.a.	0.5-1.7	<1	n.a.

information source for reference plants: HZI

Appendix C Reference Facilities

Fuel Mix

	Mixed C&D								Mixed C&I						SRF from MSW	MSW
		paper/card	plastic	textile	glass	vegetation	wood	hazardous (hospital waste)		paper/card	plastic	textile	flock waste			
TNG	**28.7 %**	x	x	x	x	x	x	-	**71.3 %**	x	x	x	x	**0.0 %**	-	-
Grossräschen *	**9.8 %**	x	x	-	x	x	x	x	**83.2 %**	x	x	x	x	**7.0 %**	x	x
Heringen *	**13.6 %**	x	x	x	-	x	x	x	**62.4 %**	x	x	x	-	**24.0 %**	x	-
Premnitz *	**14.3 %**	x	x	x	-	x	x	x	**57.0 %**	x	x	x	x	**28.7 %**	x	-
Hannover *	**9.0 %**	x	x	x	-	x	x	x	**75.3 %**	x	x	x	x	**15.7 %**	x	x
Knapsack	**10.0 %**	x	x	x	-	x	x	x	**90.0 %**	x	x	x	-	**0.0 %**	x	-
Ferrybridge [1]	**10.0 %** [2]	n.a.	n.a.	n.a.	n.a.	n.a	x	n.a.	**30.0 %**	n.a.	n.a.	n.a.	n.a.	**60.0 %**	x	x
Riverside	**n.a.**	x	x	x	x	x	x	-	**n.a.**	x	x	x	-	**n.a.**	x	-

[1] Design Waste

[2] Waste Wood

* values from the year 2014, see https://www.itad.de/information/abfallverwertungsanlagen

all other values given from the operators verbally

SRF Solid Recovered Fuel

MSW Municipal Solid Waste

n.a. not available

RAMBOLL

ENERGY

MEMO

Job **TNG Energy from Waste Facility, Eastern Creek,**
850°C minimum operating temperature
Date **2016-09-27**
From **Ahmet Erol**

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

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850°C minimum operating temperature

The design of the proposed Energy from Waste (EfW) facility includes a secondary combustion chamber to optimise flow conditions and temperature profile and reduce CO, VOC and other organic pollutants emissions.

A minimum flue gas temperature of 850°C with a residence time of at least 2 seconds is kept at any time after the last injection of air (in this case the secondary air). The energy contained in the waste, the design of the secondary combustion chamber and the combustion control enable the plant to run at these conditions without any additional fuel or energy input.

Running an EfW facility at a temperature of 1100°C and a residence time of at least 2 seconds after secondary air injection is not possible with only the energy of the waste. The auxiliary burners (fuelled by gas or diesel) have to support the combustion to reach this temperature and residence time. This additional (fossil) energy input reduces the overall energy efficiency of the facility.

The requirement of 1100°C given by the IED is in Europe only applies for hazardous waste treatment facilities where rather small quantities of hazardous/chemical waste are treated and where (due to the limited size of the plant) energy efficiency is not a key issue.

Based on the waste analysis and the mixing described in the Project Definition Brief (chapter 2.3.1) a maximum chlorine content of the mixed waste of 1% can be assumed.

RAMBOLL

ENERGY

MEMO

Job **TNG Energy from Waste Facility, Eastern Creek,**
Treated Wood Waste
Date **2016-08-30**
From **Martin Brunner, Ahmet Erol**

Treated wood waste

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

The EfW plant must burn 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, after the last injection of combustion air to a minimum temperature of 850 °C for two seconds. If a 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.

Certain wood wastes are treated with wood preservatives or coatings like listed above.
One of the main sources for organic chlorine is varnish containing Polychlorinated biphenyl (PCB).

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

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To get an idea of how much chlorine in treated wood can be, a simple calculation with following assumptions made:

Wood size:	0.0254 m x 0.0254 m x 1 m (1 inch x 1 inch)
Varnish thickness on wood:	60 µm
Specific weight wood	700 kg/m^3
Specific weight varnish	900 kg/m^3
Calculated varnish weight on treated wood	5.48 g
Calculated wood weight	452 g
Percentage of varnish on wood	1.2%

The chlorine content of PCB varies from 20% to 70% depending on PCB configuration[1].

With the assumptions and calculation above the possible chlorine content in treated wood for TNG is as follows.
The wood content in TNG design fuel is varying from 0 to 58.20% with an average of 30.24%.
Assumption: 100% CRW incineration with 58.20% of waste wood and varnish contents 100% chlorine. The chlorine content for this unrealistic case of the incinerated waste would be about 0.71%.
More realistic is to calculate with the average waste wood content of 30.24% and chlorine content in varnish of 50%. For this case the chlorine content in incinerated waste would be about 0.19%.

Conclusion

Even if TNG would incinerate 100% CRW fraction with the highest waste wood content, it is unrealistic to reach the chlorine content of 1%. There is no reason at any time to raise the incineration temperature to 1,100°C for at least two seconds.

Source

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

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[1] Polychlorinated biphenyl (PCB) is an organic chlorine compound with the formula $C_{12}H_{10-x}Cl_x$. There are 209 configurations with 1 to 10 chlorine atoms.
https://en.wikipedia.org/wiki/Polychlorinated_biphenyl

MEMO

Job	**BAT Evaluation**
Client	**DADI TNG NSW**
Memo no.	**4**
Date	**18/02/2016**
To	**To whom it may concern**
From	**Martin Brunner**
Copy to	**Ian Malouf (DADI)** **Phill Andrew (Savills)** **Rachael Snape (Urbis)** **Geert Stryg (Ramboll)**

Date 11.02.2016

Ramboll
Hardturmstrasse 132
CH-8005 Zürich

T +41 44 500 35 80
F +41 44 500 35 89
www.ramboll.com/energy

Revision 100

1. Methodology to compare the TNG technology with the BAT requirements

Based on the long term experience of Waste-to-Energy in Europe the best available techniques (BAT) have been evaluated, defined and documented in the "Reference Document on the Best Available Techniques for Waste Incineration (August 2006)" (in short BREF).

Following a request by TNG Ramboll has compared the requirements as summarized as 68 basic requirements in Chapter 5.1 and 5.2 of the above document.

2. Results and conclusions

The detailed evaluation of each point is found in the attachment. In summary the results of the evaluation are:

1. Design: all requirements defined by BREF are fulfilled
2. Emissions: The expected emissions are within the required operational values given by BREF
3. Energy efficiency: The TNG facility exceeds the requirements of the BREF

It can therefore be concluded that the TNG facility fulfils the BREF requirements and therefore is BAT.

BAT	TNG	BAT fullfilled?
1. the selection of an installation design that is suited to the characteristics of the waste received, as described in 4.1.1 and 4.2.1 and 4.2.3	The thermal treatment is calculated for a calorific value of 8,5 MJ/kg- 16,5 MJ/kg. The plant is designed for a waste throughput of 25,35 t/h to 46,48 t/h. The waste type is mainly Chute Residual Waste (CRW) from the Genesis Facility, Commercial and Industrial (C&I), Construction and Demolition (C&D) and flock waste. A combination of water cooled grate and air cooled grate was chosen. The air cooled grate is characterized through: - suitable for waste with low to medium heat values - suitable for municipal and other heterogeneous solid wastes - can cope with sewage sludge and/or medical waste mixed with municipal waste - applied at most modern MSW installations The water cooled grate protects the grate against intense heat (LCV: 10 – 20 GJ/t) otherwise it has the same characteristics. The design features of the secondary combustion chamber are a central current flow.	Yes
2. the maintenance of the site in a generally tidy and clean state, as described in 4.1.2	It is integral part of the contract; it is defined as one the operator’s tasks.	Yes
3. to maintain all equipment in good working order, and to carry out maintenance inspections and preventative maintenance in order to achieve this	The Proposed Facility will be operated and maintained by a dedicated Operations and Maintenance team. For planning the major shutdown a short shutdown is carried out approx. 1 year in advance. A normal duration for such a short shutdown is generally a few days. The operator installs a computer-controlled program used to ensure ongoing maintenance of the plant components. The program records conducted maintenance jobs and systematic maintenance can be planned for the individual components. A maintenance plan will be established to determine weekly, monthly, annual or longer interval inspections, tests and maintenance activities which have to be performed.	Yes

BAT	TNG	BAT fullfilled?
4. to establish and maintain quality controls over the waste input, according to the types of waste that may be received at the installation, as described in: 4.1.3.1 Establishing installation input limitations and identifying key risks, and 4.1.3.2 Communication with waste suppliers to improve incoming waste quality control, and 4.1.3.3 Controlling waste feed quality on the incinerator site, and 4.1.3.4 Checking, sampling and testing incoming wastes, and 4.1.3.5 Detectors for radioactive materials.	A three point checking procedure will be on-site to ensure only permitted waste is unloaded into the waste bunker. Initial inspections of the vehicle loads are undertaken at the weighbridge to check the content of the incoming and its origin. All loads are recorded and monitored by on-site CCTV when entering the tipping hall and while the loads are tipped off. Suspect loads are either rejected from the facility or are analysed in a designated inspection area or on the tipping hall floor prior to being tipped into the waste bunker. If the analysis shows that the load contains unsuitable material the waste is reloaded to the vehicle and rejected. Detectors for radioactive material are not necessary.	Yes
5. the storage of wastes according to a risk assessment of their properties, such that the risk of potentially polluting released is minimised. In general it is BAT to store waste in areas that have sealed and resistant surfaces, with controlled and separated drainage as described in 4.1.4.1.	The waste bunker is built of concrete and has a resistant surface. Due to the high thermal value of the waste there is no need for controlled and separated drainage.	Yes
6. to use techniques and procedures to restrict and manage waste storage times, as described in 4.1.4.2, in order to generally reduce the risk of releases from storage of waste/container deterioration, and of processing difficulties that may arise. In general it is BAT to: ☐ prevent the volumes of wastes stored from becoming too large for the storage provided ☐ in so far as is practicable, control and manage deliveries by communication with waste suppliers, etc.	- The waste bunker has the capacity to store the amount of 5-7 days of waste delivery. - The waste is continuously removed. - It is ensured that no excessive amounts will arrive.	Yes
7. to minimise the release of odour (and other potential fugitive releases) from bulk waste storage areas (including tanks and bunkers, but excluding small volume wastes stored in containers) and waste pre-treatment areas by passing the extracted atmosphere to the incinerator for combustion (see 4.1.4.4). In addition it is also considered to be BAT to make provision for the control of odour (and other potential fugitive releases) when the incinerator is not available (e.g. during maintenance) by: a. avoiding waste storage overload, and/or b. extracting the relevant atmosphere via an alternative odour control system	The incineration air supply (primary or secondary) is taken from the waste storage areas. By enclosing the waste storage areas and limiting the size of the entrances to the waste storage areas, a slight under pressure can be ensured on whole waste storage area.	
8. the segregation of the storage of wastes according to a risk assessment of their chemical and physical characteristics to allow safe storage and processing, as described in 4.1.4.5	The waste is delivered in defined fractions. Segregation of the storage of wastes is not necessary.	Yes

BAT	TNG	BAT fullfilled?
9. the clear labelling of wastes that are stored in containers such that they may continually be identified, as described in 4.1.4.6.	The waste is not stored in containers.	Not relevant
10. the development of a plan for the prevention, detection and control (described in 4.1.4.7) of fire hazards at the installation, in particular for: ☐ waste storage and pre-treatment areas ☐ furnace loading areas ☐ electrical control systems ☐ bag house filters and static bed filters. It is generally BAT for the plan implemented to include the use of: a. automatic fire detection and warning systems, and b. the use of either a manual or automatic fire intervention and control system as required according to the risk assessment carried out.	Fire detection and firefighting systems are installed at the critical areas of the plant (e.g. waste bunker, electrical rooms, feed hopper,...). In case of fire detection the firefighting systems start automatically.	Yes
11. the mixing (e.g. using bunker crane mixing) or further pre-treatment (e.g. the blending of some liquid and pasty wastes, or the shredding of some solid wastes) of heterogeneous wastes to the degree required to meet the design specifications of the receiving installation (4.1.5.1). When considering the degree of use of mixing/pre-treatment it is of particular importance to consider the cross-media effects (e.g. energy consumption, noise, odour or other releases) of the more extensive pre-treatment's (e.g. shredding). Pre-treatment is most likely to be a requirement where the installation has been designed for a narrow specification, homogeneous waste.	The waste bunker has sufficient space and sufficient capacity for the mixing of different waste streams. The waste is mainly delivered as shredded fraction.	Yes
12. the use of the techniques described in 4.1.5.5 or 4.6.4 to, as far as practicably and economically viable, remove ferrous and non-ferrous recyclable metals for their recovery either: a. after incineration from the bottom ash residues, or b. where the waste is shredded (e.g. when used for certain combustion systems) from the shredded wastes before the incineration stage.	The recyclable material is removed before the waste is delivered to the waste incineration plant.	Yes
13. the provision of operators with a means to visually monitor, directly or using television screens or similar, waste storage and loading areas, as described in 4.1.6.1	A video system is installed to monitor waste reception, feeding and storage, furnace as well as main out streams and their loading areas.	Yes
14. the minimisation of the uncontrolled ingress of air into the combustion chamber via waste loading or other routes, as described in 4.1.6.4	To minimize the uncontrolled ingress of air into the combustion chamber, the feed hopper always has to be filled to a certain level during operation. The level of the feed hopper is checked by the DCS.	Yes

BAT	TNG	BAT fullfilled?
15. the use of flow modelling which may assist in providing information for new plants or existing plants where concerns exist regarding the combustion or FGT performance (such as described in 4.2.2), and to provide information in order to: a. optimise furnace and boiler geometry so as to improve combustion performance, and b. optimise combustion air injection so as to improve combustion performance, and c. where SNCR or SCR is used, to optimise reagent injection points so as to improve the efficiency of NO_x abatement whilst minimising the generation of nitrous oxide, ammonia and the consumption of reagent (see general sections on SCR and SNCR at 4.4.4.1 and 4.4.4.2).	The incineration and the boiler layout are based on good experiences and are realised on several operating plants. The SNCR (injection of ammonia), the secondary combustion chamber and the FGT design is based on a fluid dynamics flow model.	Yes
16. in order to reduce overall emissions, to adopt operational regimes and implement procedures (e.g. continuous rather than batch operation, preventative maintenance systems) in order to minimise as far as practicable planned and unplanned shutdown and start-up operations, as described in 4.2.5	The waste feeding is continuously. Implementation of a process orientated automatic start up and shut down procedure to minimise the emissions in those operational cases. Mixture of the waste to get a homogeneous fuel and preventative maintenance system avoid unplanned shutdowns.	Yes
17. the identification of a combustion control philosophy, and the use of key combustion criteria and a combustion control system to monitor and maintain these criteria within appropriate boundary conditions, in order to maintain effective combustion performance, as described in 4.2.6. Techniques to consider for combustion control may include the use of infrared cameras (see 4.2.7), or others such as ultra-sound measurement or differential temperature control	The following information is part of the combustion control system: - grate temperatures at various positions - caloric value of the waste - thickness of waste layer on the grate (visual control) - furnace and flue gas temperature at various positions - CO-, O_2-, CO_2- and H_2O-measurements at various positions - steam production data (e.g. temperature, pressure) - openings in the combustion wall for visual observation by cameras - length and position of the fire in the furnace - emission data for combustion related substances	Yes

BAT	TNG	BAT fullfilled?
18. the optimisation and control of combustion conditions by a combination of: a. the control of air (oxygen) supply, distribution and temperature, including gas and oxidant mixing b. the control of combustion temperature level and distribution, and c. the control of raw gas residence time. Appropriate techniques for securing these objectives are described in: 4.2.8 Optimisation of air supply stoichiometry 4.2.9 Primary air supply optimisation and distribution 4.2.11 Secondary air injection, optimisation and distribution 4.2.19 Optimisation of time, temperature, turbulence of gases in the combustion zone, and oxygen concentrations 4.2.4 Design to increase turbulence in the secondary combustion chamber	For an optimal combustion the thermal processes are monitored and regulated by measurements of the furnance temperature and the content of CO and O2 in the flue gas. For a more detailed description see point 17. by means of combustion control the following elements are controlled: - Primary air quantity and distribution - Oxygen content of flue gas (stoichiometry) - Secondary air quantity and distribution - Injection of recirculating flue gas in order to increase turbulence in the	Yes
19. in general it is BAT to use those operating conditions (i.e. combustion temperatures residence times and turbulence) that are specified in Article 6 of Directive 2000/76. The use of operating conditions in excess of those that are required for efficient destruction of the waste should generally be avoided. The use of other operating conditions may also be BAT – if they provide for a similar or better level of overall environmental performance. For example, where the use of operational temperatures of below the 1100 °C (as specified for certain hazardous waste in 2000/76/EC) have been demonstrated to provide for a similar or better level of overall environmental performance, the use of such lower temperatures is considered to be BAT.	The temperature / time requirements of the post-combustion chamber are continuously monitored. See point 17.	Yes
20. the preheating of primary combustion air for low calorific value wastes, by using heat recovered within the installation, in conditions where this may lead to improved combustion performance (e.g. where low LCV/high moisture wastes are burned) as described in 4.2.10. In general this technique is not applicable to hazardous waste incinerators.	For high energy efficiency and optimal combustion conditions preheating of primary and secondary combustion air is realised by using low pressure steam and saturated steam from the boiler drum.	Yes
21. the use of auxiliary burner(s) for start-up and shut-down and for maintaining the required operational combustion temperatures (according to the waste concerned) at all times when unburned waste is in the combustion chamber, as described in 4.2.20	Only in the case that the temperature in the secondary combustion chamber drops below a minimum temperature of 850 °C oil or gas fired support burners automatically start operation. Otherwise, the burners remain in a standby position.	Yes

BAT	TNG	BAT fullfilled?
22. the use of a combination of heat removal close to the furnace (e.g. the use of water walls in grate furnaces and/or secondary combustion chambers) and furnace insulation (e.g. refractory areas or other lined furnace walls) that, according to the NCV and corrosiveness of the waste incinerated, provides for: a. adequate heat retention in the furnace (low NCV wastes require higher retention of heat in the furnace) b. additional heat to be transferred for energy recovery (higher NCV wastes may allow/require heat removal from earlier furnace stages) The conditions under which the various techniques may be applicable are described in 4.2.22 and 4.3.12	To protect the walls of the boiler against corrosion Inconel will be cladded in sections where the flue gas temperature exceeds 850 °C.	Yes
23. the use of furnace (including secondary combustion chambers etc.) dimensions that are large enough to provide for an effective combination of gas residence time and temperature such that combustion reactions may approach completion and result in low and stable CO and VOC emissions, as described in 4.2.23	The furnace dimensions are large enough to ensure that for 2 seconds residence time the flue gas has a temperature above 850 °C (for all operational conditions). Experiences of several plants have shown low values for CO and VOC. After the combustion chamber two empty passes are installed to enable a complete burnout. In addition to secondary air a part of the flue gas is recirculated and injected together with the secondary air to achieve a maximum turbulence and burnout as well as stable CO and VOC emissions.	Yes
24. When gasification or pyrolysis is used, in order to avoid the generation of waste, it is BAT to: a. combine the gasification or pyrolysis stage with a subsequent combustion stage with energy recovery and flue-gas treatment that provides for operational emission levels to air within the BAT associated emission ranges specified in this BAT chapter, and/ or b. recover or supply for use of the substances (solid, liquid or gaseous) that are not combusted	No gasification or pyrolysis.	Not relevant

BAT	TNG	BAT fullfilled?
25. in order to avoid operational problems that may be caused by higher temperature sticky fly ashes, to use a boiler design that allows gas temperatures to reduce sufficiently before the convective heat exchange bundles (e.g. the provision of sufficient empty passes within the furnace/boiler and/or water walls or other techniques that aid cooling), as described in 4.2.23 and 4.3.11. The actual temperature above which fouling is significant is waste type and boiler steam parameter dependent. In general for MSW it is usually 600 – 750 ºC, lower for HW and higher for SS. Radiative heat exchangers, such as platten type super heaters, may be used at higher flue-gas temperatures than other designs (see 4.3.14).	At the first position in the horizontal pass a protection evaporator is installed. The calculated gas temperature before the protection evaporator is around 650°C. This evaporator protects the superheater in order to minimize fouling. Further a conservative spacing of the boiler tubes prevents clogging and resulting operational problems.	Yes
26. the overall optimisation of installation energy efficiency and energy recovery, taking into account the techno-economic feasibility (with particular reference to the high corrosivity of the flue-gases that results from the incineration of many wastes e.g. chlorinated wastes), and the availability of users for the energy so recovered, as described in 4.3.1, and in general: a. to reduce energy losses with flue-gases, using a combination of the techniques described in 4.3.2 and 4.3.5 b. the use of a boiler to transfer the flue-gas energy for the production of electricity and/or supply of steam/heat with a thermal conversion efficiency of: i. for mixed municipal waste at least 80 % (ref. Table 3.46) ii. for pretreated municipal wastes (or similar waste) treated in fluidized bed furnaces, 80 to 90 % iii. for hazardous wastes giving rise to increased boiler corrosion risks (typically from chlorine/sulphur content), above 60 to 70 % iv. for other wastes conversion efficiency should generally be increased in the range 60 to 90 % c. for gasification and pyrolysis processes that are combined with a subsequent combustion stage, the use of a boiler with a thermal conversion efficiency of at least 80 %, or the use of a gas engine or other electrical generation technology	The most important measures to reduce the energy loss are: a) reduce excess air b) recirculate flue gas c) reduce the flue gas temperature at the boiler exit of 145°C d) heat recovery by condensate preheating The thermal conversion of the boiler is 91,9%.	Yes
27. to secure where practicable, long-term base-load heat/steam supply contracts to large heat/steam users (see 4.3.1) so that a more regular demand for the recovered energy exists and therefore a larger proportion of the energy value of the incinerated waste may be used.	The average net electrical efficiency is 29,6%. Necessary measures have been foreseen for later export of heat.	Yes

BAT	TNG	BAT fullfilled?
28. the location of new installations so that the use of the heat and/or steam generated in the boiler can be maximised through any combination of: a. electricity generation with heat or steam supply for use (i.e. use CHP) b. the supply of heat or steam for use in district heating distribution networks c. the supply of process steam for various, mainly industrial, uses (see examples in 4.3.18) d. the supply of heat or steam for use as the driving force for cooling/air conditioning systems Selection of a location for a new installation is a complex process involving many local factors (e.g. waste transport, availability of energy users, etc) which are addressed by IPPC Directive Article 9(4). The generation of electricity only may provide the most energy efficient option for the recovery of the energy from the waste in specific cases where local factors prevent heat/steam recovery.	See point 27.	Yes
29. in cases where electricity is generated, the optimisation of steam parameters (subject to user requirements for any heat and steam produced), including consideration of (see 4.3.8): a. the use of higher steam parameters to increase electrical generation, and b. the protection of boiler materials using suitably resistant materials (e.g. claddings or special boiler tube materials) The optimal parameters for an individual installation are highly dependent upon the corrosivity of the flue-gases and hence upon the waste composition.	Depending on the flue gas composition and the waste conditions the steam parameters were determined to be 73barA/430°C. This superheated steam parameters ensure high energy efficiency. The net electrical efficiency is 29,6%.	Yes
30. the selection of a turbine suited to: a. the electricity and heat supply regime, as described in 4.3.7 b. high electrical efficiency	A condensing turbine was chosen as there are no possibilities to supply heat to customers.	Yes
31. at new or upgrading installations, where electricity generation is the priority over heat supply, the minimisation of condenser pressure, as described in 4.3.9	The turbine exhaust pressure (100 mbar, 22°C) and the air cooled condenser are designed so that the high ambient temperatures of Sydney can be handled.	Yes

BAT	TNG	BAT fullfilled?
32. the general minimisation of overall installation energy demand, including consideration of the following (see 4.3.6): a. for the performance level required, the selection of techniques with lower overall energy demand in preference to those with higher energy demand b. wherever possible, ordering flue-gas treatment systems in such a way that flue gas reheating is avoided (i.e. those with the highest operational temperature before those with lower operational temperatures) c. where SCR is used; i. to use heat exchangers to heat the SCR inlet flue-gas with the flue-gas energy at the SCR outlet ii. to generally select the SCR system that, for the performance level required (including availability/fouling and reduction efficiency), has the lower operating temperature d. where flue-gas reheating is necessary, the use of heat exchange systems to minimise flue-gas reheating energy demand e. avoiding the use of primary fuels by using self produced energy in preference to imported sources	To minimise the overall energy consumption the following measures were taken: - SNCR instead of SCR to avoid the flue gas reheating for the catalytic reaction - efficient preheating of primary and secondary air - minimal condenser pressure - placing high temperature equipment before (upstream) lower temperature equipment - use of frequency controlled rotating equipment for those equipment parts which operate at variable speeds. - high efficient DCS system to minimise the measure failure SCR is not relevant.	Yes
33. where cooling systems are required, the selection of the steam condenser cooling system technical option that is best suited to the local environmental conditions, taking particular account of potential cross-media impacts, as described in 4.3.10	As result of the local conditions and to minimize the water consumption an air cooled condenser has been chosen.	Yes
34. the use of a combination of on-line and off-line boiler cleaning techniques to reduce dust residence and accumulation in the boiler, as described in 4.3.19	Online cleaning devices for all parts of the boiler are foreseen. Offline cleaning is carried out manually during revisions.	Yes
35. the use of an overall flue-gas treatment (FGT) system that, when combined with the installation as a whole, generally provides for the operational emission levels for releases to air associated with the use of BAT listed in Table 5.2	The emission guarantees are in accordance with the European Industrial Emission Directive. The expected operational emission levels are in line with the values given in Table 5.2.	Yes

BAT	TNG	BAT fullfilled?
36. when selecting the overall FGT system, to take into account: a. the general factors described in 4.4.1.1 and 4.4.1.3 b. the potential impacts on energy consumption of the installation, as described in section 4.4.1.2 c. the additional overall-system compatibility issues that may arise when retrofitting existing installations (see 4.4.1.4)	The following factors have been taken account for the selection of the FGT system: - type of waste, its composition and variation - type of combustion process, and its size - through recirculation of flue gases less flue gas flow and lower flue gas temperature - flue gas composition and fluctuations in the composition - target emission limit values - restrictions on discharge of aqueous effluents - availability of land and space - availability and cost of outlets for residues accumulated/recovered - minimize consumables	Yes
37. when selecting between wet / semi-wet / and dry FGT systems, to take into account the (non-exhaustive) general selection criteria given as an example in Table 5.3 [See at the end of this document]	The Flue gas cleaning process is characterised by the following features: - No effluent as necessary for wet FGT - minimized consumables and residues - Dry injection of Calcium Hydroxide (Ca(OH)2) and Powdered Activated Carbon (PAC) - Separate injection of water for conditioning and reactivation of recycled lime particles - Compact design - Low manpower requirement	Yes
38. to prevent the associated increased electrical consumption, to generally (i.e. unless there is a specific local driver) avoid the use of. two bag filters in one FGT line (as described in 4.4.2.2 and 4.4.2.3)	The installation has only one bag filter.	Yes

BAT	TNG	BAT fullfilled?
39. the reduction of FGT reagent consumption and of FGT residue production in dry, semi-wet, and intermediate FGT systems by a suitable combination of: a. adjustment and control of the quantity of reagent(s) injected in order to meet the requirements for the treatment of the flue-gas such that the target final operational emission levels are met b. the use of the signal generated from fast response upstream and/or downstream monitors of raw HCl and/or SO2 levels (or other parameters that may prove useful for this purpose) for the optimisation of FGT reagent dosing rates, as described in 4.4.3.9 c. the re-circulation of a proportion of the FGT residues collected, as described in 4.4.3.7 The applicability and degree of use of the above techniques that represents BAT will vary according to, in particular: the waste characteristics and consequential flue-gas nature, the final emission level required, and technical experience from their practical use at the installation	a) The quantity of reagents injected is regularly checked by measuring the target final operational emission levels. Depending on the emission level the reagents are injected. b) Measuring devices are installed to check the raw gas c) A part of the residues are recirculated into the semi dry reactor which results in a high efficiency, lower consumption of absorbent, protection of filter bags and a higher operational safety.	Yes
40. the use of primary (combustion related) NO_X reduction measures to reduce NO_X production, together with either SCR (4.4.4.1) or SNCR (4.4.4.2), according to the efficiency of flue-gas reduction required. In general SCR is considered BAT where higher NO_X reduction efficiencies are required (i.e. raw flue-gas NO_X levels are high) and where low final flue-gas emission concentrations of NOX are desired. One MS reported that technical difficulties have been experienced in some cases when retrofitting SNCR abatement systems to existing small MSW incineration installations, and that the cost effectiveness (i.e. NOX reduction per unit cost) of NOX abatement (e.g. SNCR) is lower at small MSWIs (i.e. those MSWIs of capacity <6 tonnes of waste/hour).	In the first pass of the boiler ammonia is injected into the flue gas stream. The results are well controlled and low NOx emissions which are below the levels given by the Industrial Emissions Directive. The most important factors for NOx reduction measures are: - O_2 content - flue gas recirculation - optimized secondary air injection Neither retrofitting nor small installation, therefore not relevant.	Yes

BAT	TNG	BAT fullfilled?
41. for the reduction of overall PCDD/F emissions to all environmental media, the use of: a. techniques for improving knowledge of and control of the waste, including in particular its combustion characteristics, using a suitable selection of techniques described in 4.1, and b. primary (combustion related) techniques (summarised in 4.4.5.1) to destroy PCDD/F in the waste and possible PCDD/F precursors, and c. the use of installation designs and operational controls that avoid those conditions (see 4.4.5.2) that may give rise to PCDD/F reformation or generation, in particular to avoid the abatement of dust in the temperature range of 250 – 400 °C. Some additional reduction of de-novo synthesis is reported where the dust abatement operational temperature has been further lowered from 250 to below 200 °C, and d. the use of a suitable combination of one or more of the following additional PCDD/F abatement measures: i. adsorption by the injection of activated carbon or other reagents at a suitable reagent dose rate, with bag filtration, as described in 4.4.5.6, or ii. adsorption using fixed beds with a suitable adsorbent replenishment rate, as described in 4.4.5.7, or iii. multi layer SCR, adequately sized to provide for PCDD/F control, as described in 4.4.5.3, or iv. the use of catalytic bag filters (but only where other provision is made for effective metallic and elemental Hg control), as described in 4.4.5.4	For the reduction of PCDD/F emissions the following techniques are applied: - optimized secondary air injection - maximal gas burn out - minimization of fly ash deposits in the boiler - continuous boiler cleaning - no dedusting equipment where the gas temperature is above 200°C - SNCR	Yes
42. where wet scrubbers are used, to carry out an assessment of PCDD/F build up (memory effects) in the scrubber and adopt suitable measures to deal with this build up and prevent scrubber breakthrough releases. Particular consideration should be given to the possibility of memory effects during shut-down and start-up periods.	No wet scrubbers are used.	Not relevant
43. if re-burn of FGT residues is applied, then suitable measures should be taken to avoid the re-circulation and accumulation of Hg in the installation	No re-burn of FGT residues is applied.	Not relevant

BAT	TNG	BAT fullfilled?
44. for the control of Hg emissions where wet scrubbers are applied as the only or main effective means of total Hg emission control: a. the use of a low pH first stage with the addition of specific reagents for ionic Hg removal (as described in 4.4.6.1, 4.4.6.6 and 4.4.6.5), in combination with the following additional measures for the abatement of metallic (elemental) Hg, as required in order to reduce final air emissions to within the BAT emission ranges given for total Hg b. activated carbon injection, as described in 4.4.6.2, or c. activated carbon or coke filters, as described in 4.4.6.7	No wet scrubbers are used.	Not relevant
45. for the control of Hg emissions where semi-wet and dry FGT systems are applied, the use of activated carbon or other effective adsorptive reagents for the adsorption of PCDD/F and Hg, as described in 4.4.6.2, with the reagent dose rate controlled so that final air emissions are within the BAT emission ranges given for Hg	For the control of Hg emissions an activated carbon injection into the semi dry reactor is applied. The reagent dose rate is controlled to ensure that the final air emissions are within the BAT ranges given for Hg.	Yes
46. the general optimisation of the re-circulation and re-use of waste water arising on the site within the installation, as described in 4.5.8, including for example, if of sufficient quality, the use of boiler drain water as a water supply for the wet scrubber in order to reduce scrubber water consumption by replacing scrubber feed-water (see 4.5.6)	To avoid additional water consumption a complete recirculation of condensate is installed. The boiler drain water is used for the bottom ash quenching.	Yes
47. the use of separate systems for the drainage, treatment and discharge of rainwater that falls on the site, including roof water, so that it does not mix with potential or actual contaminated waste water streams, as described in 4.5.9. Some such waste water streams may require only little or no treatment prior to their discharge, depending on contamination risk and local discharge factors	A separate system is used for the drainage, treatment and discharge of rainwater so that it does not mix with potential or actual contaminated waste water streams.	Yes

BAT	TNG	BAT fullfilled?
48. where wet flue-gas treatment is used: a. the use of on-site physico/chemical treatment of the scrubber effluents prior to their discharge from the site, as described in 4.5.11, and thereby to achieve, at the point of discharge from the effluent treatment plant (ETP), emission levels generally within the BAT associated operational emission level ranges that are identified in Table 5.4 [See at the end of this document] b. the separate treatment of the acid and alkaline waste water streams arising from the scrubber stages, as described in 4.5.13, when there are particular drivers for the additional reduction of releases to water that result, and/or where HCl and/or gypsum recovery is to be carried out c. the re-circulation of wet scrubber effluent within the scrubber system, and the use of the electrical conductivity (mS/cm) of the re-circulated water as a control measure, so as to reduce scrubber water consumption by replacing scrubber feed-water, as de- scribed in 4.5.4 d. the provision of storage/buffering capacity for scrubber effluents, to provide for a more stable waste water treatment process, as described in 4.5.10 e. the use of sulphides (e.g. M-trimercaptotriazine) or other Hg binders to reduce Hg (and other heavy metals) in the final effluent, as described in 4.5.11 f. when SNCR is used with wet scrubbing the ammonia levels in the effluent discharge may be reduced using ammonia stripping, as described in 4.5.12, and the recovered ammonia re-circulated for use as a NOX reduction reagent	No wet flue gas treatment is used.	Not relevant

BAT	TNG	BAT fullfilled?
49. the use of a suitable combination of the techniques and principles described in 4.6.1 for improving waste burnout to the extent that is required so as to achieve a TOC value in the ash residues of below 3 wt % and typically between 1 and 2 wt %, including in particular: a. the use of a combination of furnace design (see combustion technology selection in 4.2.1), furnace operation (see 4.2.17) and waste throughput rate (see 4.2.18) that provides sufficient agitation and residence time of the waste in the furnace at sufficiently high temperatures, including any ash burn-out areas b. the use of furnace designs that, as far as possible, physically retain the waste within the combustion chamber (e.g. narrow grate bar spacings for grates, rotary or static kilns for appreciably liquid wastes) to allow its combustion. The return of early grate riddlings to the combustion chamber for re-burn may provide a means to improve overall burn out where they contribute significantly to the deterioration of burnout (see 4.2.21) c. the use of techniques for mixing and pre-treatment of the waste, as described in BAT 11, according to the type(s) of waste received at the installation d. the optimisation and control of combustion conditions, including air (oxygen) supply and distribution, as described in BAT 18	The expected value of TOC is < 1%. A combination of different techniques/measures is used to improve the waste burnout: - optimal combustion conditions with a classic combustion control system, - flow optimised secondary combustion chamber, - visual check of the fire on the grate, - optimal design of the boiler geometry, - optimal temperature distribution on the grate, - optimal waste distribution over the grate - adjustment of particular grate speed - ensuring that the plant is operated within its capacity (fire control diagram) - good mixing of the waste before feeding	Yes
50. the separate management of bottom ash from fly ash and other FGT residues, so as to avoid contamination of the bottom ash and thereby improve the potential for bottom ash recovery, as described in 4.6.2. Boiler ash may exhibit similar or very different levels of contamination to that seen in bottom ash (according to local operational, design and waste specific factors) – it is therefore also BAT to assess the levels of contaminants in the boiler ash, and to assess whether separation or mixing with bottom ash is appropriate. It is BAT to assess each separate solid waste stream that arises for its potential for recovery either alone or in combination.	There is a separate management of bottom ash from fly ash and FGT residues. The FGT residues will be stored in separate enclosed silos before being transported by sealed tankers to an appropriate offsite treatment facility. This complies with the hazardous waste legislation.	Yes
51. where a pre-dedusting stage (see 4.6.3 and 4.4.2.1) is in use, an assessment of the composition of the fly ash so collected should be carried out to assess whether it may be recovered, either directly or after treatment, rather than disposed of	No pre-dedusting stage is installed.	Not relevant
52. the separation of remaining ferrous and non-ferrous metals from bottom ash (see 4.6.4), as far as practicably and economically viable, for their recovery	A magnetic separator is placed above a conveyor to remove ferrous metals from bottom ash.	Yes

BAT	TNG	BAT fullfilled?
53. the treatment of bottom ash (either on or off-site), by a suitable combination of: a. dry bottom ash treatment with or without ageing, as described in 4.6.6 and 4.6.7, or b. wet bottom ash treatment, with or without ageing, as described in 4.6.6and 4.6.8, or c. thermal treatment, as described in 4.6.9 (for separate treatment) and 4.6.10 (for in-process thermal treatment) or d. screening and crushing (see 4.6.5) to the extent that is required to meet the specifications set for its use or at the receiving treatment or disposal site e.g. to achieve a leaching level for metals and salts that is in compliance with the local environmental conditions at the place of use.	The bottom ash is treated according to b) before reuse or landfill	Yes
54. the treatment of FGT residues (on or off-site) to the extent required to meet the acceptance requirements for the waste management option selected for them, including consideration of the use of the FGT residue treatment techniques described in 4.6.11	The FGT residues will be stored in separate enclosed silos before being transported by sealed tankers to an appropriate offsite treatment facility. This complies with the hazardous waste legislation.	Yes
55. the implementation of noise reduction measures to meet local noise requirements (techniques are described in 4.7 and 3.6)	Noise reduction measures are installed at the turbine-generator, at the fans and at other critical plant sections.	Yes
56. apply environmental management. A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have. BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features: (see Chapter 4.8) [Number of bullet points omitted]	The plant is operated by qualified personnel and the staff will be sent to relevant qualifying courses. To ensure that employees are aware of the relevant parts of the environmental permit, regular dialogue meetings are held with the employees. The plant is ISO 14001 and OHSA 18001 certified. Additional information can be found in the quality manual where environmental measurements, reports and factors such as environmental requirements, responsibilities and competencies of facilities and technical installations are described. The operator is responsible to install the environmental system.	Yes
57. the storage of all waste, (with the exception of wastes specifically prepared for storage or bulk items with low pollution potential e.g. furniture), on sealed surfaces with controlled drainage inside covered and walled buildings	The waste is stored in the waste bunker. The waste bunker has sealed surfaces.	Yes

BAT	TNG	BAT fullfilled?
58. when waste is stockpiled (typically for later incineration) it should generally be baled (see Section 4.1.4.3) or otherwise prepared for such storage so that it may be stored in such a manner that risks of odour, vermin, litter, fire and leaching are effectively controlled.	The risks of odour, vermin, litter, fire and leaching are effectively controlled because the waste is stockpiled in a closed building. There is no influence to the environment (only the open delivery boxes).	Yes
59. to pre-treat the waste, in order to improve its homogeneity and therefore combustion characteristics and burn-out, by: a. mixing in the bunker (see 4.1.5.1), and b. the use of shredding or crushing for bulky wastes e.g. furniture (see 4.1.5.2) that are to be incinerated, to the extent that is beneficial according to the combustion system used. In general grates and rotary kilns (where used) require lower levels of pre-treatment (e.g. waste mixing with bulky waste crushing) whereas fluidized bed systems require greater waste selection and pre- treatment, usually including full shredding of the MSW.	The pre-treat of waste in order to improve its homogeneity is a) mixing of waste in the bunker b) shredding of waste.	Yes
60. the use of a grate design that incorporates sufficient cooling of the grate such that it permits the variation of the primary air supply for the main purpose of combustion control, rather than for the cooling of the grate itself. Air-cooled grates with well distributed air cooling flow are generally suitable for wastes of average NCV of up to approx 18 MJ/kg. Higher NCV wastes may require water (or other liquid) cooling in order to prevent the need for excessive primary air levels (i.e. levels that result in a greater air supply than the optimum for combustion control) to control grate temperature and length/position of fire on the grate (see section 4.2.14)	For the grate a combination of water cooled blocks and air cooled blocks is used. The calorific value is below 18 GJ/t (usually 10-11 GJ/t).	Yes
61. the location of new installations so that the use of CHP and/or the heat and/or steam utilisation can be maximised, so as to generally exceed an overall total energy export level of 1.9 MWh/tonne of MSW (ref. Table 3.42), based on an average NCV of 2.9 MWh/tonne (ref. Table 2.11)	The thermal efficiency is above 79,3 % (based on calculation of R1). Currently no heat or steam export is planned (however the plant is designed for heat export in case of future possibilities)	Yes

BAT	TNG	BAT fullfilled?
62. in situations where less than 1.9 MWh/tonne of MSW (based on an average NCV of 2.9 MWh /tonne) can be exported, the greater of: a. the generation of an annual average of 0.4 – 0.65 MWh electricity/tonne of MSW (based on an average NCV of 2.9 MWh/tonne (ref. Table 2.11) processed (ref. Table 3.40), with additional heat/steam supply as far as practicable in the local circum- stances, or b. the generation of at least the same amount of electricity from the waste as the annual average electricity demand of the entire installation, including (where used) on-site waste pre-treatment and on-site residue treatment operations (ref. Table 3.48)	The annual average production is 1,02 MWh electricity/tonne of waste.	Yes
63. to reduce average installation electrical demand (excluding pre-treatment or residue treatment) to be generally below 0.15 MWh/tonne of MSW processed (ref. Table 3.47 and section 4.3.6) based on an average NCV of 2.9 MWh/tonne of MSW (ref. Table 2.11)	The electrical demand of the of the plant is 0,123 MWh electricity/tonne of waste.	Yes
64. the storage of wastes: a. in enclosed hoppers or, b. on sealed surfaces with controlled drainage inside covered and walled buildings	The waste is stored in the waste bunker. The waste bunker has sealed surfaces and is inside a closed building.	Yes
65. when waste is stockpiled (typically for later incineration) it should generally be baled (see Section 4.1.4.3) or otherwise prepared for such storage so that it may be stored in such a manner that risks of odour, vermin, litter, fire and leaching are effectively controlled	see point 58.	
66. at new and existing installations, the generation of the greater of: a. an annual average of generally at least 0.6 – 1.0 MWh electricity/tonne of waste (based on an average NCV of 4.2 MWh/tonne), or b. the annual average electricity demand of the entire installation, including (where used) on-site waste pretreatment and on-site residue treatment operations	The annual average production is 1,02 MWh electricity/tonne of waste.	Yes

BAT	TNG	BAT fullfilled?
67. the location of new installations so that: a. as well as the 0.6 – 1.0 MWhe/ tonne of electricity generated, the heat and/or steam can also be utilised for CHP, so that in general an additional thermal export level of 0.5 – 1.25 MWh/tonne of waste (ref. section 3.5.4.3) can be achieved (based on an average NCV of 4.2 MWh/tonne), or b. where electricity is not generated, a thermal export level of 3 MWh/tonne of waste can be achieved (based on an average NCV of 4.2 MWh/tonne)	The annual average production is 1,02 MWh electricity/tonne of waste.	Yes
68. to reduce installation energy demand and to achieve an average installation electrical demand (excluding pretreatment or residue treatment) to generally below 0.2 MWh/tonne of waste processed (ref. Table 3.47 and section 4.3.6) based on an average NCV of 4.2 MWh/tonne of waste	The electrical demand of the plant is 0,123 MWh electricity/tonne of waste.	Yes

ENERGY

MEMO

Job TNG Energy from Waste Facility, Eastern Creek,
Differences between quoted design Ash outputs and operational ash outputs
Date **2016-10-24**
From **Ahmet Erol**

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

File; TNGWTE-141-015 Explanation design Ash and operational Ash outputs.docx
Ver. 3

Differences between quoted design Ash outputs and operational ash outputs

Introduction

TNG have been asked to provide an explanation for the differences between quoted design ash outputs and operational ash outputs from the reference facilities.

Factors influencing bottom ash quantity of EfW plants

The design of an EfW plant is based on the waste amount, the waste composition and the calorific value (CV) of the waste.

An important aspect of the waste composition is the ash content which is made up of the ash of combustible fuel (ash of wood, paper, etc.) as well as inert materials like metal, glass, stone, sand etc.

Depending on the nature of the waste the ash content varies. Even different waste streams with identical CV can have a variation of the ash content. The CV is mainly influenced by the relation between combustible, water and inert. A waste with high water but low ash content can have the same CV as a waste with high ash and low water content.

As a result there can be a certain variation (usually +/- 3-5% points) of the ash in real operation compared to the design value even if a plant is running at its designed throughput capacity.

Ash outputs

						Bottom Ash Dry %	
Facility / Location	**LHV @ LPN** MJ/kg	**Design** t/a	**Fuel mix**	**bottom ash (wet)** t/a	**bottom ash Quantity (wet)** %	**Operation**	**Design**
TNG	12.3	4 x 276'250	C&I, C&D	293'166	26.5%	-	21.49%
Grossräschen	12.5	1 x 246'000	C&I, C&D	68'729	27.9%	22.4%	18.8%
Knapsack	11-17	2 x 150'000	C&I, C&D	81'000	27.0%	21.6%	19.0%
Ferrybridge	8.5	2 x 256'500	C&I, C&D, some MSW, wood	57'830	11.3%	9.0%	12.8%
Riverside	9.6	3 x 195'000	MSW, C&I	146'250	25.0%	20.0%	19.7%
TIRME Mallorca	10	2 x 208'000	MSW, C&I, C&D, Hospital waste, sewage sludge, tyres	92'350	22.2%	17.8%	20.0%

The above table shows updated the design and operational values of several EfW plants. The operation and design bottom ash quantities are all within a variation range of 3-4%.

The ash quantities in case of TIRME Mallorca have been derived from the Environmental Master plan (design) and information received from the operator (operation). The data given in earlier memos was data from the initial design fuel and the reference sheet of the supplier which were obviously outdated.

Appendix D FUEL COMPOSITION

Table D-1: Material composition of the proposed feedstock – arising from existing and planned facilities (MRA, 2017)

Category	Sub-category	Sources (current or planned)						TOTAL (t)	%
		Genesis MPC and Genesis Alexandria (t)[7]	Genesis EC Landfill		C&I Dirty MRF (t)[8]	Genesis EC (excl. MPC)			
			MRF residual (t)[9]	Shredder Floc (t)[10]		Waste wood (t)	Textiles (t)		
Paper	Recyclable paper	865	4,543	317	46,187	-	-	65,300	11.82%
	Disposable contaminated (soft) paper	687	4,197						
	Cardboard	2,560	4,696						
	Liquid paperboard	11	242						
	Nappies	11	983						
Wood or timber	Untreated wood - MDF board	5,132	346	2,425	38,161	58,557	-	172,182	31.16%
	Untreated wood - All other	60,508	1,531						
	Treated wood - CCA treated	5,343	180			-			
	Treated wood - lead painted	-	-						
Plastic	Recyclable plastic containers excl. EPS	111	1,489	17,428	37,742	-	-	82,641	14.96%
	Other rigid plastics excl. EPS	2,948	4,370						
	EPS	89	388						
	Soft (films) plastics	3,458	10,340						
	Composite plastics	1,507	2,770						
Metal (Ferrous and non-ferrous)	Recyclable metal containers	44	464	1,147	7,554	-	-	13,863	2.51%
	Composite	366	990						
	Other metals	1,663	1,634						
	Food/kitchen - vegetable	11	1,461	-	24,062	-	-		

---

[7] This waste stream has been characterised as chute residual waste ("CRW") (i.e. residual from mixed C&D processing). Residual from the Genesis MPC has been audited, please refer to Appendix F for the audit report. It is assumed that residual from Genesis Alexandria is of a similar composition to that of residual from the Genesis MPC.

[8] This waste stream has been characterised as mixed C&I, as audited at the point of disposal. The composition of this waste stream was derived from 'Disposal-based audit: Commercial and industrial waste stream in the regulated areas of New South Wales' (NSW EPA, 2015).

[9] This waste stream has been characterised as residual from material recovery facilities ("MRF"). Residual from MRFs currently received by the Proponent has been audited, please refer to Appendix G for a summary of the audit results.

[10] This waste stream has been characterised as shredder floc ("Floc"). Shredder floc currently received by the Proponent has been audited, please refer to Appendix H for a summary of the audit results.

Category	Sub-category	Sources (current or planned)						TOTAL (t)	%
		Genesis MPC and Genesis Alexandria (t)[7]	Genesis EC Landfill		C&I Dirty MRF (t)[8]	Genesis EC (excl. MPC)			
			MRF residual (t)[9]	Shredder Floc (t)[10]		Waste wood (t)	Textiles (t)		
Organic (not wood or timber)	Food/kitchen - meat	-	125	-		-	-	109,492	19.82%
	Garden/vegetables	1,441	713	-	12,746	-	-		
	Textiles/rags	10,907	18,041	8,877	13,738	-	9,812		
	Rubber	488	603	3,905	1,925	-	-		
	Leather	111	526		-	-	-		
WEE	e-waste	-	-	-	-	-	-	-	0.00%
	Mobiles	-	-						
	Toners	-	-						
Hazardous	Medical	-	-	-	-	-	-	-	0.00%
	Chemicals	-	-						
	Paint	-	-						
	Asbestos	-	-						
	Batteries car	-	-						
	Batteries other	-	-						
	Other hazardous	-	-						
Glass	Glass containers	-	55	-	3,844	-	-	6,850	1.24%
	Glass other	111	2,840						
Other (including earth and building materials)	Insulation	67	-	-	11,361	-	-	102,172	18.49%
	Carpet/underlay	887	-						
	Compounds (excl. plastic and metal)	1,053	1,378						
	Asphalt	1,330	-						
	Inert incl. non-hazardous building waste	8,247	1,745	47,263	28,842				
TOTAL (t)		**109,954**	**66,653**	**81,361**	**226,162**	**43,537**	**9,812**	**552,727**	**100.00%**

Table D-2: Fuel mix (Ramboll, 2017)

	CRW	MRF	Floc Waste	Mixed C&I	Specified Waste	Design Fuel Mix
Chemical Analysis						
Carbon (C)	38.54%	44.18%	23.45%	25.92%	36.18%	31.51%
Hydrogen (H)	4.61%	6.09%	4.17%	3.33%	4.37%	4.17%
Oxygen (O)	25.20%	19.29%	7.99%	18.16%	30.50%	19.69%
Nitrogen (N)	0.77%	0.42%	0.96%	0.72%	1.36%	0.81%
Sulphur(S)	0.18%	0.07%	0.26%	0.16%	0.50%	0.21%
Chloride (Cl)	0.37%	0.32%	0.52%	0.06%	0.27%	0.25%
Ash	14.72%	19.04%	49.50%	20.92%	7.45%	22.04%
Water (H2O)	15.60%	10.59%	13.15%	30.73%	19.36%	21.32%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
NCV MJ/kg	14.71	18.79	10.98	9.50	13.07	**12.30**

Appendix E SENSITIVE RECEPTORS

Table E-1: Sensitive receptor locations

Sensitive Receptor	Easting (m)	Northing (m)
James Erskine Primary School	296748	6257187
Erskine Park High School	296709	6256992
Clairgate Public School	296299	6258187
Minchinbury Public School	299287	6259084
Pinegrove Memorial Park Lawn Cemetery	300567	6258692
Sunny Patch Preparation School & Long Day Care Centre	297153	6258266
Eastern Creek Public School	301201	6259319
St Agnes Catholic High School	300761	6259894
All Areas Family Day Care Pty	299581	6258986
Maria Hawey Child Care Centre	299370	6259272
Jiminey Cricket Long Day Care	298562	6259310
White Bunny Child Care Centre	299792	6259530
LITTLESMARTIES	296419	6258212
Kidz Fun Factory	298128	6259445
Industrial facility	297743	6259085
Industrial facility	298017	6259102
Industrial facility	298262	6259157
Industrial facility	298362	6259444
Industrial facility	298106	6259473
Industrial facility	297650	6259598
Industrial facility	297391	6259845
Industrial facility	297425	6259607
Industrial facility	297528	6259706
Industrial facility	297827	6259711
Industrial facility	297923	6259624
Industrial facility	298057	6259589
Industrial facility	298165	6259576
Industrial facility	298169	6259723
Industrial facility	297988	6259754
Industrial facility	297855	6259871
Industrial facility	298473	6259809
Industrial facility	298254	6259912
Industrial facility	297964	6259979
Industrial facility	297807	6260039
Industrial facility	299645	6258440
Industrial facility	299645	6258037
Industrial facility	299709	6257886
Industrial facility	299541	6257851
Industrial facility	299441	6258055
Industrial facility	299490	6257405
Industrial facility	299906	6257425
Industrial facility	300157	6257390
Industrial facility	300263	6257339
Industrial facility	300447	6257583

Sensitive Receptor	Easting (m)	Northing (m)
Industrial facility	300228	6257651
Industrial facility	300560	6257928
Industrial facility	300633	6257735
Industrial facility	300948	6257833
Industrial facility	300802	6257591
Industrial facility	300633	6257403
Industrial facility	300755	6257374
Industrial facility	301037	6257567
Industrial facility	301057	6257410
Industrial facility	301003	6257186
Industrial facility	300950	6257066
Industrial facility	300910	6256975
Industrial facility	300682	6257126
Industrial facility	300691	6257026
Industrial facility	300830	6257241
Industrial facility	300436	6257299
Industrial facility	299601	6257064
Industrial facility	299490	6256891
Industrial facility	299689	6256705
Industrial facility	299501	6256224
Industrial facility	300008	6256426
Industrial facility	300219	6256526
Industrial facility	300529	6256577
Industrial facility	300899	6256202
Industrial facility	300786	6255839
Industrial facility	301006	6255854
Industrial facility	298652	6255402
Industrial facility	298508	6255389
Industrial facility	298584	6255037
Industrial facility	296204	6256521
Industrial facility	296614	6256526
Industrial facility	296388	6256355
Industrial facility	296643	6256280
Industrial facility	296700	6256087
Industrial facility	296946	6256040
Industrial facility	296598	6255723
Industrial facility	296410	6255743
Industrial facility	296055	6255881
Industrial Facility (Fisher and Paykel)	299251	6258615
Commercial Land (Sargents)	298093	6258488
Commercial Land (Dept of Planning)	297926	6258109
Commercial Land (Dept of Planning)	298154	6257844
Commercial Land (Dept of Planning)	298091	6257443
Commercial Land (Dept of Planning)	298470	6257372
Commercial Land (Dept of Planning)	298175	6257034

Sensitive Receptor	Easting (m)	Northing (m)
Commercial Land (Dept of Planning)	298746	6257137
Industrial Facility (Hanson)	299072	6257670
Industrial Facility (Jacfin)	299136	6256900
Prospect Dam	303431	6255769

Appendix F FIVE YEAR ANALYSIS OF METEOROLOGY

As specified in the EPA's *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* five years of data are required to be reviewed so that a representative year of meteorological conditions can be selected.

Annual and seasonal wind roses for St Marys OEH Weather Station have been prepared for 2009 through 2013 and are shown below. Rainfall data was unavailable from St Marys OEH Station, and so annual rainfall data from BOM site Horsley Park Equestrian Centre has been presented in **Figure F8** to give further indication of meteorological conditions in the region for the given years. All five years of data collected at St Marys OEH Station show a similar pattern both annually and seasonally. There are some minor differences which are discussed below.

On an annual basis the prevailing wind directions originate from all directions of the compass, with fewer winds experienced from the northeast and north-northeast as well as from the southwest and west-southwest.

During summer the prevailing winds are dominated by flows originating from the southern and south-eastern quadrants.

Conversely, the months of winter are dominated by wind from the south, south-southwestern and north-northwestern quadrants. Almost no winds are experienced from the eastern, south-eastern and north-eastern directions in winter across all years of data examined.

The wind distribution patterns for autumn show a consistent trend to southern, south-southwesterly and south-southeasterly winds.

Spring conditions are less consistent, showing a mixed pattern with some prevalence for Southern, south-southeasterly and south-southwesterly winds as well as a north-northwesterly wind.

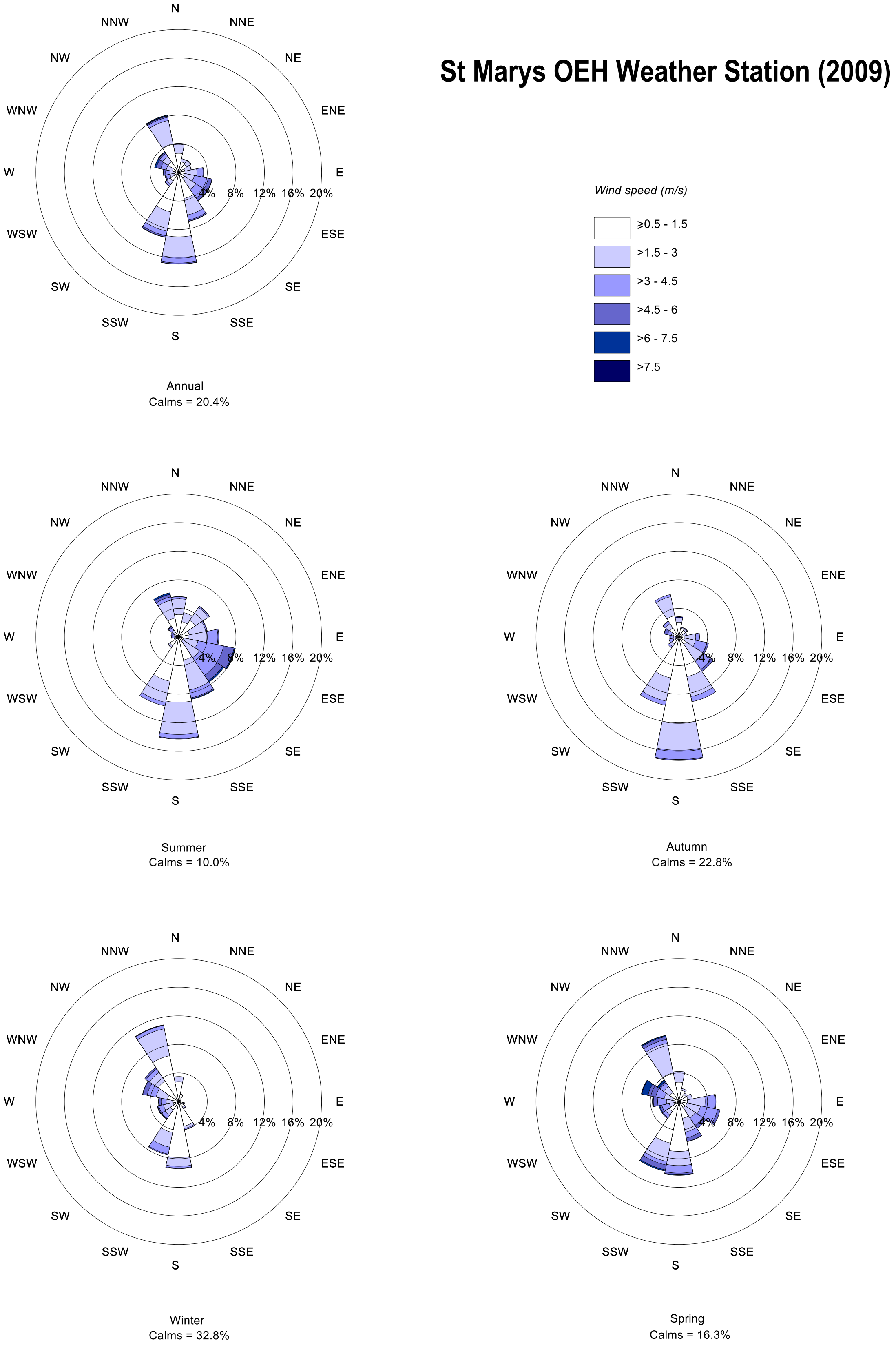
The percentage of calms is fairly consistent across all years and ranged between 20.4% for 2009 and 24.7% for 2013.

Further analysis was conducted for the five years of data. The long-term trend of monthly average temperature and monthly average wind speed is also shown below, though temperature data was unavailable for 2009.

A strong seasonal trend in monthly average temperatures is evidenced with the highest temperatures experienced during the summer months of December, January and February and the lowest temperatures during the winter months of June, July and August. 2011 and 2013 are shown to experience higher monthly average temperatures across most months. Generally speaking, the monthly average temperatures at St Marys OEH Weather Station do not vary significantly from year to year.

There is no strong relationship between the time of year and the monthly average wind speed. Generally speaking, the monthly average wind speeds are less during the months of April, May, June and July. 2009 measured clearly the highest winds speed across the five years investigated.

From this analysis, in addition to the consistent wind distribution patterns experienced discussed above it is considered that 2013 is a typical year and is therefore deemed a representative year for dispersion modelling.



St Marys OEH Weather Station (2009)

Annual
Calms = 20.4%

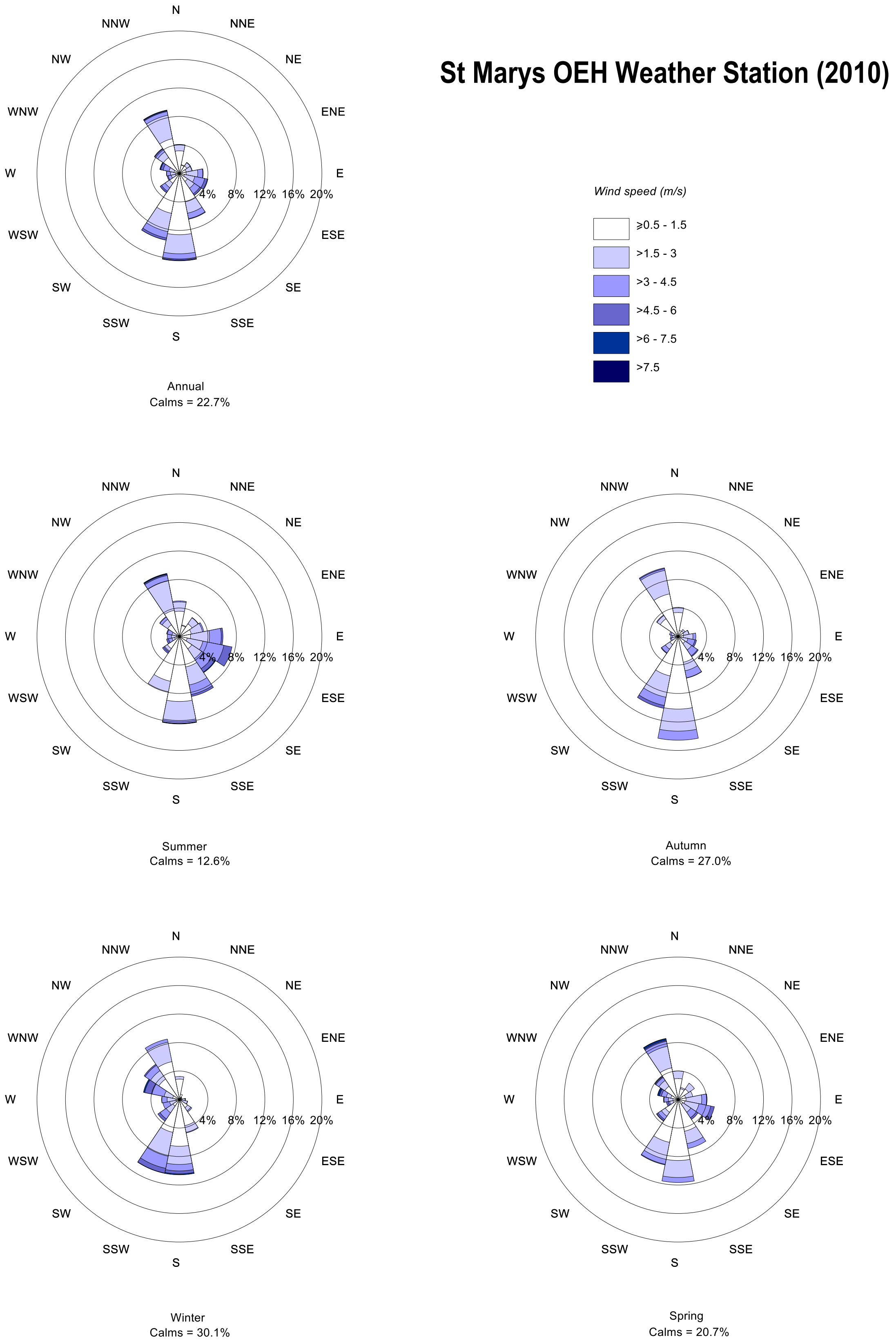
Summer
Calms = 10.0%

Autumn
Calms = 22.8%

Winter
Calms = 32.8%

Spring
Calms = 16.3%

Figure F-1: Annual and seasonal wind roses for St Marys OEH Station (2009)



Annual
Calms = 22.7%

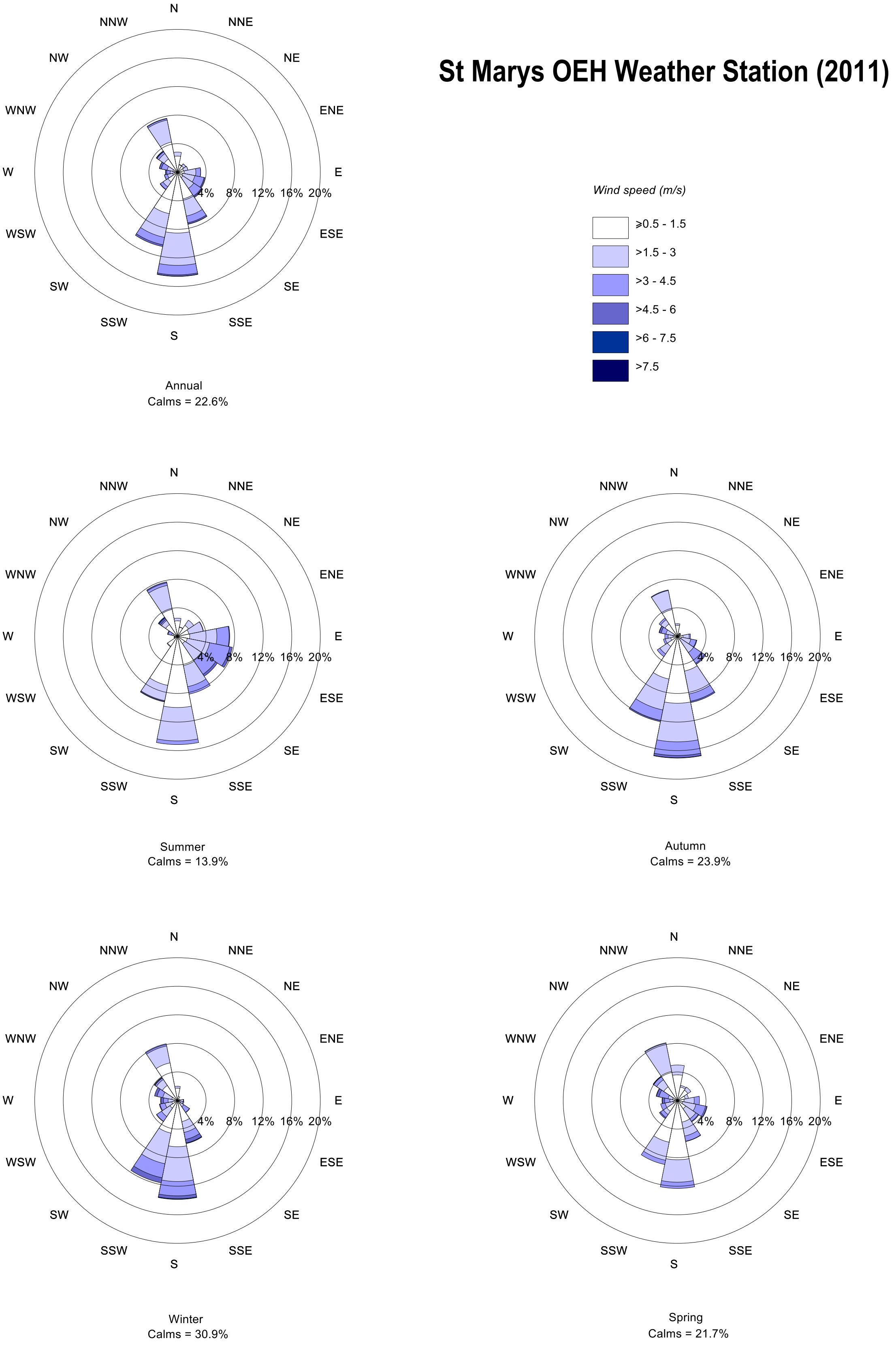
Summer
Calms = 12.6%

Autumn
Calms = 27.0%

Winter
Calms = 30.1%

Spring
Calms = 20.7%

Figure F-2: Annual and seasonal wind roses for St Marys OEH Station (2010)



Annual
Calms = 22.6%

Summer
Calms = 13.9%

Autumn
Calms = 23.9%

Winter
Calms = 30.9%

Spring
Calms = 21.7%

Figure F-3: Annual and seasonal wind roses for St Marys OEH Station (2011)

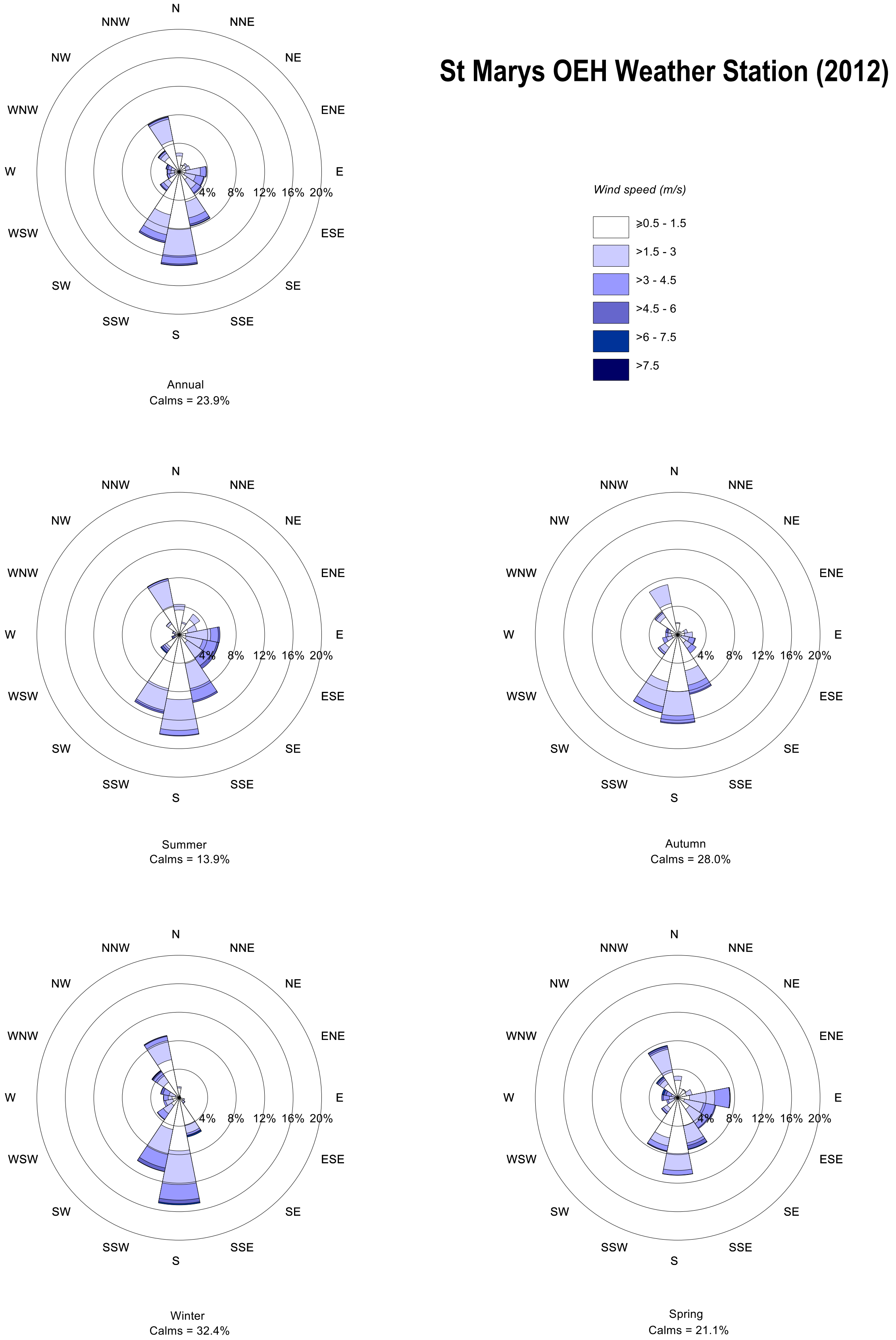


Figure F-4: Annual and seasonal wind roses for St Marys OEH Station (2012)

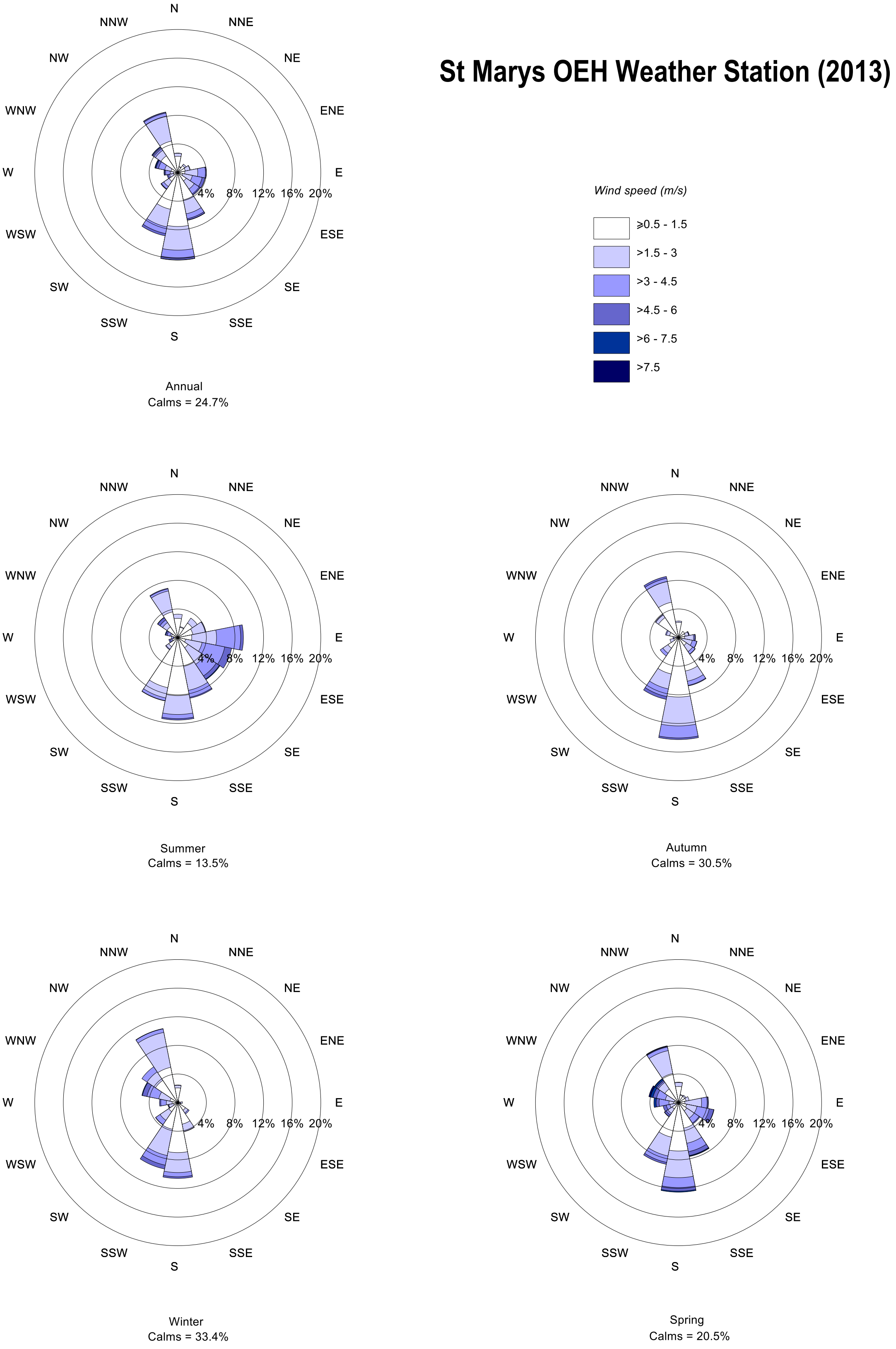


Figure F-5: Annual and seasonal wind roses for St Marys OEH Station (2013)

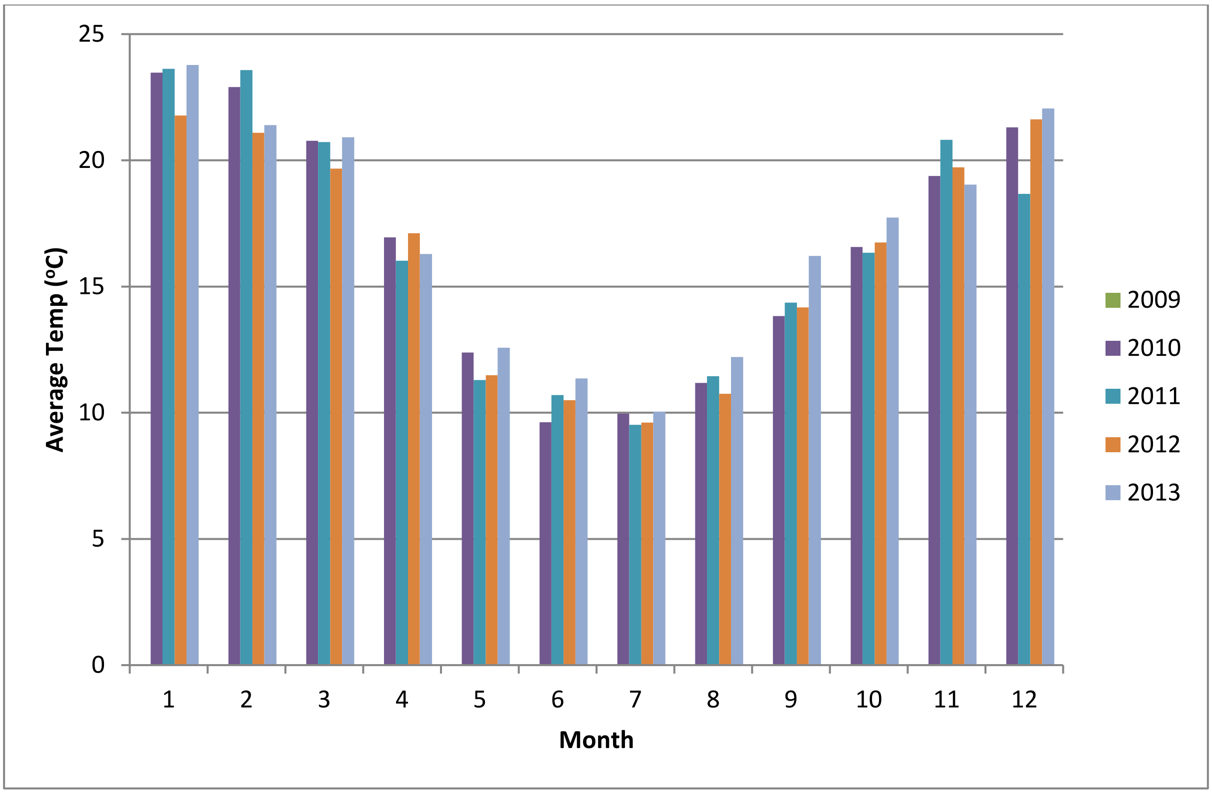


Figure F-6: Monthly average temperature at St Marys OEH Station (2009 – 2013)

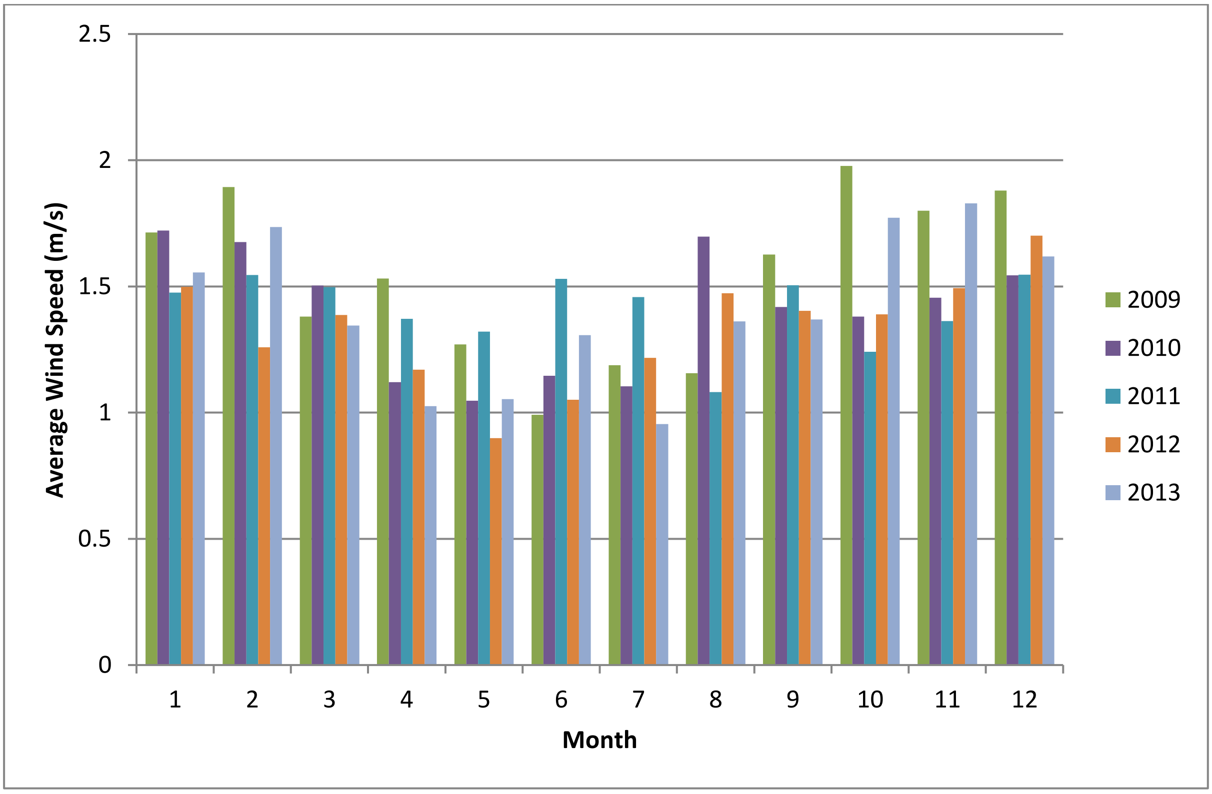


Figure F-7: Monthly average wind speed at St Marys OEH Station (2009 – 2013)

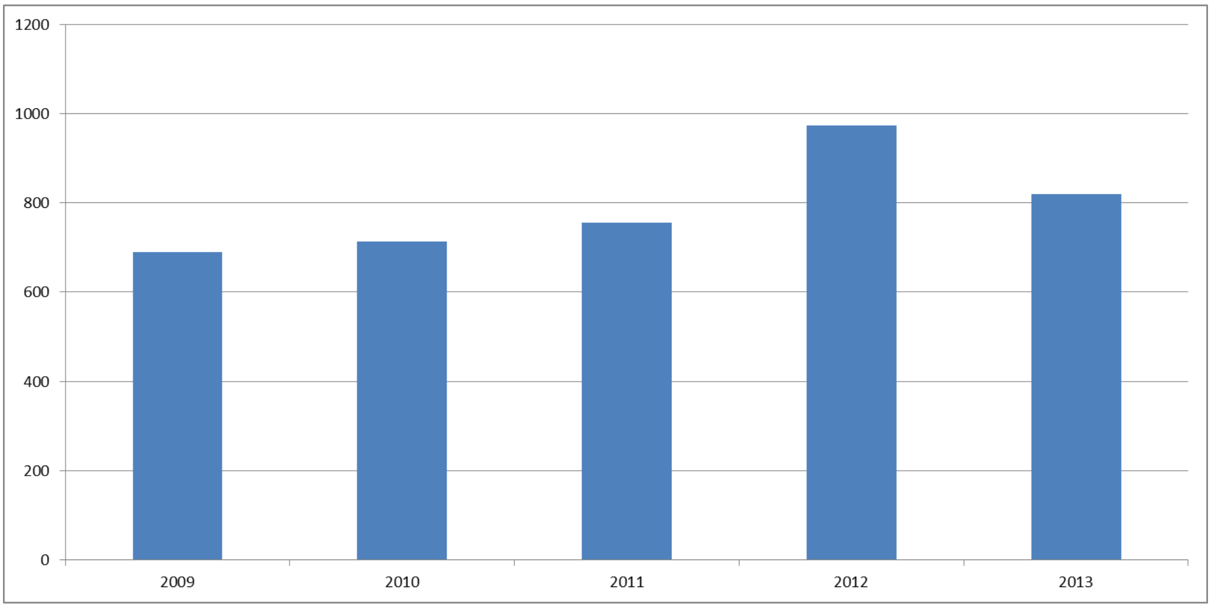


Figure F-8: Annual rainfall at Horsley Park Equestrian Centre (2009 – 2013)

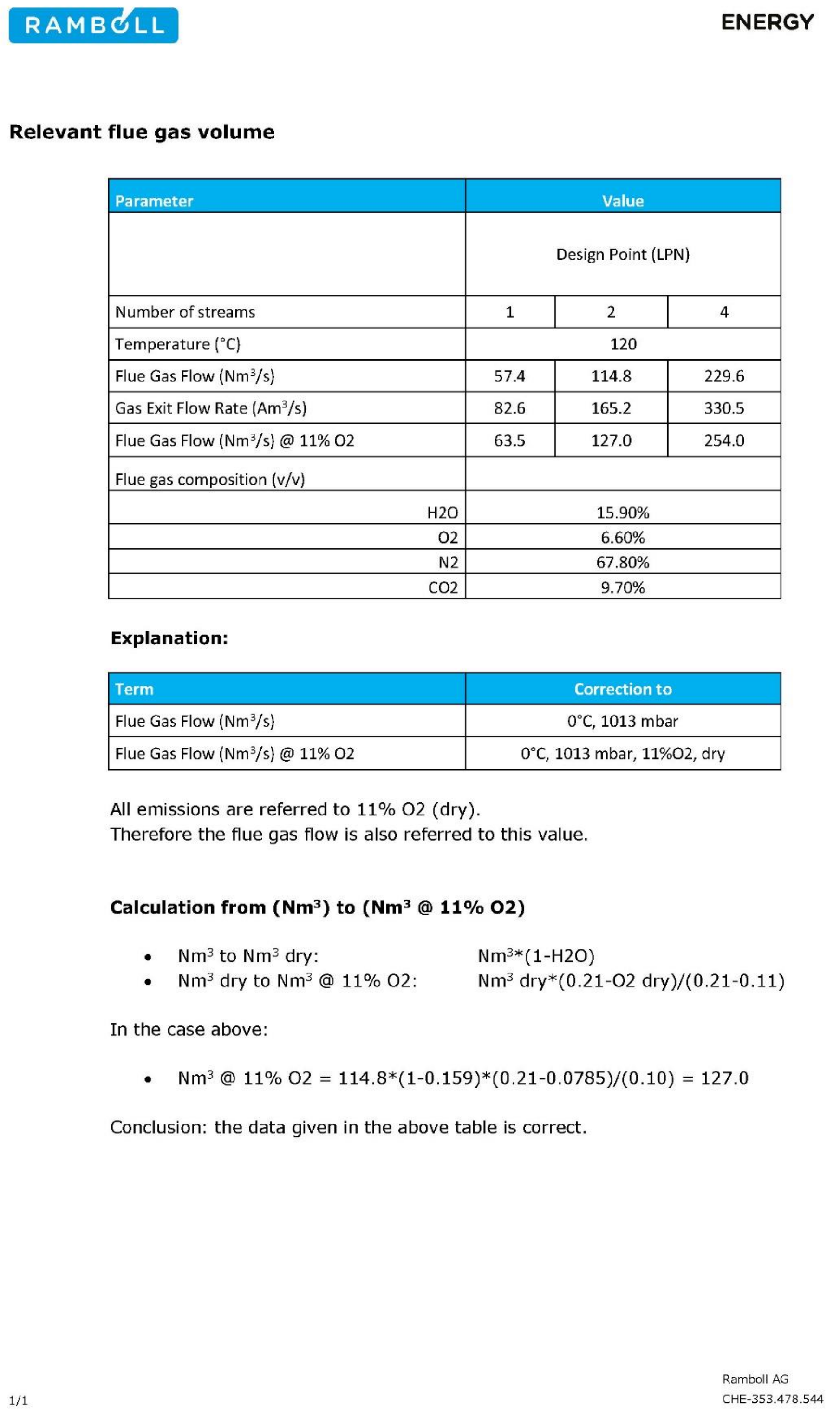
Appendix G SUMMARY OF IN-STACK CONCENTRATION ESTIMATES AND FLOW CALCULATIONS

-

Table G-1: In-stack concentrations

Parameter	In Stack Concentration (mg/m^3)	
	Expected Conditions	Upset Conditions
Benzoic Acid	1.0E-01	1.0E+00
Hexa-decanoic Acid	3.7E-02	3.7E-01
Ethyl Benzoic Acid	3.5E-02	3.5E-01
Toluene	3.0E-02	3.0E-01
Phthalate	2.0E-02	2.0E-01
Dichloro-methane	2.0E-02	2.0E-01
Acetone (propanone)	1.8E-02	1.8E-01
Tetra-decanoic Acid	1.5E-02	1.5E-01
Benzene	1.5E-02	1.5E-01
Acetonitrile	1.4E-02	1.4E-01
Xylene	1.0E-02	1.0E-01
Trichloro-phenol	9.0E-03	9.0E-02
Methyl-hexane	6.0E-03	6.0E-02
Trichloro-ethylene	5.0E-03	5.0E-02
Heptane	5.0E-03	5.0E-02
PM_{10}	1.0E+00	1.0E+02
$PM_{2.5}$	1.0E+00	1.0E+02
HCl	9.0E+00	1.0E+02
HF	5.0E-01	5.0E+00
H_2S	1.0E+00	1.0E+01
SO_2	2.7E+01	5.0E+02
NO_2	1.2E+02	4.0E+02
CO	2.3E+01	5.0E+02
NH3	2.0E+00	2.0E+01
Hg	4.0E-03	5.0E-01
Cd	9.0E-03	4.5E-01
Tl	1.0E-03	5.0E-02
Be	7.0E-06	5.3E-04
Ag	3.4E-04	2.6E-02
Zn	3.7E-02	5.1E+00
Sn	3.3E-03	2.5E-01
Mo	2.2E-05	2.6E-03
Se	2.1E-03	2.1E-02
As	2.5E-02	7.9E-02
Sb	1.5E-02	1.2E-01
Cr (III)	9.2E-02	6.7E-01
Pb	1.7E-01	8.7E-01
Ni	2.2E-01	1.2E+00
Cu	1.6E-02	5.9E-01

Parameter	In Stack Concentration (mg/m³)	
	Expected Conditions	Upset Conditions
Co	5.6E-03	7.9E-02
Mn	6.0E-02	1.3E+00
V	6.0E-03	4.0E-02
PCDD/F	1.0E-08	1.0E-06
PCBs	1.6E-08	1.6E-07
HCB	8.2E-06	8.2E-05
PAHs	5.0E-04	5.0E-03
Phenol	5.0E-03	5.0E-02
Hexane	5.0E-03	5.0E-02
Phthalate	2.0E-02	2.0E-01
Chromium (VI)	1.3E-04	1.3E-03
TVOC (assessed as Benzene)	1.2E+00	1.0E+02
HBr	2.0E+00	2.0E+01
Brominated flame retardants (BFR)	5.0E-06	5.0E-05
Total brominated dioxins (TBD)	5.0E-08	5.0E-07



RAMBOLL **ENERGY**

Relevant flue gas volume

Parameter	Value		
	Design Point (LPN)		
Number of streams	1	2	4
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
Flue Gas Flow (Nm^3/s) @ 11% O2	63.5	127.0	254.0
Flue gas composition (v/v)			
H2O	15.90%		
O2	6.60%		
N2	67.80%		
CO2	9.70%		

Explanation:

Term	Correction to
Flue Gas Flow (Nm^3/s)	0°C, 1013 mbar
Flue Gas Flow (Nm^3/s) @ 11% O2	0°C, 1013 mbar, 11%O2, dry

All emissions are referred to 11% O2 (dry).
Therefore the flue gas flow is also referred to this value.

Calculation from (Nm^3) to (Nm^3 @ 11% O2)

- Nm^3 to Nm^3 dry: $Nm^3*(1-H_2O)$
- Nm^3 dry to Nm^3 @ 11% O2: Nm^3 dry*(0.21-O2 dry)/(0.21-0.11)

In the case above:

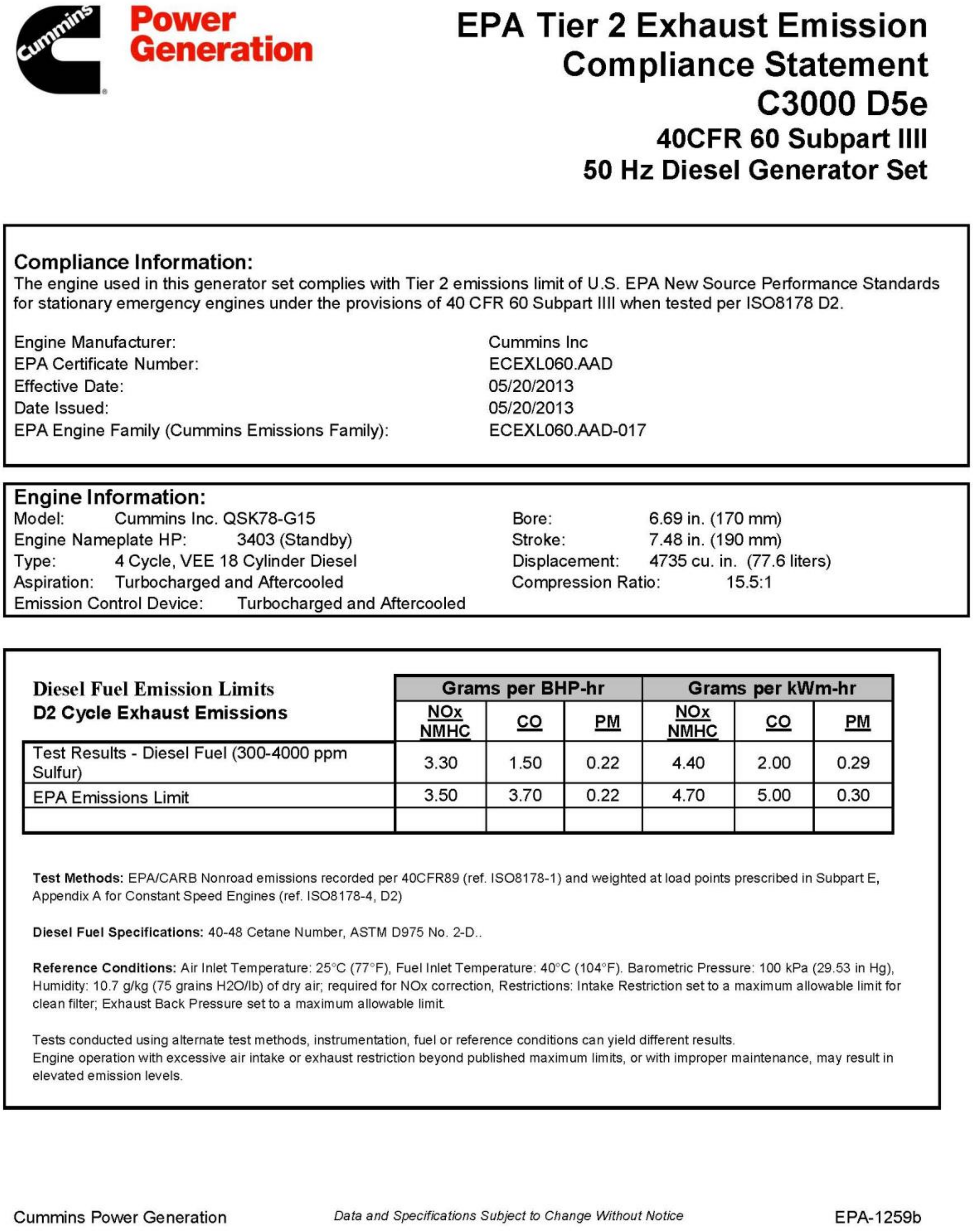
- Nm^3 @ 11% O2 = 114.8*(1-0.159)*(0.21-0.0785)/(0.10) = 127.0

Conclusion: the data given in the above table is correct.

1/1

Ramboll AG
CHE-353.478.544

Appendix H PERFORMANCE SPECIFICATIONS FOR EMERGENCY DIESEL GENERATOR



Cummins Power Generation

EPA Tier 2 Exhaust Emission Compliance Statement

C3000 D5e

40CFR 60 Subpart IIII

50 Hz Diesel Generator Set

Compliance Information:

The engine used in this generator set complies with Tier 2 emissions limit of U.S. EPA New Source Performance Standards for stationary emergency engines under the provisions of 40 CFR 60 Subpart IIII when tested per ISO8178 D2.

Engine Manufacturer:	Cummins Inc
EPA Certificate Number:	ECEXL060.AAD
Effective Date:	05/20/2013
Date Issued:	05/20/2013
EPA Engine Family (Cummins Emissions Family):	ECEXL060.AAD-017

Engine Information:

Model:	Cummins Inc. QSK78-G15	Bore:	6.69 in. (170 mm)
Engine Nameplate HP:	3403 (Standby)	Stroke:	7.48 in. (190 mm)
Type:	4 Cycle, VEE 18 Cylinder Diesel	Displacement:	4735 cu. in. (77.6 liters)
Aspiration:	Turbocharged and Aftercooled	Compression Ratio:	15.5:1
Emission Control Device:	Turbocharged and Aftercooled		

Diesel Fuel Emission Limits **D2 Cycle Exhaust Emissions**	Grams per BHP-hr			Grams per kWm-hr		
	NOx NMHC	CO	PM	NOx NMHC	CO	PM
Test Results - Diesel Fuel (300-4000 ppm Sulfur)	3.30	1.50	0.22	4.40	2.00	0.29
EPA Emissions Limit	3.50	3.70	0.22	4.70	5.00	0.30

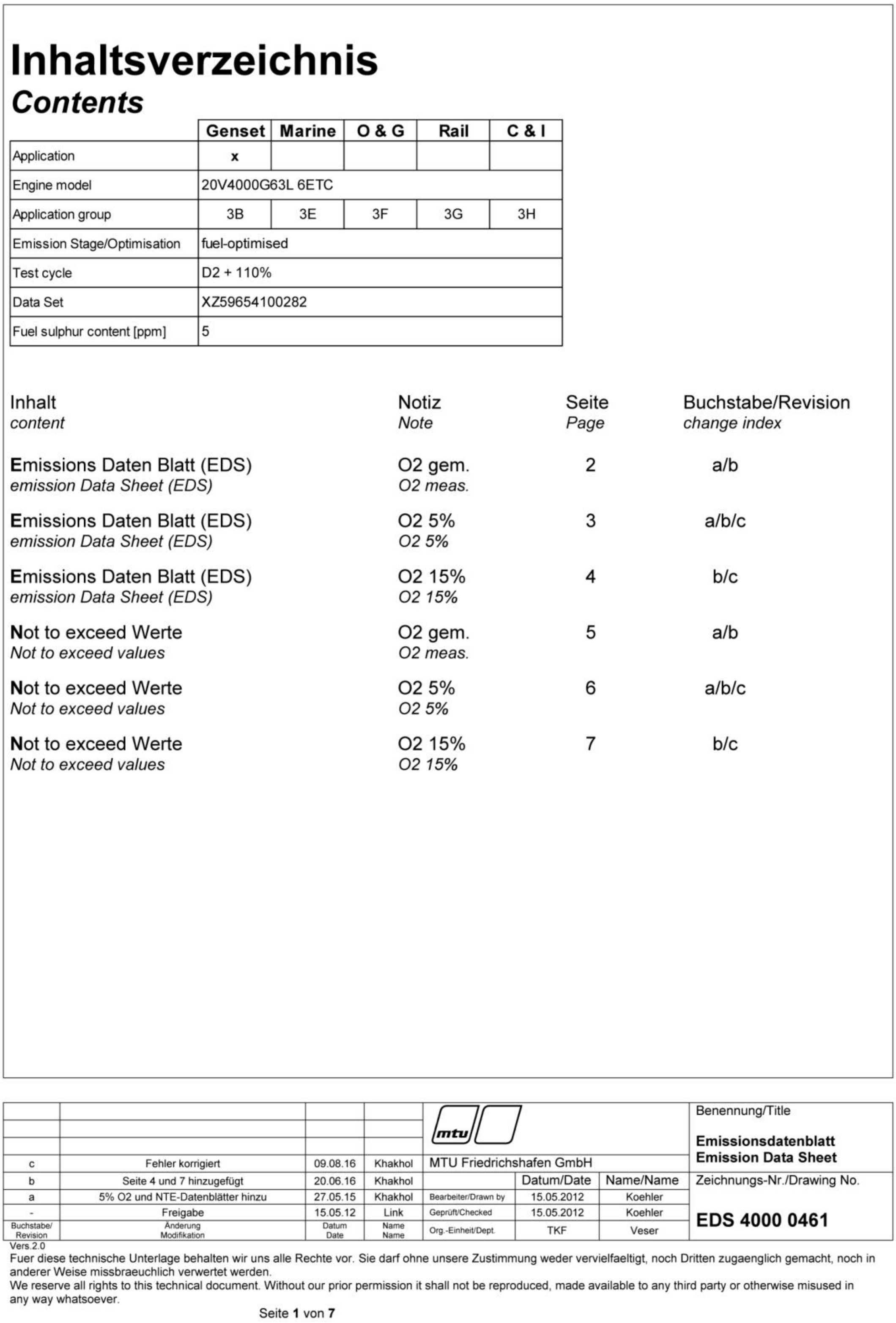
Test Methods: EPA/CARB Nonroad emissions recorded per 40CFR89 (ref. ISO8178-1) and weighted at load points prescribed in Subpart E, Appendix A for Constant Speed Engines (ref. ISO8178-4, D2)

Diesel Fuel Specifications: 40-48 Cetane Number, ASTM D975 No. 2-D..

Reference Conditions: Air Inlet Temperature: 25°C (77°F), Fuel Inlet Temperature: 40°C (104°F). Barometric Pressure: 100 kPa (29.53 in Hg), Humidity: 10.7 g/kg (75 grains H2O/lb) of dry air; required for NOx correction, Restrictions: Intake Restriction set to a maximum allowable limit for clean filter; Exhaust Back Pressure set to a maximum allowable limit.

Tests conducted using alternate test methods, instrumentation, fuel or reference conditions can yield different results.
Engine operation with excessive air intake or exhaust restriction beyond published maximum limits, or with improper maintenance, may result in elevated emission levels.

Cummins Power Generation *Data and Specifications Subject to Change Without Notice* EPA-1259b



Inhaltsverzeichnis
Contents

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
Data Set	XZ59654100282				
Fuel sulphur content [ppm]	5				

Inhalt *content*	Notiz *Note*	Seite *Page*	Buchstabe/Revision *change index*
Emissions Daten Blatt (EDS) *emission Data Sheet (EDS)*	O2 gem. *O2 meas.*	2	a/b
Emissions Daten Blatt (EDS) *emission Data Sheet (EDS)*	O2 5% *O2 5%*	3	a/b/c
Emissions Daten Blatt (EDS) *emission Data Sheet (EDS)*	O2 15% *O2 15%*	4	b/c
Not to exceed Werte *Not to exceed values*	O2 gem. *O2 meas.*	5	a/b
Not to exceed Werte *Not to exceed values*	O2 5% *O2 5%*	6	a/b/c
Not to exceed Werte *Not to exceed values*	O2 15% *O2 15%*	7	b/c

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b	Seite 4 und 7 hinzugefügt	20.06.16	Khakhol		Datum/Date	Name/Name
a	5% O2 und NTE-Datenblätter hinzu	27.05.15	Khakhol	Bearbeiter/Drawn by	15.05.2012	Koehler
-	Freigabe	15.05.12	Link	Geprüft/Checked	15.05.2012	Koehler
Buchstabe/ Revision	Änderung Modifikation	Datum Date	Name Name	Org.-Einheit/Dept.	TKF	Veser

Benennung/Title

Emissionsdatenblatt
Emission Data Sheet

Zeichnungs-Nr./Drawing No.

EDS 4000 0461

Vers.2.0

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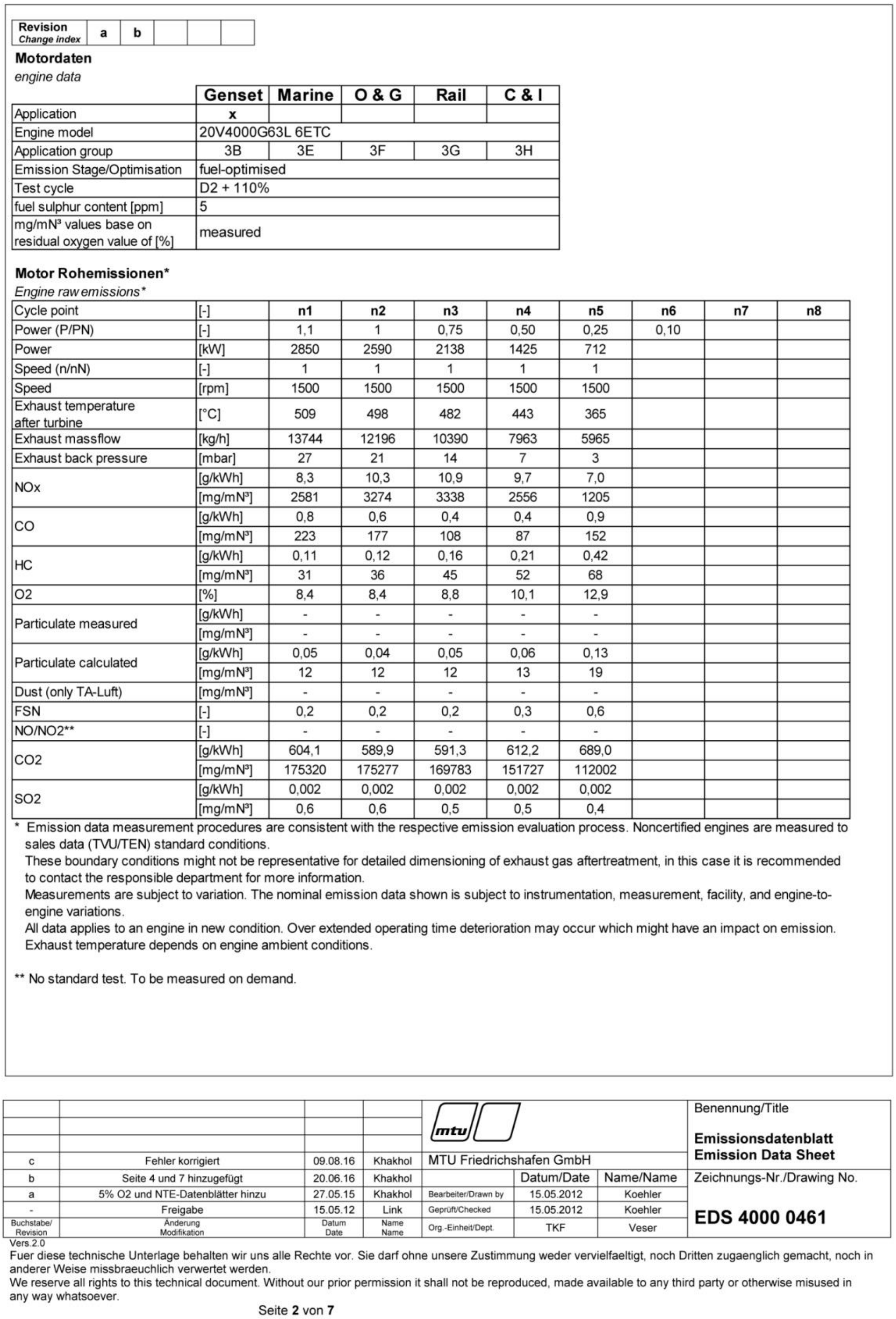

Revision *Change index*	a	b			

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	measured				

Motor Rohemissionen*

*Engine raw emissions**

Cycle point	[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)	[-]	1,1	1	0,75	0,50	0,25	0,10		
Power	[kW]	2850	2590	2138	1425	712			
Speed (n/nN)	[-]	1	1	1	1	1			
Speed	[rpm]	1500	1500	1500	1500	1500			
Exhaust temperature after turbine	[°C]	509	498	482	443	365			
Exhaust massflow	[kg/h]	13744	12196	10390	7963	5965			
Exhaust back pressure	[mbar]	27	21	14	7	3			
NOx	[g/kWh]	8,3	10,3	10,9	9,7	7,0			
	[mg/mN³]	2581	3274	3338	2556	1205			
CO	[g/kWh]	0,8	0,6	0,4	0,4	0,9			
	[mg/mN³]	223	177	108	87	152			
HC	[g/kWh]	0,11	0,12	0,16	0,21	0,42			
	[mg/mN³]	31	36	45	52	68			
O2	[%]	8,4	8,4	8,8	10,1	12,9			
Particulate measured	[g/kWh]	-	-	-	-	-			
	[mg/mN³]	-	-	-	-	-			
Particulate calculated	[g/kWh]	0,05	0,04	0,05	0,06	0,13			
	[mg/mN³]	12	12	12	13	19			
Dust (only TA-Luft)	[mg/mN³]	-	-	-	-	-			
FSN	[-]	0,2	0,2	0,2	0,3	0,6			
NO/NO2**	[-]	-	-	-	-	-			
CO2	[g/kWh]	604,1	589,9	591,3	612,2	689,0			
	[mg/mN³]	175320	175277	169783	151727	112002			
SO2	[g/kWh]	0,002	0,002	0,002	0,002	0,002			
	[mg/mN³]	0,6	0,6	0,5	0,5	0,4			

* Emission data measurement procedures are consistent with the respective emission evaluation process. Noncertified engines are measured to sales data (TVU/TEN) standard conditions.
These boundary conditions might not be representative for detailed dimensioning of exhaust gas aftertreatment, in this case it is recommended to contact the responsible department for more information.
Measurements are subject to variation. The nominal emission data shown is subject to instrumentation, measurement, facility, and engine-to-engine variations.
All data applies to an engine in new condition. Over extended operating time deterioration may occur which might have an impact on emission.
Exhaust temperature depends on engine ambient conditions.

** No standard test. To be measured on demand.

				mtu			Benennung/Title **Emissionsdatenblatt** **Emission Data Sheet**
c	Fehler korrigiert	09.08.16	Khakhol	MTU Friedrichshafen GmbH			
b	Seite 4 und 7 hinzugefügt	20.06.16	Khakhol		Datum/Date	Name/Name	Zeichnungs-Nr./Drawing No.
a	5% O2 und NTE-Datenblätter hinzu	27.05.15	Khakhol	Bearbeiter/Drawn by	15.05.2012	Koehler	
-	Freigabe	15.05.12	Link	Geprüft/Checked	15.05.2012	Koehler	**EDS 4000 0461**
Buchstabe/ Revision	Änderung Modifikation	Datum Date	Name Name	Org.-Einheit/Dept.	TKF	Veser	

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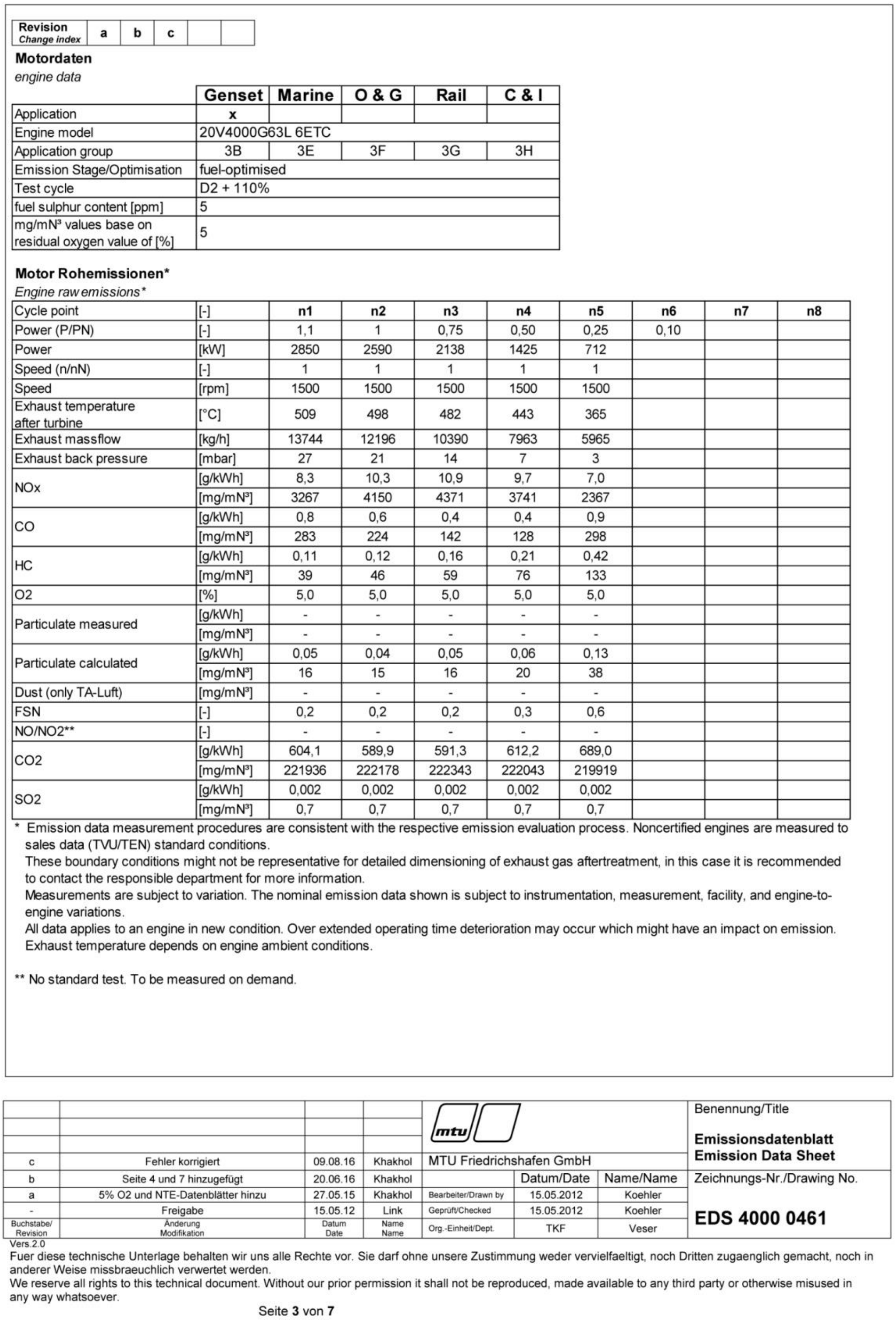

Revision *Change index*	a	b	c		

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	5				

Motor Rohemissionen*

*Engine raw emissions**

Cycle point	[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)	[-]	1,1	1	0,75	0,50	0,25	0,10		
Power	[kW]	2850	2590	2138	1425	712			
Speed (n/nN)	[-]	1	1	1	1	1			
Speed	[rpm]	1500	1500	1500	1500	1500			
Exhaust temperature after turbine	[°C]	509	498	482	443	365			
Exhaust massflow	[kg/h]	13744	12196	10390	7963	5965			
Exhaust back pressure	[mbar]	27	21	14	7	3			
NOx	[g/kWh]	8,3	10,3	10,9	9,7	7,0			
	[mg/mN³]	3267	4150	4371	3741	2367			
CO	[g/kWh]	0,8	0,6	0,4	0,4	0,9			
	[mg/mN³]	283	224	142	128	298			
HC	[g/kWh]	0,11	0,12	0,16	0,21	0,42			
	[mg/mN³]	39	46	59	76	133			
O2	[%]	5,0	5,0	5,0	5,0	5,0			
Particulate measured	[g/kWh]	-	-	-	-	-			
	[mg/mN³]	-	-	-	-	-			
Particulate calculated	[g/kWh]	0,05	0,04	0,05	0,06	0,13			
	[mg/mN³]	16	15	16	20	38			
Dust (only TA-Luft)	[mg/mN³]	-	-	-	-	-			
FSN	[-]	0,2	0,2	0,2	0,3	0,6			
NO/NO2**	[-]	-	-	-	-	-			
CO2	[g/kWh]	604,1	589,9	591,3	612,2	689,0			
	[mg/mN³]	221936	222178	222343	222043	219919			
SO2	[g/kWh]	0,002	0,002	0,002	0,002	0,002			
	[mg/mN³]	0,7	0,7	0,7	0,7	0,7			

* Emission data measurement procedures are consistent with the respective emission evaluation process. Noncertified engines are measured to sales data (TVU/TEN) standard conditions.
These boundary conditions might not be representative for detailed dimensioning of exhaust gas aftertreatment, in this case it is recommended to contact the responsible department for more information.
Measurements are subject to variation. The nominal emission data shown is subject to instrumentation, measurement, facility, and engine-to-engine variations.
All data applies to an engine in new condition. Over extended operating time deterioration may occur which might have an impact on emission.
Exhaust temperature depends on engine ambient conditions.

** No standard test. To be measured on demand.

				mtu			Benennung/Title
							Emissionsdatenblatt **Emission Data Sheet**
c	Fehler korrigiert	09.08.16	Khakhol	MTU Friedrichshafen GmbH			
b	Seite 4 und 7 hinzugefügt	20.06.16	Khakhol		Datum/Date	Name/Name	Zeichnungs-Nr./Drawing No.
a	5% O2 und NTE-Datenblätter hinzu	27.05.15	Khakhol	Bearbeiter/Drawn by	15.05.2012	Koehler	**EDS 4000 0461**
-	Freigabe	15.05.12	Link	Geprüft/Checked	15.05.2012	Koehler	
Buchstabe/ Revision	Änderung Modifikation	Datum Date	Name Name	Org.-Einheit/Dept.	TKF	Veser	

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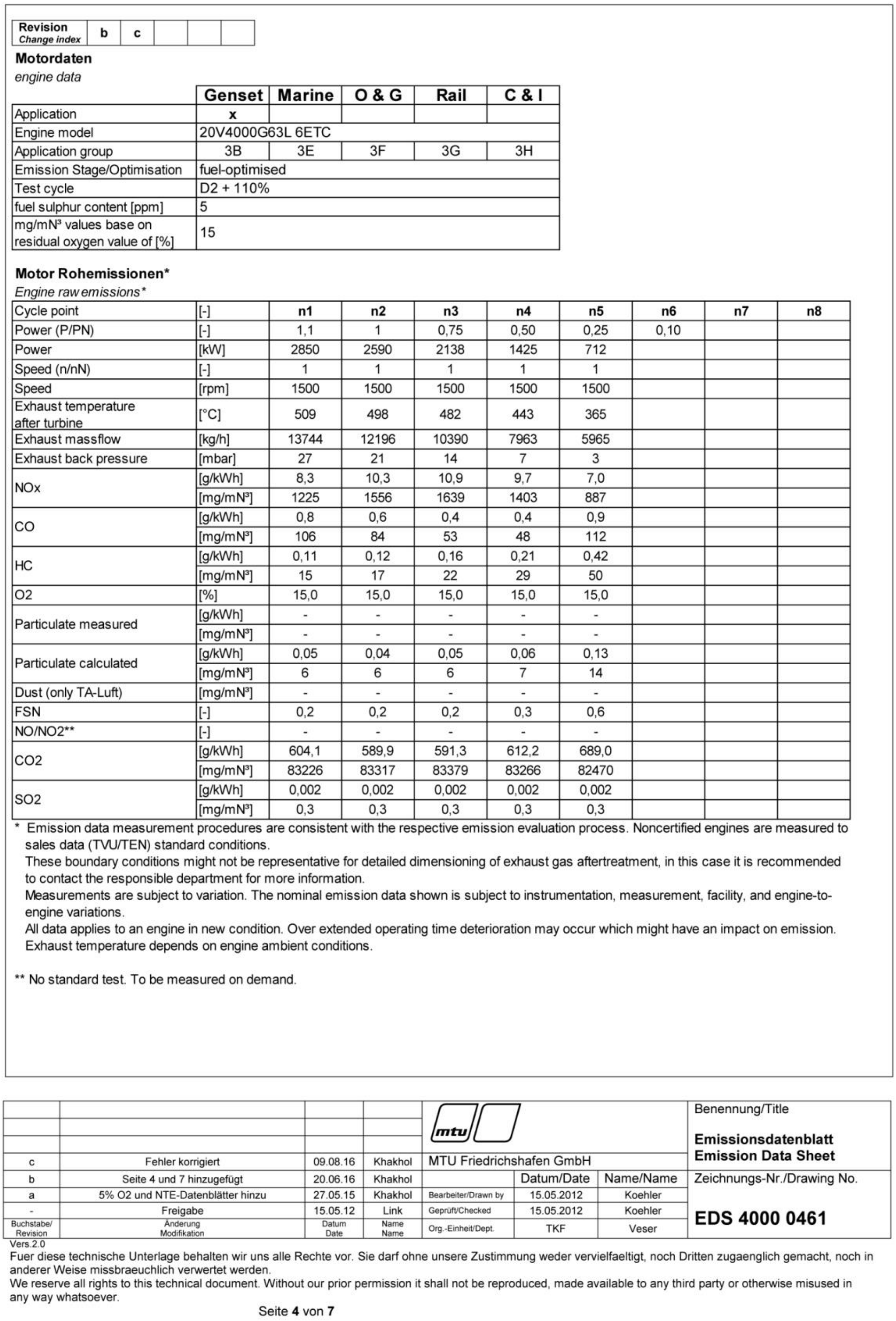

Revision *Change index*	b	c			

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	15				

Motor Rohemissionen*

*Engine raw emissions**

Cycle point	[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)	[-]	1,1	1	0,75	0,50	0,25	0,10		
Power	[kW]	2850	2590	2138	1425	712			
Speed (n/nN)	[-]	1	1	1	1	1			
Speed	[rpm]	1500	1500	1500	1500	1500			
Exhaust temperature after turbine	[°C]	509	498	482	443	365			
Exhaust massflow	[kg/h]	13744	12196	10390	7963	5965			
Exhaust back pressure	[mbar]	27	21	14	7	3			
NOx	[g/kWh]	8,3	10,3	10,9	9,7	7,0			
	[mg/mN³]	1225	1556	1639	1403	887			
CO	[g/kWh]	0,8	0,6	0,4	0,4	0,9			
	[mg/mN³]	106	84	53	48	112			
HC	[g/kWh]	0,11	0,12	0,16	0,21	0,42			
	[mg/mN³]	15	17	22	29	50			
O2	[%]	15,0	15,0	15,0	15,0	15,0			
Particulate measured	[g/kWh]	-	-	-	-	-			
	[mg/mN³]	-	-	-	-	-			
Particulate calculated	[g/kWh]	0,05	0,04	0,05	0,06	0,13			
	[mg/mN³]	6	6	6	7	14			
Dust (only TA-Luft)	[mg/mN³]	-	-	-	-	-			
FSN	[-]	0,2	0,2	0,2	0,3	0,6			
NO/NO2**	[-]	-	-	-	-	-			
CO2	[g/kWh]	604,1	589,9	591,3	612,2	689,0			
	[mg/mN³]	83226	83317	83379	83266	82470			
SO2	[g/kWh]	0,002	0,002	0,002	0,002	0,002			
	[mg/mN³]	0,3	0,3	0,3	0,3	0,3			

* Emission data measurement procedures are consistent with the respective emission evaluation process. Noncertified engines are measured to sales data (TVU/TEN) standard conditions.
These boundary conditions might not be representative for detailed dimensioning of exhaust gas aftertreatment, in this case it is recommended to contact the responsible department for more information.
Measurements are subject to variation. The nominal emission data shown is subject to instrumentation, measurement, facility, and engine-to-engine variations.
All data applies to an engine in new condition. Over extended operating time deterioration may occur which might have an impact on emission.
Exhaust temperature depends on engine ambient conditions.

** No standard test. To be measured on demand.

Buchstabe/ Revision	Änderung Modifikation	Datum Date	Name Name
c	Fehler korrigiert	09.08.16	Khakhol
b	Seite 4 und 7 hinzugefügt	20.06.16	Khakhol
a	5% O2 und NTE-Datenblätter hinzu	27.05.15	Khakhol
-	Freigabe	15.05.12	Link

MTU Friedrichshafen GmbH

	Datum/Date	Name/Name
Bearbeiter/Drawn by	15.05.2012	Koehler
Geprüft/Checked	15.05.2012	Koehler
Org.-Einheit/Dept.	TKF	Veser

Benennung/Title

Emissionsdatenblatt
Emission Data Sheet

Zeichnungs-Nr./Drawing No.

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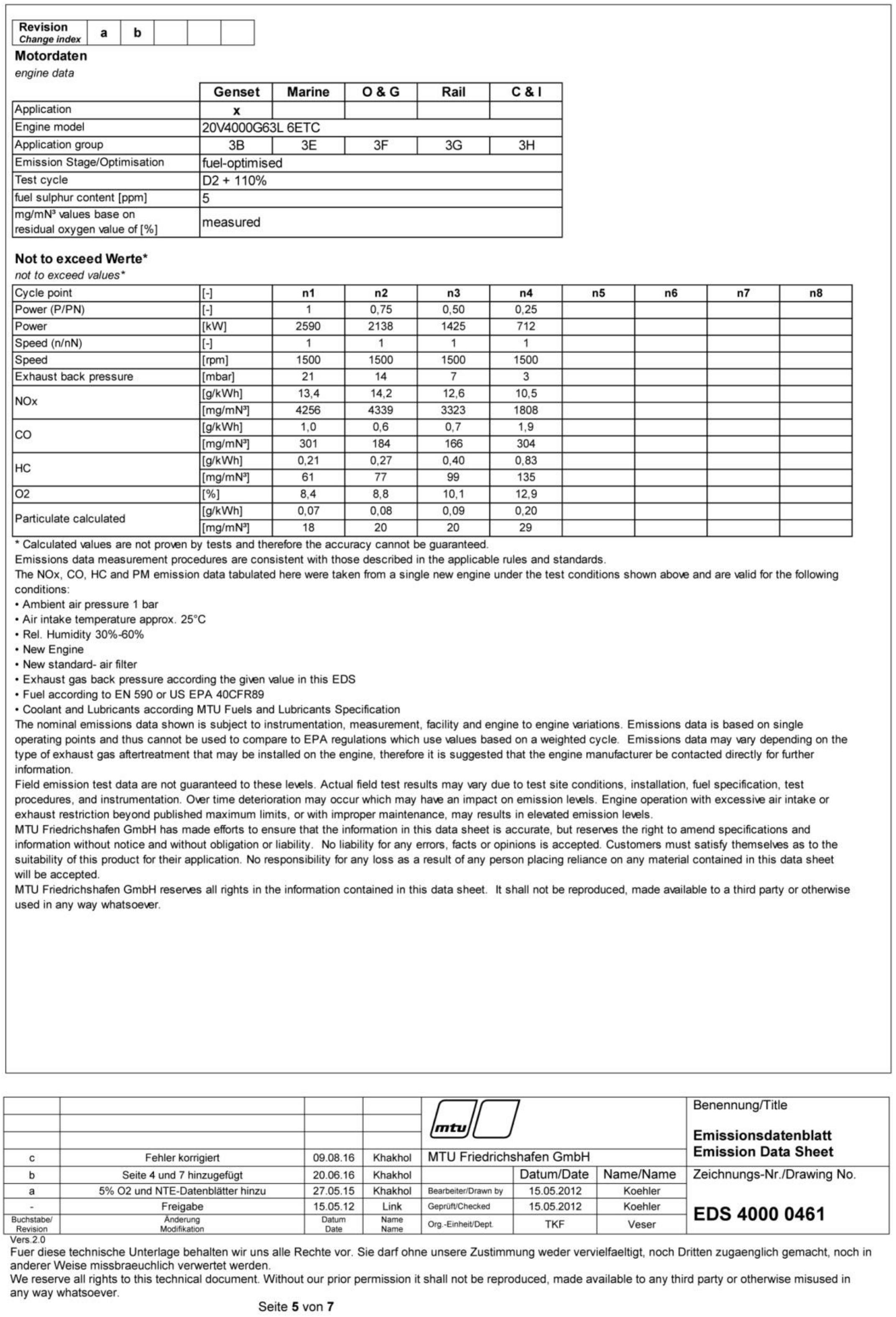
Seite **4** von **7**



Revision *Change index*	a	b			

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	measured				

Not to exceed Werte*

*not to exceed values**

Cycle point	[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)	[-]	1	0,75	0,50	0,25				
Power	[kW]	2590	2138	1425	712				
Speed (n/nN)	[-]	1	1	1	1				
Speed	[rpm]	1500	1500	1500	1500				
Exhaust back pressure	[mbar]	21	14	7	3				
NOx	[g/kWh]	13,4	14,2	12,6	10,5				
	[mg/mN³]	4256	4339	3323	1808				
CO	[g/kWh]	1,0	0,6	0,7	1,9				
	[mg/mN³]	301	184	166	304				
HC	[g/kWh]	0,21	0,27	0,40	0,83				
	[mg/mN³]	61	77	99	135				
O2	[%]	8,4	8,8	10,1	12,9				
Particulate calculated	[g/kWh]	0,07	0,08	0,09	0,20				
	[mg/mN³]	18	20	20	29				

* Calculated values are not proven by tests and therefore the accuracy cannot be guaranteed.

Emissions data measurement procedures are consistent with those described in the applicable rules and standards.

The NOx, CO, HC and PM emission data tabulated here were taken from a single new engine under the test conditions shown above and are valid for the following conditions:

- Ambient air pressure 1 bar
- Air intake temperature approx. 25°C
- Rel. Humidity 30%-60%
- New Engine
- New standard- air filter
- Exhaust gas back pressure according the given value in this EDS
- Fuel according to EN 590 or US EPA 40CFR89
- Coolant and Lubricants according MTU Fuels and Lubricants Specification

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Emissionsdatenblatt
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Zeichnungs-Nr./Drawing No.

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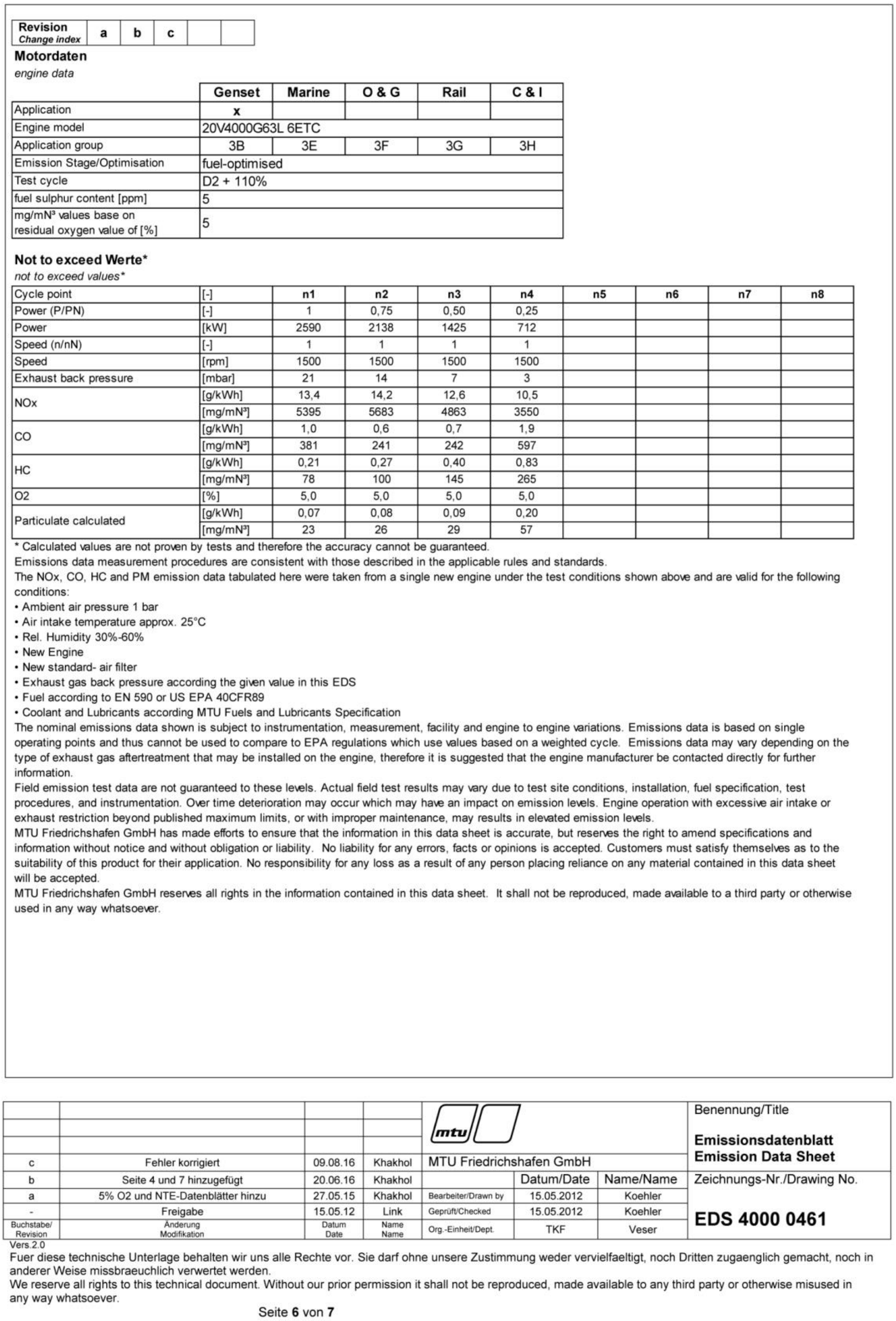

Revision *Change index*	a	b	c		

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	5				

Not to exceed Werte*

*not to exceed values**

Cycle point	[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)	[-]	1	0,75	0,50	0,25				
Power	[kW]	2590	2138	1425	712				
Speed (n/nN)	[-]	1	1	1	1				
Speed	[rpm]	1500	1500	1500	1500				
Exhaust back pressure	[mbar]	21	14	7	3				
NOx	[g/kWh]	13,4	14,2	12,6	10,5				
	[mg/mN³]	5395	5683	4863	3550				
CO	[g/kWh]	1,0	0,6	0,7	1,9				
	[mg/mN³]	381	241	242	597				
HC	[g/kWh]	0,21	0,27	0,40	0,83				
	[mg/mN³]	78	100	145	265				
O2	[%]	5,0	5,0	5,0	5,0				
Particulate calculated	[g/kWh]	0,07	0,08	0,09	0,20				
	[mg/mN³]	23	26	29	57				

* Calculated values are not proven by tests and therefore the accuracy cannot be guaranteed.

Emissions data measurement procedures are consistent with those described in the applicable rules and standards.

The NOx, CO, HC and PM emission data tabulated here were taken from a single new engine under the test conditions shown above and are valid for the following conditions:

- Ambient air pressure 1 bar
- Air intake temperature approx. 25°C
- Rel. Humidity 30%-60%
- New Engine
- New standard- air filter
- Exhaust gas back pressure according the given value in this EDS
- Fuel according to EN 590 or US EPA 40CFR89
- Coolant and Lubricants according MTU Fuels and Lubricants Specification

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Emissionsdatenblatt
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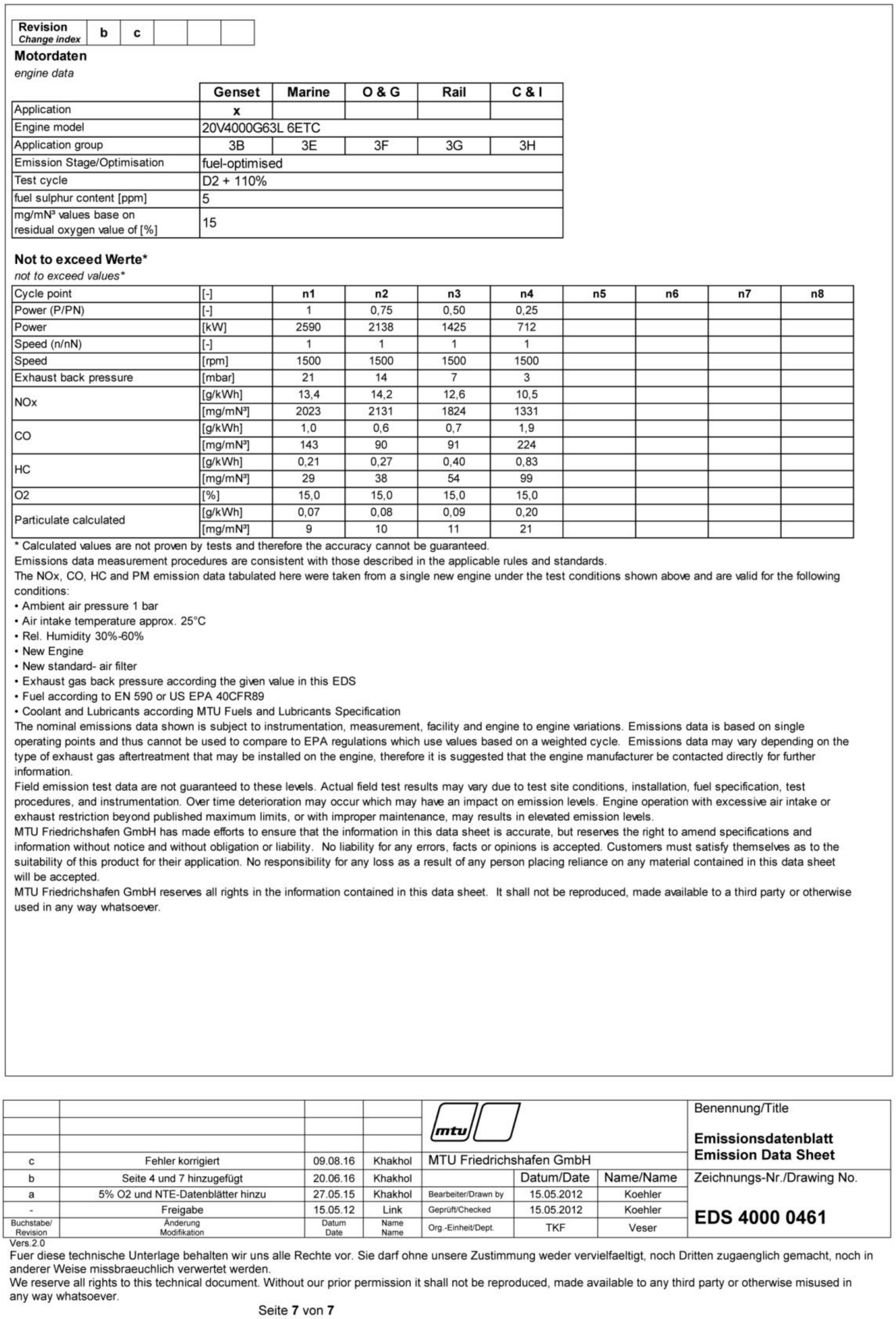

Revision *Change index*	b	c			

Motordaten

engine data

	Genset	Marine	O & G	Rail	C & I
Application	x				
Engine model	20V4000G63L 6ETC				
Application group	3B	3E	3F	3G	3H
Emission Stage/Optimisation	fuel-optimised				
Test cycle	D2 + 110%				
fuel sulphur content [ppm]	5				
mg/mN³ values base on residual oxygen value of [%]	15				

Not to exceed Werte*

*not to exceed values**

Cycle point		[-]	n1	n2	n3	n4	n5	n6	n7	n8
Power (P/PN)		[-]	1	0,75	0,50	0,25				
Power		[kW]	2590	2138	1425	712				
Speed (n/nN)		[-]	1	1	1	1				
Speed		[rpm]	1500	1500	1500	1500				
Exhaust back pressure		[mbar]	21	14	7	3				
NOx		[g/kWh]	13,4	14,2	12,6	10,5				
		[mg/mN³]	2023	2131	1824	1331				
CO		[g/kWh]	1,0	0,6	0,7	1,9				
		[mg/mN³]	143	90	91	224				
HC		[g/kWh]	0,21	0,27	0,40	0,83				
		[mg/mN³]	29	38	54	99				
O2		[%]	15,0	15,0	15,0	15,0				
Particulate calculated		[g/kWh]	0,07	0,08	0,09	0,20				
		[mg/mN³]	9	10	11	21				

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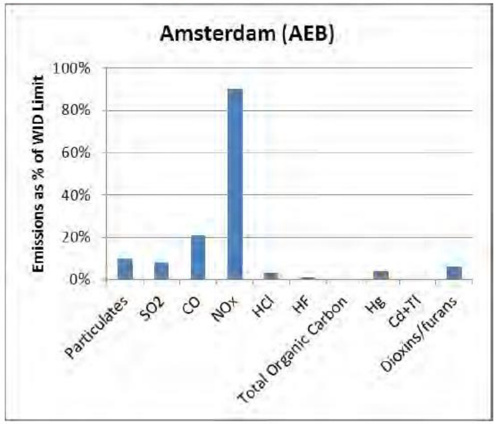
Appendix I SUMMARY OF EMISSIONS PERFORMANCE

I.1 SUMMARY OF EMISSIONS PERFORMANCE REPORTED IN WSP (2000)

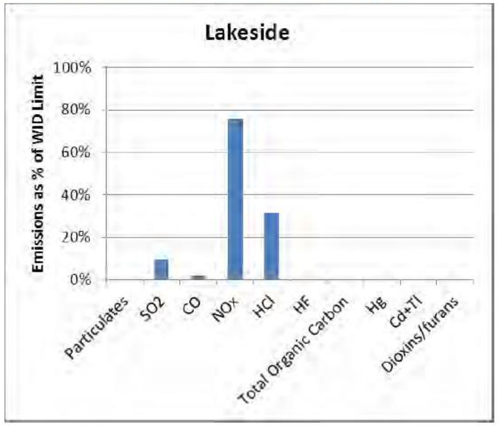
Figure 2-1-7: Emission performance at Amsterdam



Source: interpreted from AEB data (circa Feb 2011)

AEB Amsterdam

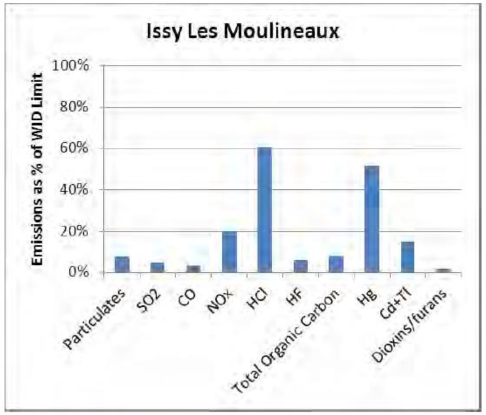
Figure 2-2-4: Emissions data for the Lakeside WtE plant



Source: WSP analysis of data from 1st to 25th November 2012

Lakeside, UK

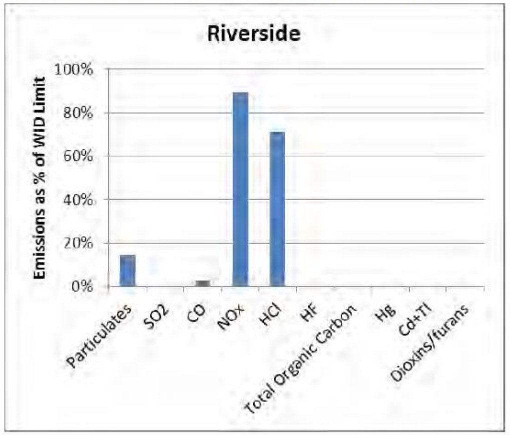
Figure 2-5-3: Emission limits for the ISSEANE plant in Paris for 2011



Source: WSP analysis of plant data

Issy

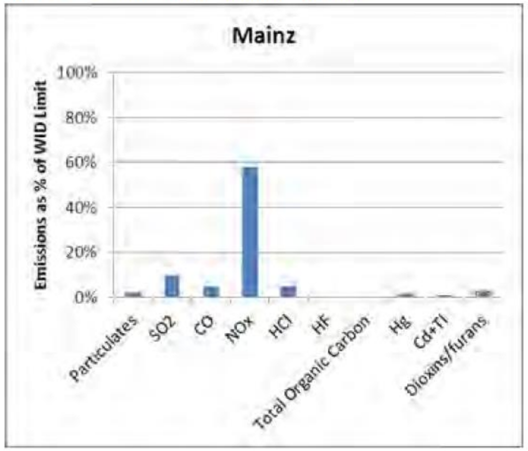
Figure 2-10-9: Emissions data for August to October 2012



Source: WSP analysis of plant data

Riverside, UK

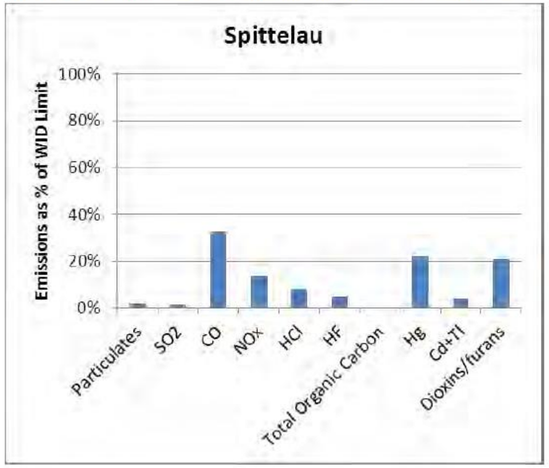
Figure 2-11-6: Emissions from the Mainz plant



Source: WSP analysis of plant data

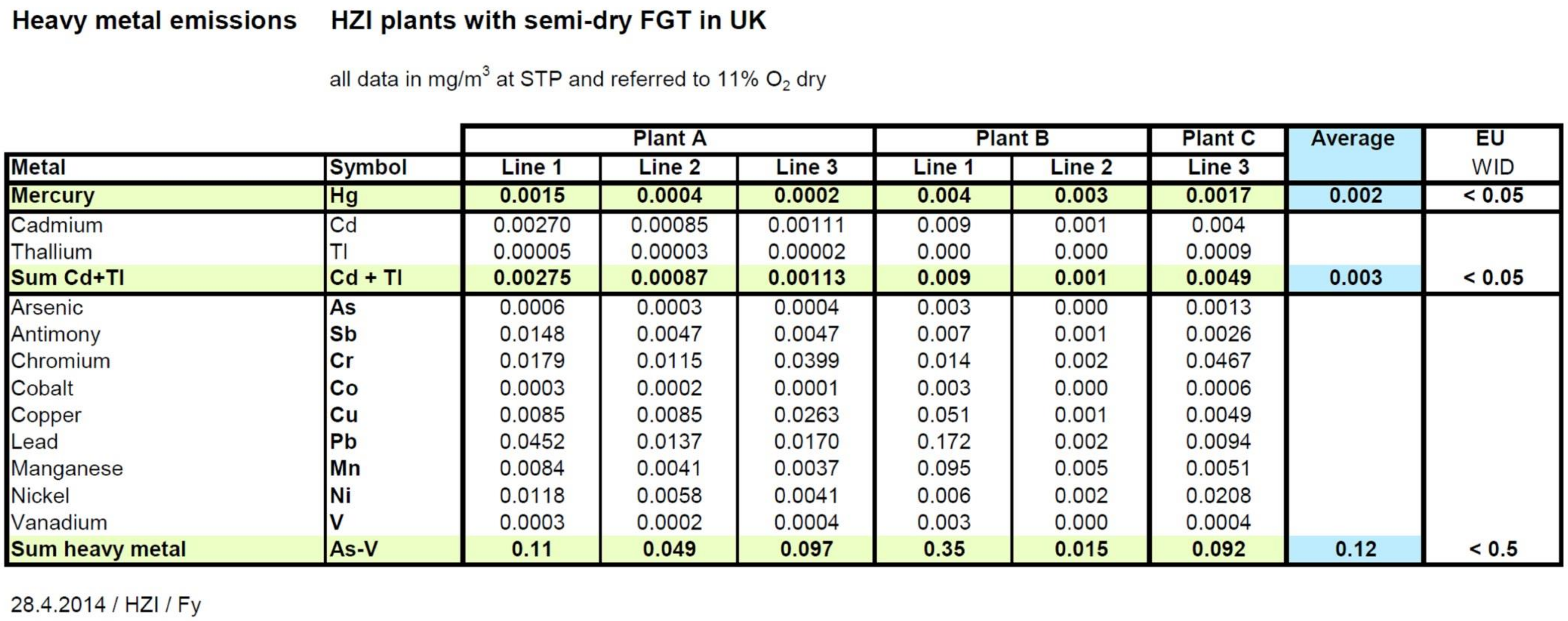
Mainz, Germany

Figure 2-3-5: Emission values in the stack gas (2006) at Spittelau



Spittelau, Austria

I.2 CADMIUM AND METALS EMISSIONS PERFORMANCE IN HZI FACILITIES



Heavy metal emissions **HZI plants with semi-dry FGT in UK**

all data in mg/m^3 at STP and referred to 11% O_2 dry

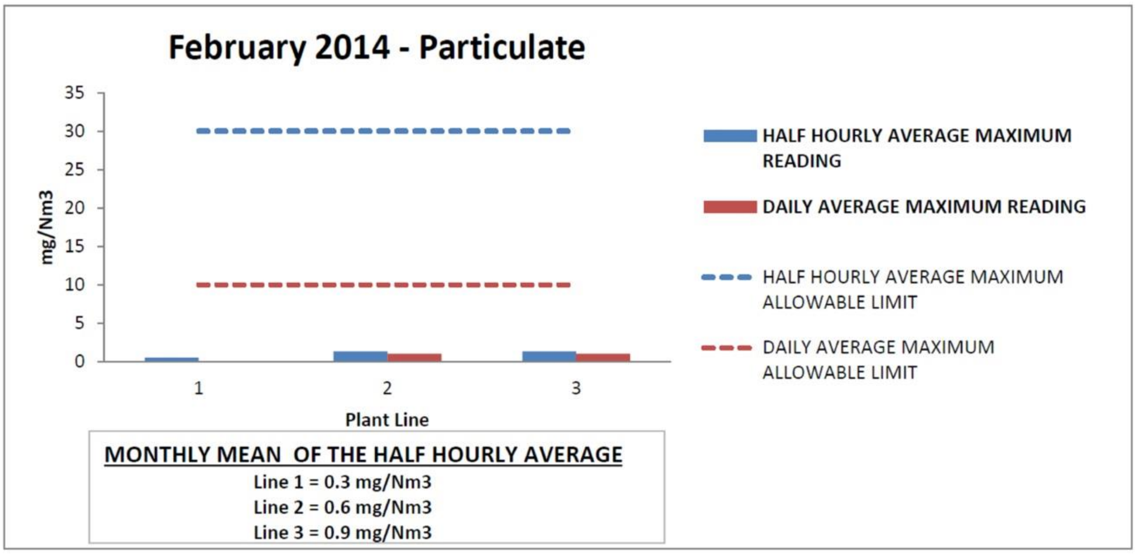
		Plant A			Plant B		Plant C	Average	EU
Metal	**Symbol**	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**		WID
Mercury	**Hg**	**0.0015**	**0.0004**	**0.0002**	**0.004**	**0.003**	**0.0017**	**0.002**	**< 0.05**
Cadmium	Cd	0.00270	0.00085	0.00111	0.009	0.001	0.004		
Thallium	Tl	0.00005	0.00003	0.00002	0.000	0.000	0.0009		
Sum Cd+Tl	**Cd + Tl**	**0.00275**	**0.00087**	**0.00113**	**0.009**	**0.001**	**0.0049**	**0.003**	**< 0.05**
Arsenic	**As**	0.0006	0.0003	0.0004	0.003	0.000	0.0013		
Antimony	**Sb**	0.0148	0.0047	0.0047	0.007	0.001	0.0026		
Chromium	**Cr**	0.0179	0.0115	0.0399	0.014	0.002	0.0467		
Cobalt	**Co**	0.0003	0.0002	0.0001	0.003	0.000	0.0006		
Copper	**Cu**	0.0085	0.0085	0.0263	0.051	0.001	0.0049		
Lead	**Pb**	0.0452	0.0137	0.0170	0.172	0.002	0.0094		
Manganese	**Mn**	0.0084	0.0041	0.0037	0.095	0.005	0.0051		
Nickel	**Ni**	0.0118	0.0058	0.0041	0.006	0.002	0.0208		
Vanadium	**V**	0.0003	0.0002	0.0004	0.003	0.000	0.0004		
Sum heavy metal	**As-V**	**0.11**	**0.049**	**0.097**	**0.35**	**0.015**	**0.092**	**0.12**	**< 0.5**

28.4.2014 / HZI / Fy

I.3 SAMPLE CEMS REPORT FROM RIVERSIDE

Riverside Resource Recovery emission report – February 2014

The following charts summarise the emission data for the Riverside Resource Recovery facility. The charts show the **MAXIMUM** readings taken during the month.

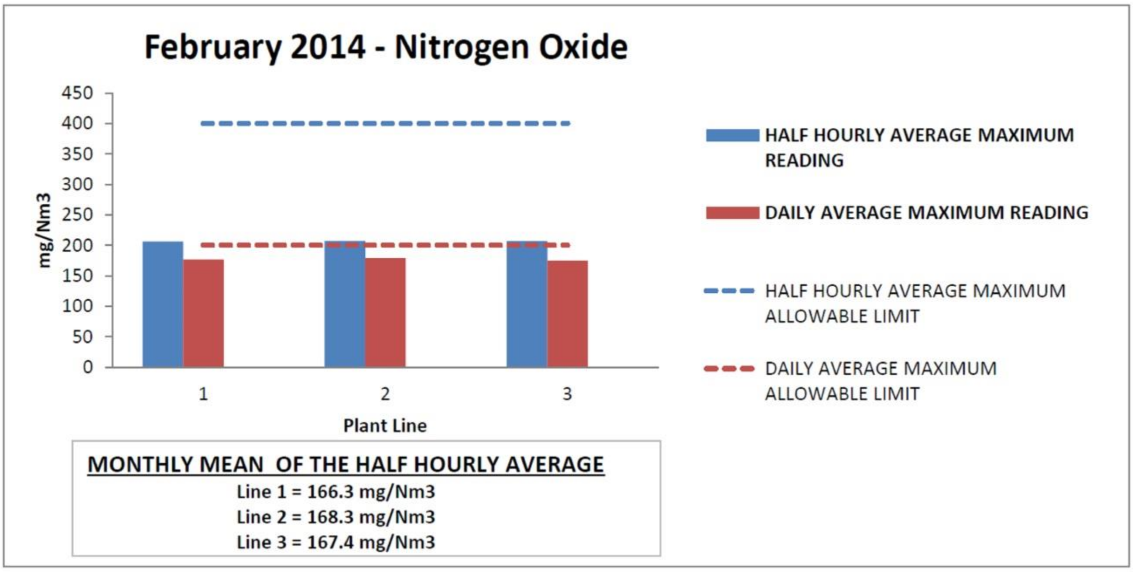


MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 0.3 mg/Nm3
Line 2 = 0.6 mg/Nm3
Line 3 = 0.9 mg/Nm3

Why do we control and monitor Particulates (dust)?

Particulates is the term used to describe tiny particles in the air, made up of a complex mixture of soot, organic and inorganic materials having a particle size less than or equal to 10 microns diameter (10 microns is equal to one hundredth part of a millimetre). Particulates is one of the eight substances for which the government has established an air quality standard as part of

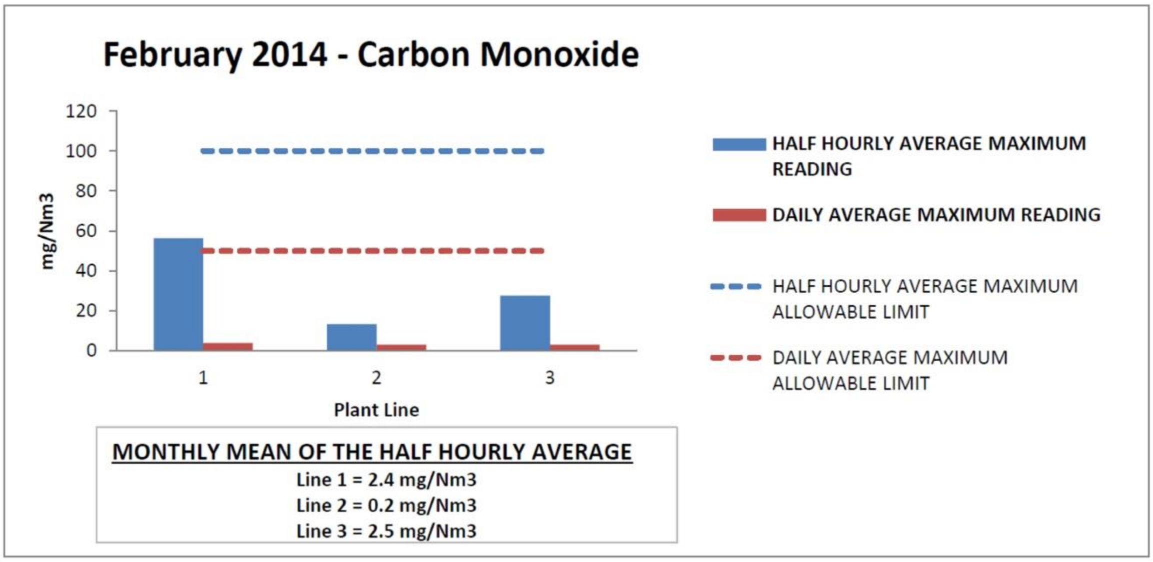


MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 166.3 mg/Nm3
Line 2 = 168.3 mg/Nm3
Line 3 = 167.4 mg/Nm3

Why do we control and monitor Oxides of Nitrogen (NOx)?

NOx includes various compounds, but is usually used to group two gases; nitrogen dioxide (NO_2) and nitric oxide (NO). These can be formed naturally, but are also formed from man-made processes like fuel combustion or biomass burning. There are a number of health and environmental issues attributed to NOx, including smog, acid rain, and possibly global warming.



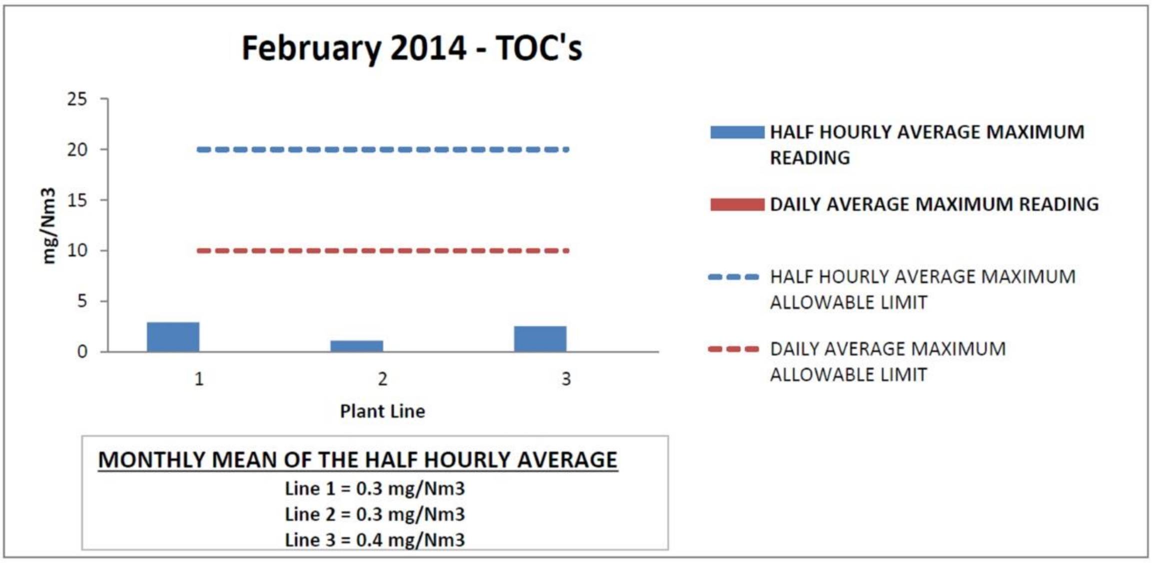
MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 2.4 mg/Nm3
Line 2 = 0.2 mg/Nm3
Line 3 = 2.5 mg/Nm3

Why do we control and monitor Carbon Monoxide?

Carbon monoxide is both a common naturally occurring chemical and is manufactured by man. It is a colourless, odourless poisonous gas. Carbon monoxide is one of the eight substances for which the government has established an air quality standard as part of its national Air Quality Strategy.

Carbon monoxide can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues.

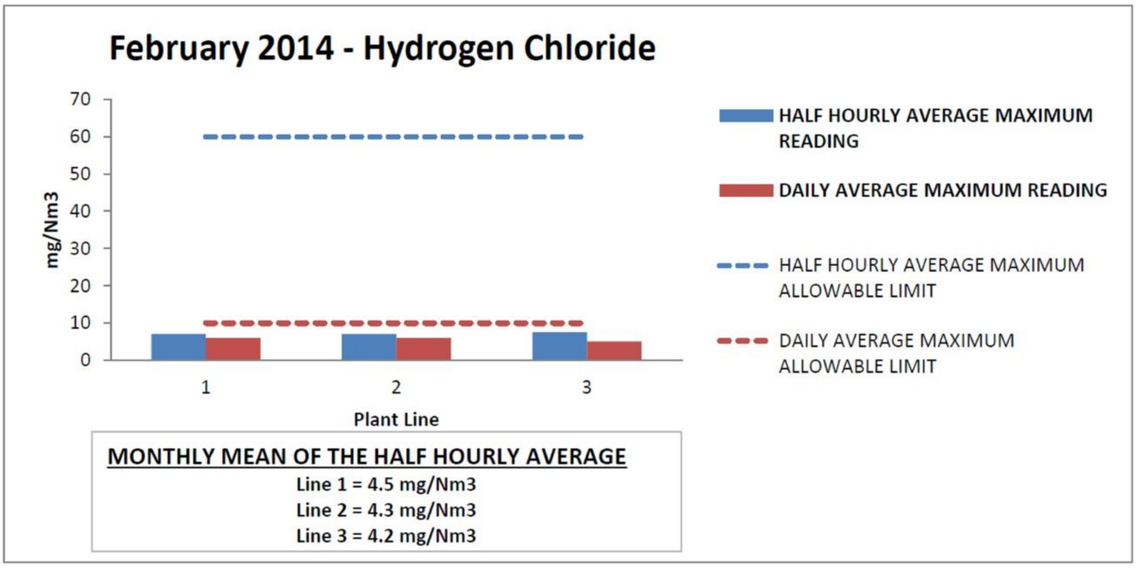


MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 0.3 mg/Nm3
Line 2 = 0.3 mg/Nm3
Line 3 = 0.4 mg/Nm3

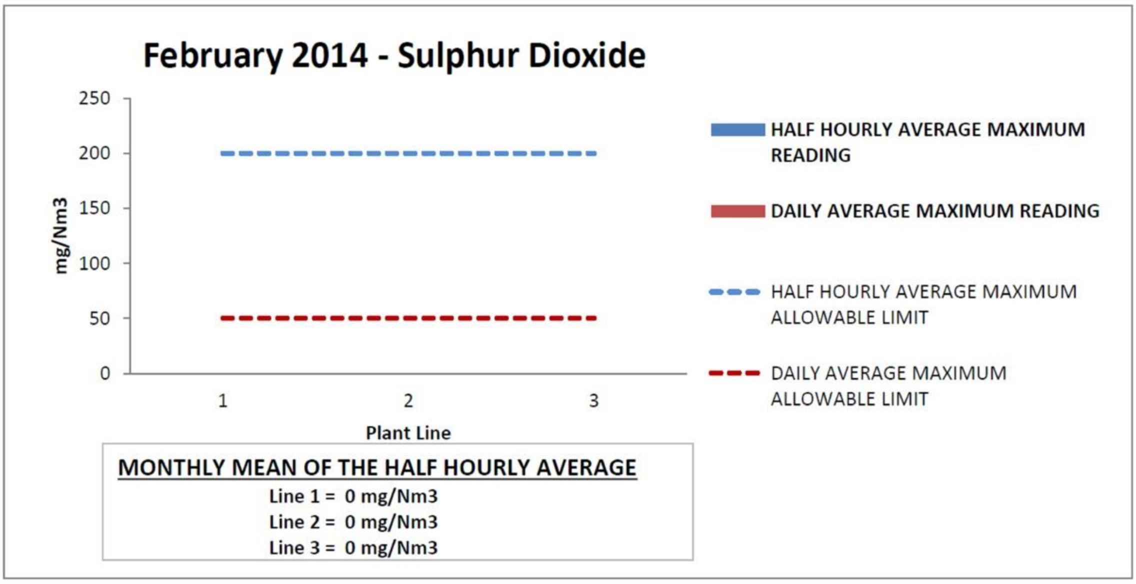
Why do we control and monitor Total Organic Carbon (TOC)?

Total Organic Carbon (TOC) consists of a wide range of organic compounds including Volatile Organic Compounds (VOCs). VOCs are numerous, varied and found everywhere. VOCs are of general concern because of their ability to react with other pollutants (such as nitrogen oxides) in the lower atmosphere to form ozone. High concentrations of ozone at ground level can harm human health, damage crops and affect materials such as rubber. Some VOCs may be directly harmful to human health, contribute to global warming or destroy stratospheric ozone needed to shield the earth's surface from harmful ultra violet radiation.



MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 4.5 mg/Nm3
Line 2 = 4.3 mg/Nm3
Line 3 = 4.2 mg/Nm3

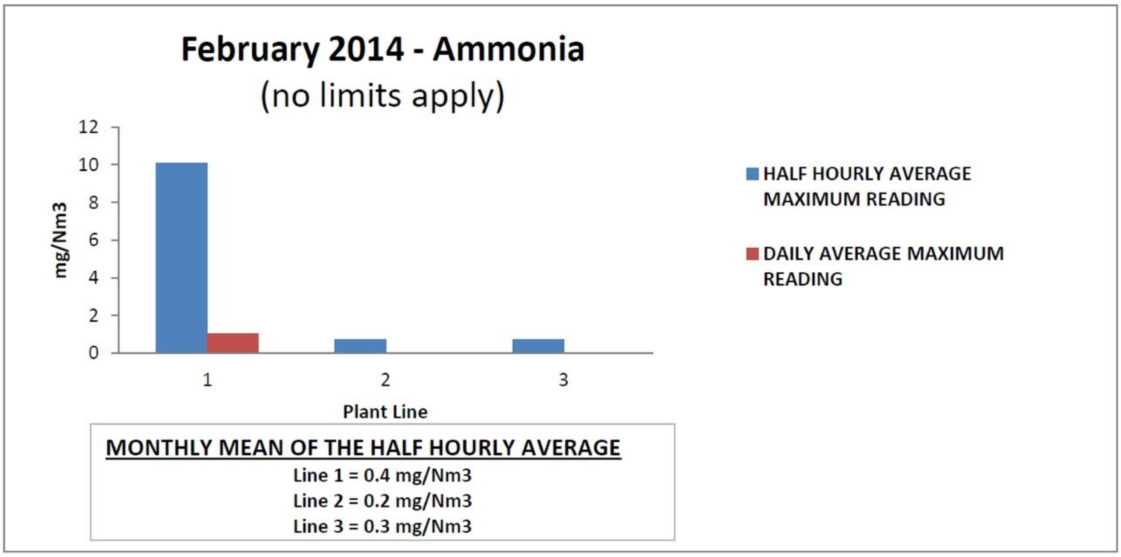


MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 0 mg/Nm3
Line 2 = 0 mg/Nm3
Line 3 = 0 mg/Nm3

Why do we control and monitor Sulphur Dioxide and Hydrogen Chloride?

Both gases dissolve in water to form strong acids and thus can contribute to the formation of acid rain. Acid rain is environmentally damaging to crops, soils and waters.



MONTHLY MEAN OF THE HALF HOURLY AVERAGE

Line 1 = 0.4 mg/Nm3
Line 2 = 0.2 mg/Nm3
Line 3 = 0.3 mg/Nm3

Why do we control and monitor Ammonia?

Although in wide-use in several industries, ammonia is both caustic and hazardous. It is a colourless gas with a characteristic pungent odour.

Ammonia, unlike the other species monitored, is not a product from the incineration of waste but is actually introduced into the furnace. Under the right conditions, ammonia is able to reduce oxides of nitrogen found in the flue gas by the chemical process Selective Non-Catalytic Reduction (SNCR) to nitrogen and water vapour which are both non-hazardous.

Appendix J MODELLING PREDICTIONS FOR ALL AIR QUALITY METRICS

The results presented in this appendix were provided to AECOM for input into the Human Health Risk Assessment. It is noted that in previous versions of the air quality assessment there was a numerical error in the deposition calculations (all concentration predictions used for air quality assessment were unaffected). This error was identified and has subsequently been rectified within the current deposition results.

Further, for deposition modelling, the emission assumptions for Scenario 1 (Expected) and Scenario 3 (Upset) are as per the **Section 6.3.1** and **Section 6.3.3** of the main body of this report. However, given the conservatism adopted within the air quality assessment for Scenario 2 (Regulatory (POEO limits) and Scenario 4 (Regulatory (IED limits), it is inappropriate that the emission assumptions documented within **Section 6.3.2** and **Section 6.3.4** are referenced within an assessment of chronic (i.e. long-term) exposure, as is used in the HRA.

This is since the air quality assessment emission assumptions have been adopted to evaluate the facility's performance against short-term air quality criteria, representing a transient fluctuation of peak emissions.

For the HRA, the regulatory scenarios represent an evaluation of the plant operating at the respective emission limits, as they would be realised over longer timeframes. It is reinforced that these two scenarios represent a theoretical emission limit, rather than any expected operational scenario.

Specifically, for the two regulatory scenarios, in-stack concentrations for the Type 1 and Type 2 metals (excluding Cd and Hg, where specific limits are prescribed) have been ratioed in accordance with the relevant percentage contributions established for the 'Expected' emissions scenario. As noted in **Section 6.3.2** and **Section 6.3.4**, for short-term assessment purposes all metals are modelled as if they individually comprised 100% of the Type 1 and 2 metals Regulation limit.

For these regulatory scenarios the following assumptions have thus been adopted:

- For Scenario 4 (Regulatory (IED limits)) the *daily* IED emission limits have been referenced. This approach is considered appropriate for the characterisation of the upper limit of long term ground level deposition.
- For both Scenario 2 (Regulatory (POEO limits)) and Scenario 4 (Regulatory (IED limits)) the limit for expected Type 1 and 2 metals (refer Table 4-2 and **Table 4-3**) has been considered as an aggregate of all expected metals. The contribution of each individual metal to the Type 1 and 2 metals limit as a whole is based on data published by the UK Environment Agency **(UK EA, 2016)** on metals composition within emissions from waste incineration.
- An in-stack concentration limit of 0.04 mg/Nm^3 was applied to Cd (IED limit is 0.05mg/m^3). This site-specific emission limit was established as as part of previous works when two stack were originally proposed, and has been retained within this air quality assessment, as noted in **Section 9.1.4**.

The revised in-stack concentrations adopted for Scenario 2 and Scenario 4 (long-term (chronic) exposure) are provided in **Table J-1** below. The ground level concentration predictions at the maximum at and beyond the boundary and maximum sensitive receptor are provided in **Table J2** through **Table J5**.

The HRA also required information on the annual deposition rates at Prospect Dam. A conservative approach was used by including a single receptor at the western side of Prospect Dam, where a PM deposition rate of 4.5 x 10^{-8} g/m^2/day was predicted. This was then multiplied by the area of Prospect Dam (approximately 5.2 km^2 **(Water NSW, 2017)**) to give a total annual deposition rate of 0.085 kg of PM/year across the dam surface area. This value has been subsequently referenced within HRA for the Project (**AECOM, 2017**).

Table J-1: In-stack concentration assumptions used within Scenario 2 and Scenario 4 for Human Health Risk Assessment

Pollutant	Scenario 2 Regulatory (POEO limit) in-stack concentration (mg/Nm^3) (1)	Scenario 2 Regulatory (IED limit) In-stack concentration (mg/Nm^3) (2)
NO_2	500	200
SO_2	-	50
CO	125	50
PM_{10}	50	10
$PM_{2.5}$	50	10
HCl	-	10
HF	50	1
Cd	0.20	0.04
Hg	0.20	0.05
PCDD/F	1.0E-07	1.0E-07
Tl	-	0.01
As	0.04	0.01
Sb	0.02	0.01
Cr (III)	0.15	0.07
Cr (VI)	2.2E-04	4.0E-04
Pb	0.29	0.09
Ni	0.37	0.12
Cu	-	0.06
Co	0.01	0.01
Mn	0.10	0.13
V	0.01	0.00
TVOC (assessed as Benzene) (3)	71	10

Notes: (1) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 7% O_2 for all air impurities when burning a solid fuel, with the exception of dioxins and furans where the required O_2 concentration is 11% for waste incineration. For modelling these values have been converted to 11% O_2 concentration.

(2) Reference conditions defined as dry, 273.15 K, 101.3 kPa and 11% O_2.

(3) TVOCs have been assessed against the impact assessment criterion for benzene. Therefore the 40 mg/Nm^3 limit has been adjusted to 71 mg/Nm^3 to account for the difference in molecular weight.

Table J-2: Predicted ground level concentrations at maximum at or beyond boundary and sensitive receptors for the maximum 1-hour, 24-hour and annual averaging period – Scenario 1: Expected

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day
Pollutant	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor
Acetone (propanone)	2.4E-06	1.9E-06	5.7E-07	4.2E-07	1.2E-07	1.1E-07	8.3E-06	5.7E-06	6.0E-06	5.6E-06	8.3E-06	3.8E-07
Acetonitrile	1.8E-06	1.4E-06	4.4E-07	3.3E-07	9.1E-08	8.2E-08	6.5E-06	4.4E-06	4.7E-06	4.3E-06	6.4E-06	2.9E-07
Ag	4.5E-08	3.5E-08	1.1E-08	8.0E-09	2.2E-09	2.0E-09	1.6E-07	1.1E-07	1.1E-07	1.1E-07	1.6E-07	7.1E-09
As	3.3E-06	2.6E-06	7.9E-07	5.9E-07	1.6E-07	1.5E-07	1.2E-05	7.9E-06	8.4E-06	7.7E-06	1.1E-05	5.2E-07
Be	9.2E-10	7.2E-10	2.2E-10	1.7E-10	4.5E-11	4.1E-11	3.2E-09	2.2E-09	2.3E-09	2.2E-09	3.2E-09	1.5E-10
Benzene	2.0E-06	1.5E-06	4.7E-07	3.5E-07	9.7E-08	8.8E-08	6.9E-06	4.7E-06	5.0E-06	4.6E-06	6.9E-06	3.1E-07
Benzoic Acid	1.3E-05	1.0E-05	3.2E-06	2.4E-06	6.5E-07	5.9E-07	4.6E-05	3.2E-05	3.3E-05	3.1E-05	4.6E-05	2.1E-06
BFR	6.6E-10	5.2E-10	1.6E-10	1.2E-10	3.2E-11	2.9E-11	2.3E-09	1.6E-09	1.7E-09	1.5E-09	2.3E-09	1.0E-10
Cd	1.2E-06	9.3E-07	2.8E-07	2.1E-07	5.8E-08	5.3E-08	4.2E-06	2.8E-06	3.0E-06	2.8E-06	4.1E-06	1.9E-07
CO	3.0E-03	2.4E-03	7.3E-04	5.4E-04	1.5E-04	1.4E-04	1.1E-02	7.3E-03	7.7E-03	7.1E-03	1.1E-02	4.8E-04
Co	7.4E-07	5.8E-07	1.8E-07	1.3E-07	3.6E-08	3.3E-08	2.6E-06	1.8E-06	1.9E-06	1.7E-06	2.6E-06	1.2E-07
Cr (III)	1.2E-05	9.5E-06	2.9E-06	2.2E-06	6.0E-07	5.4E-07	4.3E-05	2.9E-05	3.1E-05	2.8E-05	4.2E-05	1.9E-06
Cr (VI)	1.7E-08	1.3E-08	4.1E-09	3.1E-09	8.4E-10	7.7E-10	6.0E-08	4.1E-08	4.3E-08	4.0E-08	6.0E-08	2.7E-09
Cu	2.1E-06	1.7E-06	5.1E-07	3.8E-07	1.1E-07	9.6E-08	7.5E-06	5.2E-06	5.4E-06	5.0E-06	7.5E-06	3.4E-07
Dichloro-methane	2.6E-06	2.1E-06	6.3E-07	4.7E-07	1.3E-07	1.2E-07	9.3E-06	6.3E-06	6.7E-06	6.2E-06	9.2E-06	4.2E-07
Ethyl Benzoic Acid	4.6E-06	3.6E-06	1.1E-06	8.3E-07	2.3E-07	2.1E-07	1.6E-05	1.1E-05	1.2E-05	1.1E-05	1.6E-05	7.3E-07
H$_2$S	1.3E-04	1.0E-04	3.2E-05	2.4E-05	6.5E-06	5.9E-06	4.6E-04	3.2E-04	3.3E-04	3.1E-04	4.6E-04	2.1E-05
HBr	2.6E-04	2.1E-04	6.3E-05	4.7E-05	1.3E-05	1.2E-05	9.3E-04	6.3E-04	6.7E-04	6.2E-04	9.2E-04	4.2E-05
HCB	1.1E-09	8.5E-10	2.6E-10	1.9E-10	5.3E-11	4.8E-11	3.8E-09	2.6E-09	2.7E-09	2.5E-09	3.8E-09	1.7E-10
HCl	1.2E-03	9.3E-04	2.8E-04	2.1E-04	5.8E-05	5.3E-05	4.2E-03	2.8E-03	3.0E-03	2.8E-03	4.1E-03	1.9E-04
Heptane	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
Hexa-decanoic Acid	4.9E-06	3.8E-06	1.2E-06	8.7E-07	2.4E-07	2.2E-07	1.7E-05	1.2E-05	1.2E-05	1.1E-05	1.7E-05	7.7E-07
Hexane	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
HF	6.6E-05	5.2E-05	1.6E-05	1.2E-05	3.2E-06	2.9E-06	2.3E-04	1.6E-04	1.7E-04	1.5E-04	2.3E-04	1.0E-05
Hg	5.3E-07	4.1E-07	1.3E-07	9.4E-08	2.6E-08	2.4E-08	1.9E-06	1.3E-06	1.3E-06	1.2E-06	1.8E-06	8.4E-08
Methyl-hexane	7.9E-07	6.2E-07	1.9E-07	1.4E-07	3.9E-08	3.5E-08	2.8E-06	1.9E-06	2.0E-06	1.9E-06	2.8E-06	1.3E-07
Mn	7.9E-06	6.2E-06	1.9E-06	1.4E-06	3.9E-07	3.5E-07	2.8E-05	1.9E-05	2.0E-05	1.9E-05	2.8E-05	1.3E-06
Mo	2.9E-09	2.3E-09	6.9E-10	5.2E-10	1.4E-10	1.3E-10	1.0E-08	7.0E-09	7.3E-09	6.8E-09	1.0E-08	4.6E-10
NH	2.6E-04	2.1E-04	6.3E-05	4.7E-05	1.3E-05	1.2E-05	9.3E-04	6.3E-04	6.7E-04	6.2E-04	9.2E-04	4.2E-05
Ni	2.9E-05	2.3E-05	6.9E-06	5.2E-06	1.4E-06	1.3E-06	1.0E-04	7.0E-05	7.3E-05	6.8E-05	1.0E-04	4.6E-06

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$
Pollutant	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**
NO	1.6E-02	1.2E-02	3.8E-03	2.8E-03	7.8E-04	7.1E-04	5.6E-02	3.8E-02	4.0E-02	3.7E-02	5.5E-02	2.5E-03
PAHs	6.6E-08	5.2E-08	1.6E-08	1.2E-08	3.2E-09	2.9E-09	2.3E-07	1.6E-07	1.7E-07	1.5E-07	2.3E-07	1.0E-08
Pb	2.3E-05	1.8E-05	5.4E-06	4.1E-06	1.1E-06	1.0E-06	8.0E-05	5.4E-05	5.7E-05	5.3E-05	7.9E-05	3.6E-06
PCBs	2.1E-12	1.7E-12	5.0E-13	3.8E-13	1.0E-13	9.4E-14	7.4E-12	5.1E-12	5.3E-12	5.0E-12	7.3E-12	3.3E-13
PCDD/F	1.3E-12	1.0E-12	3.2E-13	2.4E-13	6.5E-14	5.9E-14	4.6E-12	3.2E-12	3.3E-12	3.1E-12	4.6E-12	2.1E-13
Phenol	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
Phthalate	2.6E-06	2.1E-06	6.3E-07	4.7E-07	1.3E-07	1.2E-07	9.3E-06	6.3E-06	6.7E-06	6.2E-06	9.2E-06	4.2E-07
Phthalate	2.6E-06	2.1E-06	6.3E-07	4.7E-07	1.3E-07	1.2E-07	9.3E-06	6.3E-06	6.7E-06	6.2E-06	9.2E-06	4.2E-07
PM$_{10}$	1.3E-04	1.0E-04	3.2E-05	2.4E-05	6.5E-06	5.9E-06	4.6E-04	3.2E-04	3.3E-04	3.1E-04	4.6E-04	2.1E-05
PM$_{2.5}$	1.3E-04	1.0E-04	3.2E-05	2.4E-05	6.5E-06	5.9E-06	4.6E-04	3.2E-04	3.3E-04	3.1E-04	4.6E-04	2.1E-05
Sb	1.9E-06	1.5E-06	4.7E-07	3.5E-07	9.6E-08	8.7E-08	6.8E-06	4.7E-06	4.9E-06	4.6E-06	6.8E-06	3.1E-07
Se	2.8E-07	2.2E-07	6.7E-08	5.0E-08	1.4E-08	1.2E-08	9.8E-07	6.7E-07	7.1E-07	6.6E-07	9.7E-07	4.4E-08
Sn	4.4E-07	3.4E-07	1.1E-07	7.9E-08	2.2E-08	2.0E-08	1.5E-06	1.1E-06	1.1E-06	1.0E-06	1.5E-06	7.0E-08
SO	3.6E-03	2.8E-03	8.5E-04	6.4E-04	1.8E-04	1.6E-04	1.2E-02	8.5E-03	9.0E-03	8.4E-03	1.2E-02	5.6E-04
TBD	6.6E-12	5.2E-12	1.6E-12	1.2E-12	3.2E-13	2.9E-13	2.3E-11	1.6E-11	1.7E-11	1.5E-11	2.3E-11	1.0E-12
Tetra-decanoic Acid	2.0E-06	1.5E-06	4.7E-07	3.5E-07	9.7E-08	8.8E-08	6.9E-06	4.7E-06	5.0E-06	4.6E-06	6.9E-06	3.1E-07
Tl	1.3E-07	1.0E-07	3.2E-08	2.4E-08	6.5E-09	5.9E-09	4.6E-07	3.2E-07	3.3E-07	3.1E-07	4.6E-07	2.1E-08
Toluene	3.9E-06	3.1E-06	9.5E-07	7.1E-07	1.9E-07	1.8E-07	1.4E-05	9.5E-06	1.0E-05	9.3E-06	1.4E-05	6.3E-07
Trichloro-ethylene	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
Trichloro-phenol	1.2E-06	9.3E-07	2.8E-07	2.1E-07	5.8E-08	5.3E-08	4.2E-06	2.8E-06	3.0E-06	2.8E-06	4.1E-06	1.9E-07
TVOCs	1.6E-04	1.2E-04	3.8E-05	2.8E-05	7.8E-06	7.1E-06	5.6E-04	3.8E-04	4.0E-04	3.7E-04	5.5E-04	2.5E-05
V	7.9E-07	6.2E-07	1.9E-07	1.4E-07	3.9E-08	3.5E-08	2.8E-06	1.9E-06	2.0E-06	1.9E-06	2.8E-06	1.3E-07
Xylene	1.3E-06	1.0E-06	3.2E-07	2.4E-07	6.5E-08	5.9E-08	4.6E-06	3.2E-06	3.3E-06	3.1E-06	4.6E-06	2.1E-07
Zn	4.9E-06	3.8E-06	1.2E-06	8.7E-07	2.4E-07	2.2E-07	1.7E-05	1.2E-05	1.2E-05	1.1E-05	1.7E-05	7.7E-07

Table J-3: Predicted ground level concentrations at maximum at or beyond boundary and sensitive receptors for the maximum 1-hour, 24-hour and annual averaging period – Scenario 2: Regulatory (POEO limits)

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m³	mg/m³	mg/m³	mg/m³	mg/m³	mg/m³	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day
Pollutant	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor
Acetone (propanone)	-	-	-	-	-	-	-	-	-	-	-	-
Acetonitrile	-	-	-	-	-	-	-	-	-	-	-	-
Ag	-	-	-	-	-	-	-	-	-	-	-	-
As	3.9E-06	3.1E-06	9.4E-07	7.0E-07	1.9E-07	1.7E-07	1.4E-05	9.4E-06	9.9E-06	9.2E-06	1.4E-05	6.2E-07
Be	1.1E-09	8.6E-10	2.6E-10	2.0E-10	5.4E-11	4.9E-11	3.8E-09	2.6E-09	2.8E-09	2.6E-09	3.8E-09	1.7E-10
Benzene	-	-	-	-	-	-	-	-	-	-	-	-
Benzoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
BFR	-	-	-	-	-	-	-	-	-	-	-	-
Cd	1.9E-05	1.5E-05	4.5E-06	3.4E-06	9.3E-07	8.4E-07	6.6E-05	4.5E-05	4.8E-05	4.4E-05	6.6E-05	3.0E-06
CO	1.2E-02	9.2E-03	2.8E-03	2.1E-03	5.8E-04	5.3E-04	4.1E-02	2.8E-02	3.0E-02	2.8E-02	4.1E-02	1.9E-03
Co	8.8E-07	6.9E-07	2.1E-07	1.6E-07	4.3E-08	3.9E-08	3.1E-06	2.1E-06	2.2E-06	2.1E-06	3.1E-06	1.4E-07
Cr (III)	1.4E-05	1.1E-05	3.4E-06	2.6E-06	7.1E-07	6.4E-07	5.1E-05	3.5E-05	3.7E-05	3.4E-05	5.0E-05	2.3E-06
Cr (VI)	2.0E-08	1.6E-08	4.9E-09	3.6E-09	1.0E-09	9.1E-10	7.1E-08	4.9E-08	5.2E-08	4.8E-08	7.1E-08	3.2E-09
Cu	-	-	-	-	-	-	-	-	-	-	-	-
Dichloro-methane	-	-	-	-	-	-	-	-	-	-	-	-
Ethyl Benzoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
H_2S	-	-	-	-	-	-	-	-	-	-	-	-
HBr	-	-	-	-	-	-	-	-	-	-	-	-
HCB	-	-	-	-	-	-	-	-	-	-	-	-
HCl	-	-	-	-	-	-	-	-	-	-	-	-
Heptane	-	-	-	-	-	-	-	-	-	-	-	-
Hexa-decanoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
Hexane	-	-	-	-	-	-	-	-	-	-	-	-
HF	4.7E-03	3.7E-03	1.1E-03	8.4E-04	2.3E-04	2.1E-04	1.7E-02	1.1E-02	1.2E-02	1.1E-02	1.6E-02	7.5E-04
Hg	1.9E-05	1.5E-05	4.5E-06	3.4E-06	9.3E-07	8.4E-07	6.6E-05	4.5E-05	4.8E-05	4.4E-05	6.6E-05	3.0E-06
Methyl-hexane	-	-	-	-	-	-	-	-	-	-	-	-
Mn	9.4E-06	7.4E-06	2.2E-06	1.7E-06	4.6E-07	4.2E-07	3.3E-05	2.3E-05	2.4E-05	2.2E-05	3.3E-05	1.5E-06
Mo	-	-	-	-	-	-	-	-	-	-	-	-

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m³	mg/m³	mg/m³	mg/m³	mg/m³	mg/m³	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day	mg/m²/day
Pollutant	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor
NH_3	-	-	-	-	-	-	-	-	-	-	-	-
Ni	3.4E-05	2.7E-05	8.2E-06	6.2E-06	1.7E-06	1.5E-06	1.2E-04	8.3E-05	8.7E-05	8.1E-05	1.2E-04	5.5E-06
NO_2	4.7E-02	3.7E-02	1.1E-02	8.4E-03	2.3E-03	2.1E-03	1.7E-01	1.1E-01	1.2E-01	1.1E-01	1.6E-01	7.5E-03
PAHs	-	-	-	-	-	-	-	-	-	-	-	-
Pb	2.7E-05	2.1E-05	6.4E-06	4.8E-06	1.3E-06	1.2E-06	9.5E-05	6.5E-05	6.8E-05	6.3E-05	9.4E-05	4.3E-06
PCBs	-	-	-	-	-	-	-	-	-	-	-	-
PCDD/F	1.3E-11	1.0E-11	3.2E-12	2.4E-12	6.5E-13	5.9E-13	4.6E-11	3.2E-11	3.3E-11	3.1E-11	4.6E-11	2.1E-12
Phenol	-	-	-	-	-	-	-	-	-	-	-	-
Phthalate	-	-	-	-	-	-	-	-	-	-	-	-
Phthalate	-	-	-	-	-	-	-	-	-	-	-	-
PM_{10}	4.7E-03	3.7E-03	1.1E-03	8.4E-04	2.3E-04	2.1E-04	1.7E-02	1.1E-02	1.2E-02	1.1E-02	1.6E-02	7.5E-04
$PM_{2.5}$	4.7E-03	3.7E-03	1.1E-03	8.4E-04	2.3E-04	2.1E-04	1.7E-02	1.1E-02	1.2E-02	1.1E-02	1.6E-02	7.5E-04
Sb	2.3E-06	1.8E-06	5.5E-07	4.2E-07	1.1E-07	1.0E-07	8.1E-06	5.6E-06	5.9E-06	5.4E-06	8.1E-06	3.7E-07
Se	3.3E-07	2.6E-07	7.9E-08	5.9E-08	1.6E-08	1.5E-08	1.2E-06	8.0E-07	8.4E-07	7.8E-07	1.2E-06	5.3E-08
Sn	5.2E-07	4.1E-07	1.2E-07	9.3E-08	2.6E-08	2.3E-08	1.8E-06	1.3E-06	1.3E-06	1.2E-06	1.8E-06	8.3E-08
SO_2	-	-	-	-	-	-	-	-	-	-	-	-
TBD	-	-	-	-	-	-	-	-	-	-	-	-
Tetra-decanoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
Tl	-	-	-	-	-	-	-	-	-	-	-	-
Toluene	-	-	-	-	-	-	-	-	-	-	-	-
Trichloro-ethylene	-	-	-	-	-	-	-	-	-	-	-	-
Trichloro-phenol	-	-	-	-	-	-	-	-	-	-	-	-
TVOCs	6.7E-03	5.2E-03	1.6E-03	1.2E-03	3.3E-04	3.0E-04	2.3E-02	1.6E-02	1.7E-02	1.6E-02	2.3E-02	1.1E-03
V	9.4E-07	7.4E-07	2.2E-07	1.7E-07	4.6E-08	4.2E-08	3.3E-06	2.3E-06	2.4E-06	2.2E-06	3.3E-06	1.5E-07
Xylene	-	-	-	-	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-	-	-	-	-

Table J-4: Predicted ground level concentrations at maximum at or beyond boundary and sensitive receptors for the maximum 1-hour, 24-hour and annual averaging period – Scenario 3: Upset

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day
Pollutant	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**
Acetone (propanone)	2.4E-05	1.9E-05	5.7E-06	4.2E-06	1.2E-06	1.1E-06	8.3E-05	5.7E-05	6.0E-05	5.6E-05	8.3E-05	3.8E-06
Acetonitrile	1.8E-05	1.4E-05	4.4E-06	3.3E-06	9.1E-07	8.2E-07	6.5E-05	4.4E-05	4.7E-05	4.3E-05	6.4E-05	2.9E-06
Ag	3.4E-06	2.6E-06	8.0E-07	6.0E-07	1.7E-07	1.5E-07	1.2E-05	8.1E-06	8.5E-06	7.9E-06	1.2E-05	5.3E-07
As	1.0E-05	8.2E-06	2.5E-06	1.9E-06	5.1E-07	4.7E-07	3.7E-05	2.5E-05	2.6E-05	2.5E-05	3.6E-05	1.7E-06
Be	6.9E-08	5.4E-08	1.7E-08	1.2E-08	3.4E-09	3.1E-09	2.4E-07	1.7E-07	1.8E-07	1.6E-07	2.4E-07	1.1E-08
Benzene	2.0E-05	1.5E-05	4.7E-06	3.5E-06	9.7E-07	8.8E-07	6.9E-05	4.7E-05	5.0E-05	4.6E-05	6.9E-05	3.1E-06
Benzoic Acid	1.3E-04	1.0E-04	3.2E-05	2.4E-05	6.5E-06	5.9E-06	4.6E-04	3.2E-04	3.3E-04	3.1E-04	4.6E-04	2.1E-05
BFR	6.6E-09	5.2E-09	1.6E-09	1.2E-09	3.2E-10	2.9E-10	2.3E-08	1.6E-08	1.7E-08	1.5E-08	2.3E-08	1.0E-09
Cd	5.9E-05	4.6E-05	1.4E-05	1.1E-05	2.9E-06	2.6E-06	2.1E-04	1.4E-04	1.5E-04	1.4E-04	2.1E-04	9.4E-06
CO	6.6E-02	5.2E-02	1.6E-02	1.2E-02	3.2E-03	2.9E-03	2.3E-01	1.6E-01	1.7E-01	1.5E-01	2.3E-01	1.0E-02
Co	1.0E-05	8.2E-06	2.5E-06	1.9E-06	5.1E-07	4.7E-07	3.7E-05	2.5E-05	2.6E-05	2.5E-05	3.6E-05	1.7E-06
Cr (III)	8.9E-05	7.0E-05	2.1E-05	1.6E-05	4.4E-06	4.0E-06	3.1E-04	2.1E-04	2.3E-04	2.1E-04	3.1E-04	1.4E-05
Cr (VI)	1.7E-07	1.3E-07	4.1E-08	3.1E-08	8.4E-09	7.7E-09	6.0E-07	4.1E-07	4.3E-07	4.0E-07	6.0E-07	2.7E-08
Cu	7.8E-05	6.1E-05	1.9E-05	1.4E-05	3.9E-06	3.5E-06	2.8E-04	1.9E-04	2.0E-04	1.8E-04	2.7E-04	1.2E-05
Dichloro-methane	2.6E-05	2.1E-05	6.3E-06	4.7E-06	1.3E-06	1.2E-06	9.3E-05	6.3E-05	6.7E-05	6.2E-05	9.2E-05	4.2E-06
Ethyl Benzoic Acid	4.6E-05	3.6E-05	1.1E-05	8.3E-06	2.3E-06	2.1E-06	1.6E-04	1.1E-04	1.2E-04	1.1E-04	1.6E-04	7.3E-06
H_2S	1.3E-03	1.0E-03	3.2E-04	2.4E-04	6.5E-05	5.9E-05	4.6E-03	3.2E-03	3.3E-03	3.1E-03	4.6E-03	2.1E-04
HBr	2.6E-03	2.1E-03	6.3E-04	4.7E-04	1.3E-04	1.2E-04	9.3E-03	6.3E-03	6.7E-03	6.2E-03	9.2E-03	4.2E-04
HCB	1.1E-08	8.5E-09	2.6E-09	1.9E-09	5.3E-10	4.8E-10	3.8E-08	2.6E-08	2.7E-08	2.5E-08	3.8E-08	1.7E-09
HCl	1.3E-02	1.0E-02	3.2E-03	2.4E-03	6.5E-04	5.9E-04	4.6E-02	3.2E-02	3.3E-02	3.1E-02	4.6E-02	2.1E-03
Heptane	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
Hexa-decanoic Acid	4.9E-05	3.8E-05	1.2E-05	8.7E-06	2.4E-06	2.2E-06	1.7E-04	1.2E-04	1.2E-04	1.1E-04	1.7E-04	7.7E-06
Hexane	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
HF	6.6E-04	5.2E-04	1.6E-04	1.2E-04	3.2E-05	2.9E-05	2.3E-03	1.6E-03	1.7E-03	1.5E-03	2.3E-03	1.0E-04
Hg	6.6E-05	5.2E-05	1.6E-05	1.2E-05	3.2E-06	2.9E-06	2.3E-04	1.6E-04	1.7E-04	1.5E-04	2.3E-04	1.0E-05
Methyl-hexane	7.9E-06	6.2E-06	1.9E-06	1.4E-06	3.9E-07	3.5E-07	2.8E-05	1.9E-05	2.0E-05	1.9E-05	2.8E-05	1.3E-06
Mn	1.8E-04	1.4E-04	4.3E-05	3.2E-05	8.8E-06	7.9E-06	6.2E-04	4.3E-04	4.5E-04	4.2E-04	6.2E-04	2.8E-05
Mo	3.5E-07	2.7E-07	8.3E-08	6.2E-08	1.7E-08	1.5E-08	1.2E-06	8.3E-07	8.8E-07	8.1E-07	1.2E-06	5.5E-08
NH_3	2.6E-03	2.1E-03	6.3E-04	4.7E-04	1.3E-04	1.2E-04	9.3E-03	6.3E-03	6.7E-03	6.2E-03	9.2E-03	4.2E-04

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$	$mg/m^2/day$
Pollutant	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**	**Maximum at or beyond boundary**	**Maximum sensitive receptor**
Ni	1.6E-04	1.2E-04	3.8E-05	2.8E-05	7.7E-06	7.0E-06	5.5E-04	3.8E-04	4.0E-04	3.7E-04	5.5E-04	2.5E-05
NO$_2$	5.3E-02	4.1E-02	1.3E-02	9.4E-03	2.6E-03	2.4E-03	1.9E-01	1.3E-01	1.3E-01	1.2E-01	1.8E-01	8.4E-03
PAHs	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
Pb	1.1E-04	9.0E-05	2.8E-05	2.1E-05	5.7E-06	5.1E-06	4.0E-04	2.8E-04	2.9E-04	2.7E-04	4.0E-04	1.8E-05
PCBs	2.1E-11	1.7E-11	5.0E-12	3.8E-12	1.0E-12	9.4E-13	7.4E-11	5.1E-11	5.3E-11	5.0E-11	7.3E-11	3.3E-12
PCDD/F	1.3E-10	1.0E-10	3.2E-11	2.4E-11	6.5E-12	5.9E-12	4.6E-10	3.2E-10	3.3E-10	3.1E-10	4.6E-10	2.1E-11
Phenol	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
Phthalate	2.6E-05	2.1E-05	6.3E-06	4.7E-06	1.3E-06	1.2E-06	9.3E-05	6.3E-05	6.7E-05	6.2E-05	9.2E-05	4.2E-06
Phthalate	2.6E-05	2.1E-05	6.3E-06	4.7E-06	1.3E-06	1.2E-06	9.3E-05	6.3E-05	6.7E-05	6.2E-05	9.2E-05	4.2E-06
PM$_{10}$	1.3E-02	1.0E-02	3.2E-03	2.4E-03	6.5E-04	5.9E-04	4.6E-02	3.2E-02	3.3E-02	3.1E-02	4.6E-02	2.1E-03
PM$_{2.5}$	1.3E-02	1.0E-02	3.2E-03	2.4E-03	6.5E-04	5.9E-04	4.6E-02	3.2E-02	3.3E-02	3.1E-02	4.6E-02	2.1E-03
Sb	1.6E-05	1.2E-05	3.8E-06	2.8E-06	7.7E-07	7.0E-07	5.5E-05	3.8E-05	4.0E-05	3.7E-05	5.5E-05	2.5E-06
Se	2.8E-06	2.2E-06	6.7E-07	5.0E-07	1.4E-07	1.2E-07	9.8E-06	6.7E-06	7.1E-06	6.6E-06	9.7E-06	4.4E-07
Sn	3.3E-05	2.6E-05	7.9E-06	5.9E-06	1.6E-06	1.5E-06	1.2E-04	7.9E-05	8.4E-05	7.7E-05	1.1E-04	5.2E-06
SO$_2$	6.6E-02	5.2E-02	1.6E-02	1.2E-02	3.2E-03	2.9E-03	2.3E-01	1.6E-01	1.7E-01	1.5E-01	2.3E-01	1.0E-02
TBD	6.6E-11	5.2E-11	1.6E-11	1.2E-11	3.2E-12	2.9E-12	2.3E-10	1.6E-10	1.7E-10	1.5E-10	2.3E-10	1.0E-11
Tetra-decanoic Acid	2.0E-05	1.5E-05	4.7E-06	3.5E-06	9.7E-07	8.8E-07	6.9E-05	4.7E-05	5.0E-05	4.6E-05	6.9E-05	3.1E-06
Tl	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
Toluene	3.9E-05	3.1E-05	9.5E-06	7.1E-06	1.9E-06	1.8E-06	1.4E-04	9.5E-05	1.0E-04	9.3E-05	1.4E-04	6.3E-06
Trichloro-ethylene	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
Trichloro-phenol	1.2E-05	9.3E-06	2.8E-06	2.1E-06	5.8E-07	5.3E-07	4.2E-05	2.8E-05	3.0E-05	2.8E-05	4.1E-05	1.9E-06
TVOCs	1.3E-02	1.0E-02	3.2E-03	2.4E-03	6.5E-04	5.9E-04	4.6E-02	3.2E-02	3.3E-02	3.1E-02	4.6E-02	2.1E-03
V	5.2E-06	4.1E-06	1.3E-06	9.4E-07	2.6E-07	2.3E-07	1.8E-05	1.3E-05	1.3E-05	1.2E-05	1.8E-05	8.3E-07
Xylene	1.3E-05	1.0E-05	3.2E-06	2.4E-06	6.5E-07	5.9E-07	4.6E-05	3.2E-05	3.3E-05	3.1E-05	4.6E-05	2.1E-06
Zn	6.7E-04	5.3E-04	1.6E-04	1.2E-04	3.3E-05	3.0E-05	2.4E-03	1.6E-03	1.7E-03	1.6E-03	2.3E-03	1.1E-04

Table J-5: Predicted ground level concentrations at maximum at or beyond boundary and sensitive receptors for the maximum 1-hour, 24-hour and annual averaging period – Scenario 4: Regulatory (IED limits)

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day
Pollutant	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor
Acetone (propanone)	-	-	-	-	-	-	-	-	-	-	-	-
Acetonitrile	-	-	-	-	-	-	-	-	-	-	-	-
Ag	-	-	-	-	-	-	-	-	-	-	-	-
As	1.0E-06	8.2E-07	2.5E-07	1.9E-07	5.1E-08	4.7E-08	3.7E-06	2.5E-06	2.6E-06	2.5E-06	3.6E-06	1.7E-07
Be	-	-	-	-	-	-	-	-	-	-	-	-
Benzene	-	-	-	-	-	-	-	-	-	-	-	-
Benzoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
BFR	-	-	-	-	-	-	-	-	-	-	-	-
Cd	5.3E-06	4.1E-06	1.3E-06	9.4E-07	2.6E-07	2.4E-07	1.9E-05	1.3E-05	1.3E-05	1.2E-05	1.8E-05	8.4E-07
CO	6.6E-03	5.2E-03	1.6E-03	1.2E-03	3.2E-04	2.9E-04	2.3E-02	1.6E-02	1.7E-02	1.5E-02	2.3E-02	1.0E-03
Co	1.0E-06	8.2E-07	2.5E-07	1.9E-07	5.1E-08	4.7E-08	3.7E-06	2.5E-06	2.6E-06	2.5E-06	3.6E-06	1.7E-07
Cr (III)	8.9E-06	7.0E-06	2.1E-06	1.6E-06	4.4E-07	4.0E-07	3.1E-05	2.1E-05	2.3E-05	2.1E-05	3.1E-05	1.4E-06
Cr (VI)	5.2E-08	4.1E-08	1.3E-08	9.4E-09	2.6E-09	2.3E-09	1.8E-07	1.3E-07	1.3E-07	1.2E-07	1.8E-07	8.3E-09
Cu	7.8E-06	6.1E-06	1.9E-06	1.4E-06	3.9E-07	3.5E-07	2.8E-05	1.9E-05	2.0E-05	1.8E-05	2.7E-05	1.2E-06
Dichloro-methane	-	-	-	-	-	-	-	-	-	-	-	-
Ethyl Benzoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
H_2S	-	-	-	-	-	-	-	-	-	-	-	-
HBr	-	-	-	-	-	-	-	-	-	-	-	-
HCB	-	-	-	-	-	-	-	-	-	-	-	-
HCl	1.3E-03	1.0E-03	3.2E-04	2.4E-04	6.5E-05	5.9E-05	4.6E-03	3.2E-03	3.3E-03	3.1E-03	4.6E-03	2.1E-04
Heptane	-	-	-	-	-	-	-	-	-	-	-	-
Hexa-decanoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
Hexane	-	-	-	-	-	-	-	-	-	-	-	-
HF	1.3E-04	1.0E-04	3.2E-05	2.4E-05	6.5E-06	5.9E-06	4.6E-04	3.2E-04	3.3E-04	3.1E-04	4.6E-04	2.1E-05
Hg	6.6E-06	5.2E-06	1.6E-06	1.2E-06	3.2E-07	2.9E-07	2.3E-05	1.6E-05	1.7E-05	1.5E-05	2.3E-05	1.0E-06
Methyl-hexane	-	-	-	-	-	-	-	-	-	-	-	-
Mn	1.8E-05	1.4E-05	4.3E-06	3.2E-06	8.8E-07	7.9E-07	6.2E-05	4.3E-05	4.5E-05	4.2E-05	6.2E-05	2.8E-06

	1-hr		24-hr		Annual		Annual total deposition		Dry deposition		Wet deposition	
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day	mg/m^2/day
Pollutant	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor	Maximum at or beyond boundary	Maximum sensitive receptor
Mo	-	-	-	-	-	-	-	-	-	-	-	-
NH_3	-	-	-	-	-	-	-	-	-	-	-	-
Ni	1.6E-05	1.2E-05	3.8E-06	2.8E-06	7.7E-07	7.0E-07	5.5E-05	3.8E-05	4.0E-05	3.7E-05	5.5E-05	2.5E-06
NO_2	2.6E-02	2.1E-02	6.3E-03	4.7E-03	1.3E-03	1.2E-03	9.3E-02	6.3E-02	6.7E-02	6.2E-02	9.2E-02	4.2E-03
PAHs	-	-	-	-	-	-	-	-	-	-	-	-
Pb	1.1E-05	9.0E-06	2.8E-06	2.1E-06	5.7E-07	5.1E-07	4.0E-05	2.8E-05	2.9E-05	2.7E-05	4.0E-05	1.8E-06
PCBs	-	-	-	-	-	-	-	-	-	-	-	-
PCDD/F	1.3E-11	1.0E-11	3.2E-12	2.4E-12	6.5E-13	5.9E-13	4.6E-11	3.2E-11	3.3E-11	3.1E-11	4.6E-11	2.1E-12
Phenol	-	-	-	-	-	-	-	-	-	-	-	-
Phthalate	-	-	-	-	-	-	-	-	-	-	-	-
Phthalate	-	-	-	-	-	-	-	-	-	-	-	-
PM_{10}	1.3E-03	1.0E-03	3.2E-04	2.4E-04	6.5E-05	5.9E-05	4.6E-03	3.2E-03	3.3E-03	3.1E-03	4.6E-03	2.1E-04
$PM_{2.5}$	1.3E-03	1.0E-03	3.2E-04	2.4E-04	6.5E-05	5.9E-05	4.6E-03	3.2E-03	3.3E-03	3.1E-03	4.6E-03	2.1E-04
Sb	1.6E-06	1.2E-06	3.8E-07	2.8E-07	7.7E-08	7.0E-08	5.5E-06	3.8E-06	4.0E-06	3.7E-06	5.5E-06	2.5E-07
Se	-	-	-	-	-	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-	-	-	-	-
SO_2	6.6E-03	5.2E-03	1.6E-03	1.2E-03	3.2E-04	2.9E-04	2.3E-02	1.6E-02	1.7E-02	1.5E-02	2.3E-02	1.0E-03
TBD	-	-	-	-	-	-	-	-	-	-	-	-
Tetra-decanoic Acid	-	-	-	-	-	-	-	-	-	-	-	-
Tl	6.6E-07	5.2E-07	1.6E-07	1.2E-07	3.2E-08	2.9E-08	2.3E-06	1.6E-06	1.7E-06	1.5E-06	2.3E-06	1.0E-07
Toluene	-	-	-	-	-	-	-	-	-	-	-	-
Trichloro-ethylene	-	-	-	-	-	-	-	-	-	-	-	-
Trichloro-phenol	-	-	-	-	-	-	-	-	-	-	-	-
TVOCs	1.3E-03	1.0E-03	3.2E-04	2.4E-04	6.5E-05	5.9E-05	4.6E-03	3.2E-03	3.3E-03	3.1E-03	4.6E-03	2.1E-04
V	5.2E-07	4.1E-07	1.3E-07	9.4E-08	2.6E-08	2.3E-08	1.8E-06	1.3E-06	1.3E-06	1.2E-06	1.8E-06	8.3E-08
Xylene	-	-	-	-	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-	-	-	-	-