National Dioxins Program

Technical Report No. 3
Inventory of Dioxin Emissions in Australia, 2004

A consultancy funded by the Australian Government
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2. Dioxins emissions from Motor Vehicles in Australia
3. **Inventory of Dioxin Emissions in Australia, 2004**
4. Dioxins in Ambient Air in Australia
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6. Dioxins in Aquatic Environments in Australia
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Foreword

When the Australian Government established the four year National Dioxins Program in 2001, our knowledge about the incidence of dioxins in Australia was very limited.

The aim of the program was to improve this knowledge base so that governments were in a better position to consider appropriate management actions. Starting in mid 2001, a range of studies were undertaken which involved measuring emissions from sources such as bushfires, as well as dioxin levels in the environment, food and population. The findings of these studies were used to shed light on the risk dioxins pose to our health and the environment.

This work has been completed and the findings are now presented in a series of twelve technical reports.

Having good information is essential if there is to be timely and effective action by governments; these studies are a start. Our next step is to foster informed debate on how we should tackle dioxins in Australia, as this is an obligation under the Stockholm Convention on Persistent Organic Pollutants. The Department of the Environment and Heritage will be working closely with other Australian Government, State and Territory agencies to take this step.

Ultimately, the effective management of dioxins will be the shared responsibility of all government jurisdictions with the support of the community and industry.

David Borthwick
Secretary
Department of the Environment and Heritage

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The Department of the Environment and Heritage (DEH) would like to acknowledge the following individuals and organisations that contributed to the information studies and risk assessments under the National Dioxins Program:

- the project teams from the CSIRO, the National Research Centre for Environmental Toxicology and Pacific Air & Environment who undertook the studies assessing the levels of dioxins in the environment, the population and from emission sources, the overseas experts who provided advice to these organisations, and the many individuals across Australia who collected the samples in the field
- the Department of Agriculture, Fisheries and Forestry, who assessed the levels of dioxins in agricultural commodities
- Food Standards Australia New Zealand and the Department of Health and Ageing and who assessed the levels of dioxins in foods and assessed the health effects of dioxins
- officers of the Chemical Assessment Section in DEH who assessed the ecological effects of dioxins
- members of the National Dioxins Project Team which included representatives from the State and Territory environment protection agencies, the Australian Health Ministers Conference and the Primary Industries Ministers Council
- members of the National Dioxins Consultative Group which included representatives from industry and agricultural sectors, environment and public health groups and research institutions.

Project Team

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Contributors

The Project Team would like to thank all individuals and industry peak bodies and companies that provided information throughout the course of this project.

Executive Summary

As part of the Australian Government's National Dioxin Program (NDP), Pacific Air & Environment (PAE) was commissioned by the Australian Government Department of the Environment and Heritage (DEH) to compile an inventory of dioxin[1] emissions to the Australian environment for the calendar year 2002. The inventory is an update to the dioxin emissions inventory, *'Sources of Dioxins and Furans in Australia: Air Emissions - Revised'* (EA, 2002a).

The previous emissions inventory estimated emissions to air of dioxins and furans based on Australian specific data and internationally published dioxin emission factors. The updated inventory includes emissions to air, water and land of dioxins and furans and is based on a prescribed international protocol namely, the '*Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases*' (UNEP[2], 2003) (hereafter referred to as the UNEP Toolkit).

Reservoir sources of dioxins and furans are estimated under a separate cover and are not included in this inventory.

Since the publication of the original inventory, dioxins have become a reportable substance under the National Pollutant Inventory (NPI), a national program designed to provide information on the types and quantities of pollutants emitted by anthropogenic activities throughout Australia. Where possible, data and information from the NPI have been incorporated into the inventory. However, dioxin emissions reported in response to NPI requirements are designated as kilograms per annum (kg/a) whereas under the UNEP protocol emissions are reported on a mass toxic equivalence per year (g TEQ/a). Any comparison between data generated by the NPI and data provided in the dioxins inventory would require the emissions to be converted from mass (kg) to mass toxic equivalence (g TEQ), or vice versa.

The methodology used to compile this inventory follows the UNEP Toolkit guidelines and was performed as follows:

- Dioxin emission sources to air, water and land were identified in accordance with the classification provided in the UNEP Toolkit
- Activity data were collected on a national basis (e.g. material throughput, production data) from publicly available information sources for each emission source category
- Dioxin emission factors presented in the UNEP Toolkit judged suitable for Australian conditions were identified for each emission source category
- Dioxin emissions were estimated based on default UNEP emission factors and publicly available, nationally based, source activity data (i.e. this inventory is not a facility based inventory. Estimates of dioxin emissions were generated on a national level)

[1] The term 'dioxins' refers to all polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). The term "dioxin" or "dioxins" is used throughout this report as a proxy for either the full nomenclature or the shortened acronyms.
[2] United Nations Environment Programme

- Default emission estimates and report sections were supplied to industry peak bodies and government agencies for review and comment
- Estimated dioxin emissions were updated based on the response from industry peak bodies and government agencies.

Where possible, an estimate has been made of the possible range of dioxin emissions from each emission source category. The estimate of the range of dioxin emissions from each emission source category is based on the following:

1. In instances where emission testing data and specific process information are not available, the highest and lowest UNEP emission factors are used to estimate the range of dioxin emissions. The average between the high (H) and low (L) emission factor is used to generate a best estimate (BE) of dioxin emissions from the emission source category.
2. In instances where dioxin measurement data are available, the highest and lowest measured dioxin concentration is used to derive the high and low emission estimate. The median dioxin concentration is used to estimate the best estimate of dioxin emissions from the emission source category.

The estimate of the range of dioxin emission are 1.4 g TEQ/annum to 1,780 g TEQ/annum for air, water and land.

The preparation of this inventory and sources of dioxin emissions are categorised as follows (as prescribed in the UNEP Toolkit):

1. Waste incineration
2. Ferrous and Non-Ferrous Metal Production
3. Power Generation and Heating
4. Mineral Products
5. Transport
6. Uncontrolled Combustion Processes
7. Production of Chemicals and Consumer Goods
8. Miscellaneous
9. Disposal/Landfill.

Table ES1 presents summary dioxin emission estimates for each category included in the inventory.

The category with the highest estimated emission is uncontrolled combustion (i.e. biomass burning, waste burning and accidental fires). Uncontrolled combustion is estimated to contribute to nearly 70% of total emissions to air and over 80% of total emissions to land. Disposal and landfilling is estimated to be the largest source of dioxin emissions to water, contributing over 75% of total emissions.

Based on Table ES1 uncontrolled combustion processes, which are significantly influenced by emissions from grass fires, contribute approximately 75% of all emissions in Australia. This high estimate results from the combustion of a large mass under uncontrolled conditions associated with higher dioxin formation potential.

The other major emission categories, in order of decreasing emissions, are:

1. Ferrous and non ferrous metal production
2. Production of chemicals and consumer goods
3. Power generation and heating
4. Disposals/Landfilling
5. Waste Incineration.

Table ES1 Summary of dioxin emissions to air, water and land in Australia for 2002

Source Categories	AIR		WATER		LAND	
	Best estimate (g TEQ/annum)	Total Contribution to Air Emissions (%)	Best estimate (g TEQ/annum)	Total Contribution to Water Emissions (%)	Best estimate (g TEQ/annum)	Total Contribution to Land Emissions (%)
Waste Incineration	6.5	1.30	0.36	10.58	21.9	1.72
Ferrous and Non-ferrous Metal Production	112	22.45	0.02	0.44	44.4	3.48
Power Generation and Heating	35	7.05	0.00	0.00	31.8	2.49
Mineral Products	1.9	0.37	0.00	0.00	0	0.00
Transportation	9.1	1.83	0.00	0.00	0	0.00
Uncontrolled Combustion Processes	330	66.84	0.00	0.00	1030	80.75
Production of Chemicals and Consumer Goods	0.43	0.09	0.43	12.64	110	8.40
Miscellaneous	0.31	0.06	0.00	0.00	0.15	0.01
Disposal/Landfilling	0.00	0.00	2.61	76.34	40.3	3.15
TOTAL	**500**	**100**	**3.42**	**100**	**1,300**	**100**

Table ES2 summarises the information from Table ES1 by subcategory. Only the top 25 emitters are included in Table ES2 as emissions produced by the remaining subcategories become insignificant (Total 0.9 g TEQ/year over 26 subcategories).

Table ES2 Emission estimates by subcategory - top 25 emitters

Source Category	Annual Estimated Release (g TEQ/annum)			
	Air	Water	Land	Total [a]
Biomass burning	240	0	1,020	1,270
Pulp and paper production	0.4	0.4	110	110
Waste burning and accidental fires	88	0	8.7	97
Zinc production	50	0	0	50
Fossil fuel power plants	14.3	0	27.7	42.0
Aluminium production	4.45	0	31.80	36.26
Sewage and sewage treatment	0	0.9	33	34
Metal ore sintering	32	0	0	32
Medical waste incineration	6.39	0.36	21.9	28.7
Household heating and cooking with biomass	20.2	0	1.6	21.8
Iron and steel production plants	20.3	0	0.03	20.3
Copper production	1	0	13	14
Composting	0	0	7.3	7.3
Diesel engines	5.4	0	0	5.4
Other non-ferrous metal production	4	0	0	4
Heavy oil fired engines	3	0	0	3
Domestic heating and cooking with fossil fuels	0.4	0	2.5	2.9
Open water dumping	0	1.5	0	1.5
Ceramics production	1	0	0	1
Lead production	0.5	0	0	0.5
Cement production	0.48	0	0	0.48
Crematoria	0.3	0	0.15	0.46
4-Stroke Engines	0.3	0	0	0.3
Landfills and waste dumps	0	0.2	0	0.2
2-Stroke engines	0.2	0	0	0.2
Other	0.06	0.05	0.7	0.9
Total	**500**	**3.42**	**1,300**	**1,800**

[a] Total may not exactly equal the sum of emissions to air, water and land due to rounding

Figure ES1, Figure ES2 and Figure ES3 show the estimated dioxin emissions and the range of dioxin emissions from each subcategory included in the inventory to air, water and land, respectively.

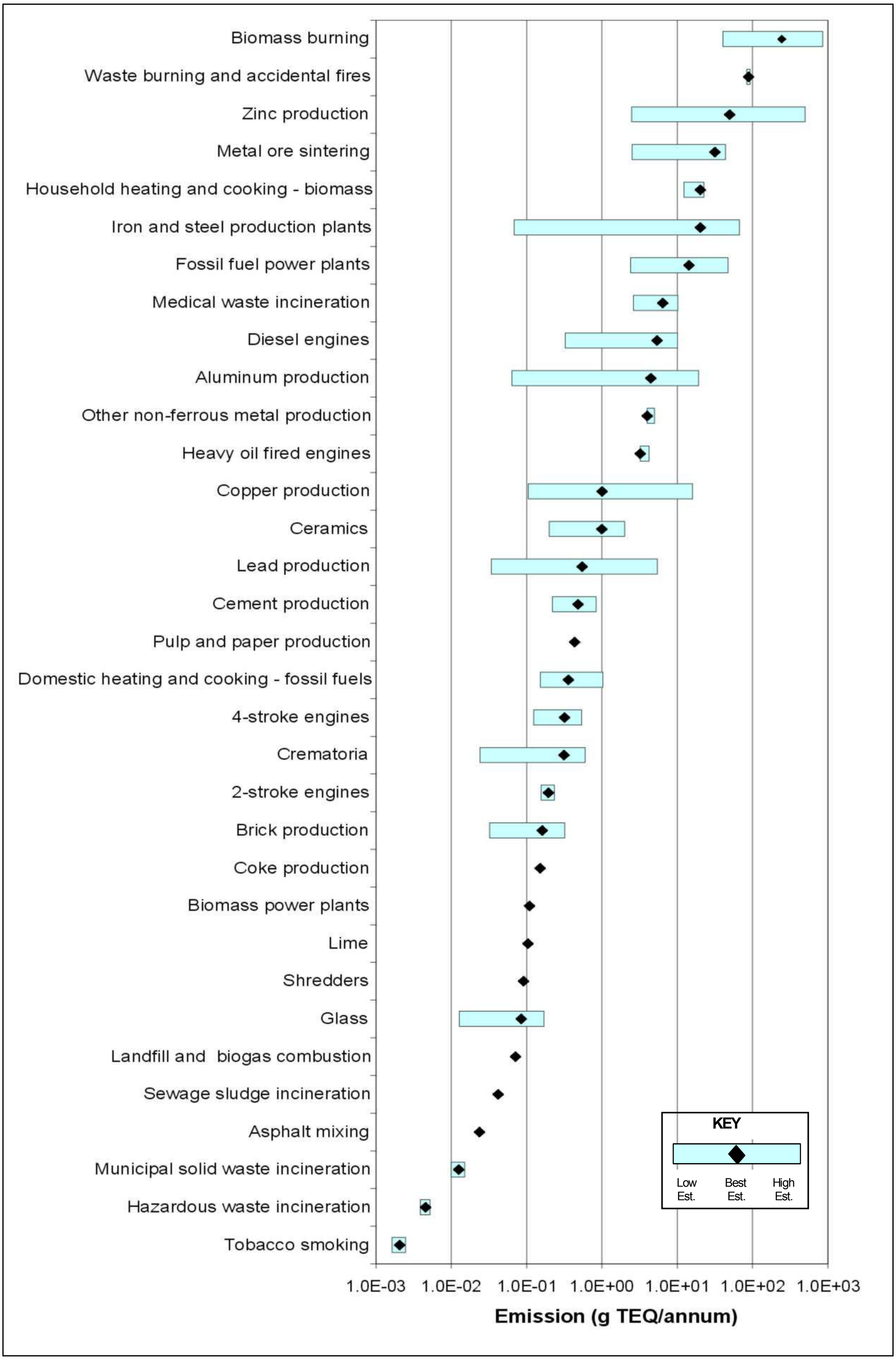

Figure ES1 Estimated Dioxin Emissions to Air, Australia, 2002

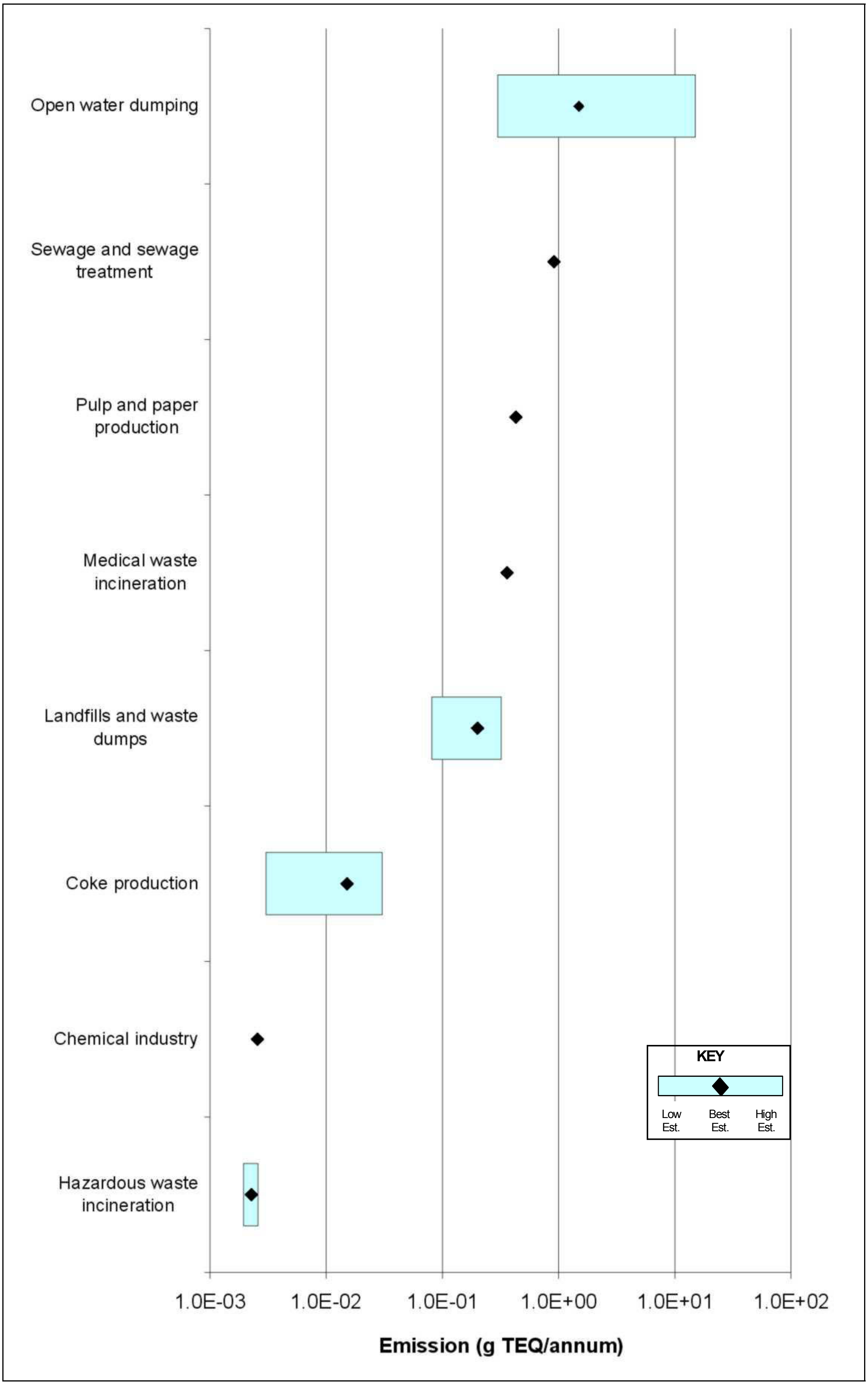

Figure ES2 Estimated Dioxin Emissions to Water, Australia, 2002

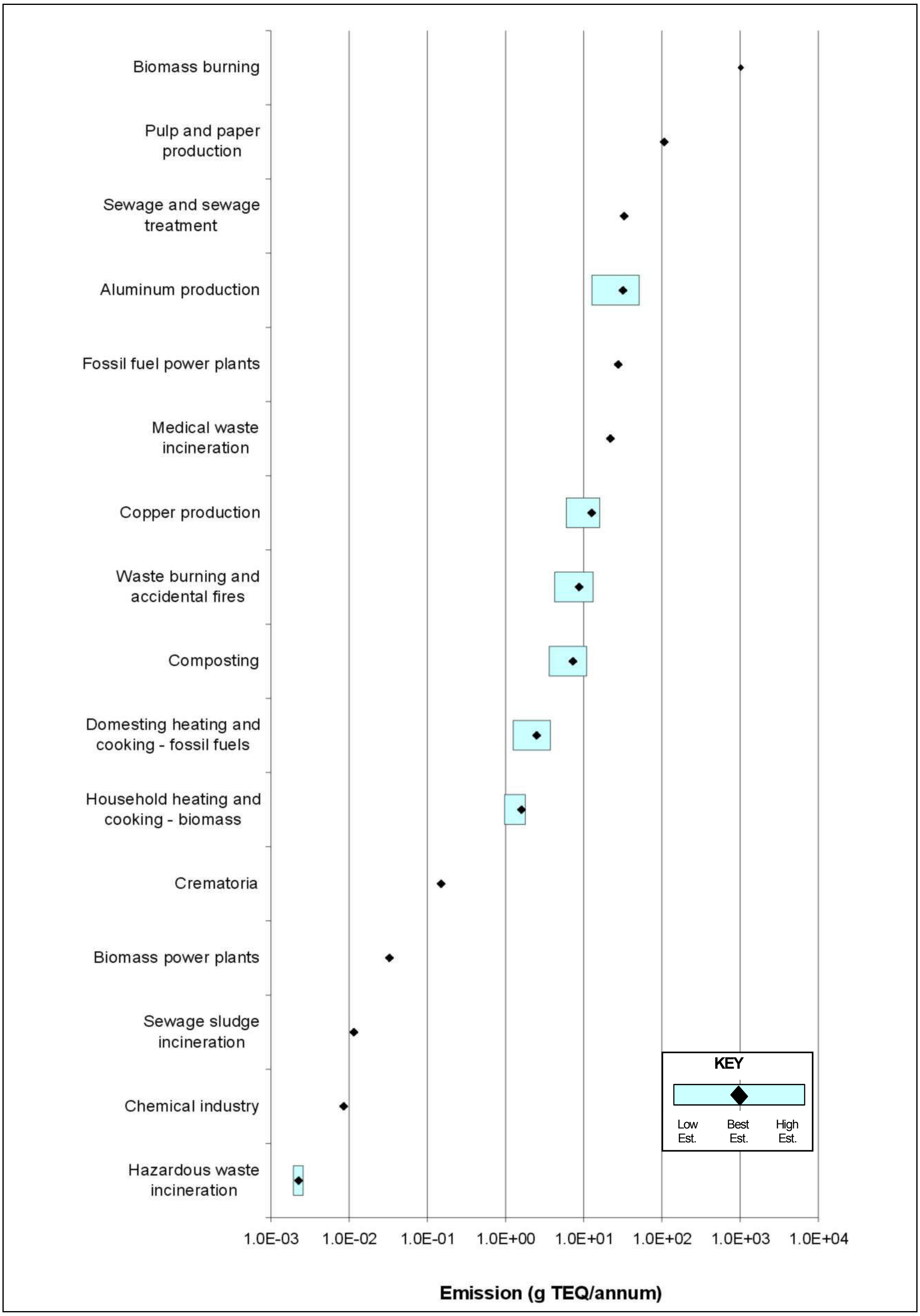

Figure ES3 Estimated Dioxin Emissions to Land, Australia, 2002

The limitations of the study are discussed below:

- The most significant limitation is the lack of source test data for Australian sources, resulting in a heavy reliance on default UNEP Toolkit emission factors based on international dioxin measurement data. Emission factors as a tool for estimating emissions are inherently prone to uncertainties as they are typically based on limited testing of a source population. When applying these international emissions data to Australian sources this uncertainty is increased due to potential differences in process technologies, operating conditions and practices and pollution control equipment
- In addition to the above point, some UNEP Toolkit emission factors were originally derived using assumed conversion factors to supplement data gaps. Examples of this include assumed fuel heat values, densities and flue gas conversion rates (i.e. m^3/tonne) to derive emission factors. This adds further to the uncertainties in the original emission factors
- The emission factors for a large number of sources span several orders of magnitude. This is indicative of the potentially large variations that are observed within a particular emission source category. With such large ranges it becomes difficult to identify significant dioxin contributors, particularly if the upper bound indicates that the source may be significant, while the lower bound indicates a minor contribution. As the estimated emission ranges indicate, a source thought to be significant may in fact be quite minor. Better source characterisation and source test data will enable greater confidence in smaller ranges
- Some source categories may have such variable process technologies, operational conditions etc. that it may be difficult to reliably predict emissions from these sources using limited data. Better characterisation of industry will enable the identification of these industry types. Industries where little variation is encountered could perhaps base emission factors upon more limited test data. This type of characterisation would initially be important for sources considered potentially large emitters
- Emission factors for many industries are based on test data taken during very short sample periods. The emission results are likely to be reflective of relatively good combustion and operational practice and therefore may not be indicative of likely emissions during process upsets and/or abnormal operation.

Considering these limitations, it is stressed that the emission estimates as determined by this study are **INDICATIVE** only of the likely dioxin releases by various sources in Australia. The estimates have been developed based on the best information currently available.

Glossary/Abbreviations

°C	Degree Celsius
µg	microgram (10^{-6} grams)
a	Annum
AAPA	Australian Asphalt Pavement Association
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ADt	Air Dried tonne
AIHW	Australian Institute of Health and Welfare
ANZSIC	Australian & New Zealand Standard Industrial Classification
APIC	Australian Paper Industry Council
BE	Best Estimate
CBPI	Clay Brick and Paver Institute
CFA	Country Fire Authority
CIF	Cement Industry Federation
CSIRO	Commonwealth Scientific & Industrial Research Organisation
DEH	Department of the Environment & Heritage
DITR	Department of Industry, Tourism and Resources
ECD	Ethylene Chlorine or 1,2-dichloroethane
ESAA	Electricity Supply Association of Australia
FBC	Fluidised Bed Combustor
g	gram
GJ	Gigajoule (10^9 Joules)
GWh	Gigawatt hour
H	High Estimate
HFO	Heavy Fuel Oil
kg	kilogram (10^3 grams)
L	Low Estimate
MCA	Minerals Council of Australia
MHF	Multiple Hearth Furnace
MJ	Megajoule (10^6 joules)
MSW	Municipal Solid Waste
Mt	Megatonne (10^6 tonnes)
MW	Medical Waste
NA	Not Applicable

ND	No Data
NDP	National Dioxins Program
NEPM	National Environment Protection Measure
ng	nanogram (10^{-9} grams)
NGGI	National Greenhouse Gas Inventory
NGGIC	National Greenhouse Gas Inventory Committee
Nm^3	Normal cubic metre (Temperature = 0 °C, Pressure = 1 atmosphere)
NPI	National Pollutant Inventory
NSWFB	New South Wales Fire Brigade
PAE	Pacific Air & Environment
PCB	Polychlorinated Biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDD/F	Polychlorinated dibenzo-p-dioxins & Polychlorinated dibenzo-p-furans
PCDF	Polychlorinated dibenzo-p-furans
PCP	Pentachlorophenol
pg	picogram (10^{-12} grams)
PJ	Petajoule (10^{15} joules)
POPs	Persistent Organic Pollutants
PVC	Polyvinyl Chloride
SWERF	Solid Waste to Energy Recycling Facility
t	tonne
TCDD	Tetrachlorodibenzo-p-dioxin
TEF	Toxicity Equivalency Factor
TEQ	Toxic Equivalent
TJ	Terajoule (10^{12} Joules)
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
VCM	Vinyl Chloride Monomer
VOCs	Volatile Organic Compounds

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Tables

1. Introduction

As part of the Australian Government's National Dioxin Program (NDP), Pacific Air & Environment (PAE) was commissioned by the Department of the Environment and Heritage (DEH) to compile an inventory of dioxin[3] emissions to the Australian environment for the calendar year 2002. The inventory is an update to the dioxin emissions inventory, *'Sources of Dioxins and Furans in Australia: Air Emissions – Revised'* (EA, 2002a).

The previous emissions inventory estimated emissions to air of dioxins and furans based on Australian specific data and internationally published dioxin emission factors. The updated inventory includes emissions to air, water and land of dioxins and furans and is based on a prescribed international protocol namely, the '*Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases*' (UNEP[4], 2003) (hereafter referred to as the UNEP Toolkit).

Since the publication of the original inventory, dioxins have become a reportable substance under the National Pollutant Inventory (NPI), a national program designed to provide information on the types and quantities of pollutants emitted by anthropogenic activities throughout Australia. Where possible, data and information from the NPI have been incorporated into the inventory. However, dioxin emissions reported in response to NPI requirements are designated as kilograms per annum (kg/a) whereas under the UNEP protocol emissions are reported on a mass toxic equivalence per annum (g TEQ/a). Any comparison between data generated by the NPI and data provided in the dioxins inventory would require the emissions to be converted from mass (kg) to mass toxic equivalence (g TEQ), or vice versa.

The UNEP Toolkit was developed to assist countries in identifying sources and estimating releases of dioxins and furans. A further aim of the toolkit is to provide a common approach to the preparation of dioxin and furan emission inventories, allowing representative comparison of inventories prepared in different countries. Current inventories are generally not directly comparable, as there is no internationally established listing of dioxin sources.

The UNEP Toolkit was used to compile this dioxin emissions inventory to air, land and water.

A number of polychlorinated biphenyls (PCBs) are also reported to exhibit dioxin-like behaviour. However, very little information is currently available on emission factors for dioxin-like PCBs, and consequently dioxin-like PCB emissions are not included in this inventory.

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[3] The term 'dioxins' refers to all polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). The term "dioxin" or "dioxins" is used throughout this report as a proxy for either the full nomenclature or the shortened acronyms.
[4] United Nations Environment Programme.

1.1 Scope and Objectives

The objective of the inventory is to:

1. Identify the principal sources of emission air, land, water in Australia
2. Quantify these emissions on the basis of reported information
3. Prepare an inventory of dioxin emissions for the calendar year 2002.

This report provides an estimate of dioxin emissions to air, land and water in Australia during the calendar year 2002.

This project was conducted as a ‘desk-top’ study using a combination of default emission factors provided by UNEP and Australian industry data where available.

This inventory has been prepared with the aid of the methodology and suggested emission factors contained in the UNEP Toolkit. The approach and methodology are described in Section 2 of this report.

This inventory addresses only direct releases and transfers to air, water and land. Releases to land include the deposit of waste in landfills. The inventory has not attempted to separate land emissions data into:

a) those materials that are spread or deposited on land and subject to dispersion and dilution by natural processes
b) those wastes which contain dioxins that are disposed of in landfills.

2. Background information on dioxins

A dioxin is any compound containing the dibenzo-p-dioxin nucleus, while a furan is any compound containing the dibenzofuran nucleus. The general formulae for each of these compounds are presented in Figure 2.1.

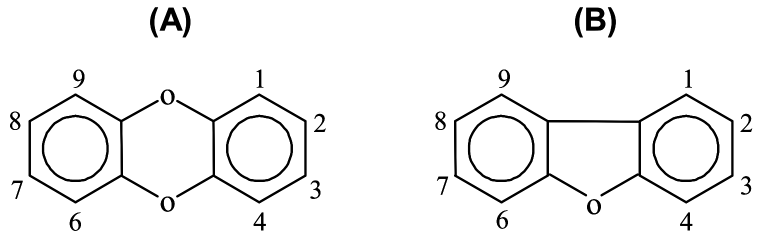

Figure 2.1 General Formulae of Dioxins and Furans

Each of the positions numbered 1 through 4 and 6 through 9 can be substituted with a chlorine atom. Each individual compound resulting from this is referred to as a congener. Each specific congener is distinguished by the number and position of chlorine atoms around the aromatic nucleus. In total, there are 75 possible polychlorinated dibenzo-p-dioxin (PCDD) congeners and 135 possible polychlorinated dibenzo-p-furan (PCDF) congeners.

Each PCDD/F congener has different physical, chemical and toxicological properties. Of the 210 PCDD/F congeners, 17 have been identified as posing significant risk to human health, with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) being identified as the most toxic compound.

PCDDs and PCDFs are not produced intentionally, but are released to the environment from a variety of industrial discharges, combustion processes and by-products in various chemical formulations (Buckland et al, 2000). Almost all 210 individual congeners have been identified in emissions from thermal and industrial processes and consequently PCDD/PCDF are found as mixtures of individual congeners in environmental matrices such as soil, sediment, air, and plants and lower animals (UNEP, 1999). PCDD/PCDF, particularly the higher chlorinated, are poorly soluble in water, have a low volatility, and adsorb strongly to particles and surfaces (UNEP, 1999). Thus, PCDD/PCDF can hardly be identified in water and are immobile in soils (UNEP, 1999). Especially, the 2,3,7,8-chlorine substituted PCDD/PCDF are extremely stable in the environment and bioaccumulate in fatty tissues of animals and humans (UNEP, 1999).

Historically the production and use of chloro-organic chemicals have been major sources of PCDDs and PCDFs in the environment (UNEP, 1999; Buckland et al, 2000). However, the main source of emissions identified in many industrialised countries in recent years is combustion processes, particularly poorly controlled or uncontrolled combustion sources (UNEP, 1999; Hayes and Marnane, 2000). It is generally accepted that dioxins and furans can be formed in thermal processes where chlorine containing substances are burned together with carbon and a suitable catalyst in the presence of excess air or oxygen (UNEP, 1999). Dioxin and furan formation also tends to occur in the zone when combustion gases cool from about 450 to 250 °C (de novo synthesis) and not in the combustion chamber (UNEP, 1999).

Human exposure to background contamination with PCDD/PCDF is possible via several routes (UNEP, 1999):

- Inhalation of air and intake of particles from air
- Ingestion of contaminated soil
- Dermal absorption
- Food consumption.

In 1990, a WHO working group concluded that 90% of the daily dioxin intake (from background contamination) results from ingestion, though it is thought that most dioxins enter the food chain from the air (UNEP, 1999).

2.1 Toxicity Equivalency Concepts

Many regulatory agencies have developed so-called Toxicity Equivalency Factors (TEF) for risk assessment of complex mixtures of PCDD/F. The TEFs are based on acute toxicity values from *in vivo* (inside a living organism) and *in vitro* (outside a living organism) studies. This approach is based on the evidence that there is a common, receptor-mediated mechanism of action for these compounds. However, the TEF approach has its limitations due to a number of simplifications. Although the scientific basis cannot be considered as solid, the TEF approach has been developed as an administrative tool and allows conversion of quantitative analytical data for individual PCDD/F congeners into a single Toxic Equivalent (TEQ). TEF particularly aid in expressing cumulative toxicity of complex PCDD/F mixtures as one single TEQ value. It should be noted that TEFs are interim values and administrative tools for order of magnitude estimates. They are based on present state of knowledge and should be revised as new data becomes available (UNEP, 2003).

Today there are two schemes applied: the older one are the TEFs established by a NATO/CCMS Working Group on Dioxins and Related Compounds as International Toxicity Equivalency Factors (I-TEF) (NATO/CCMS, 1988; Kutz et al., 1990) and the most recent scheme established by a WHO/IPCS working group, who re-evaluated the I-TEFs and established a new scheme (UNEP, 2003). The two schemes are presented in Table 2.1. Only the TEFs for human and mammalian risk assessment are shown although the WHO/IPCS group also included *non-ortho* and *mono-ortho* substituted polychlorinated biphenyls (PCB) into the TEF and established separate TEFs for fish and birds (UNEP, 2003).

Table 2.1 International Toxicity Equivalency Factors (I-TEF's) for dioxins. [a,b,c,d]

Compound	I-TEF	WHO-TEF
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDD	0.5	**1**
1,2,3,4,7,8-HxCDD	0.1	0.1
1,2,3,6,7,8-HxCDD	0.1	0.1
1,2,3,7,8,9-HxCDD	0.1	0.1
1,2,3,4,6,7,8-HpCDD	0.01	0.01
OCDD	0.001	**0.0001**
2,3,7,8-TCDF	0.1	0.1
1,2,3,7,8-PeCDF	0.05	0.05
2,3,4,7,8-PeCDF	0.5	0.5
1,2,3,4,7,8-HxCDF	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01
OCDF	0.001	**0.0001**

[a] Source: UNEP (2003)
[b] T – Tetra (four chlorine atoms attached)
Pe – Penta (five chlorine atoms attached)
Hx – Hexa (six chlorine atoms attached)
Hp – Hepta (seven chlorine atoms attached)
O – Octa (eight chlorine atoms attached)
CDD - Chlorinated Dibenzo-p-Dioxins
CDF - Chlorinated Dibenzo-p-Furans
[c] For all non-2,3,7,8-substituted congeners, no TEF has been assigned
[d] Numbers in bold represent TEFs which have been changed by WHO from I-TEFs

In this emissions inventory, source strengths are estimated as annual mass flow rates of dioxins expressed in grams TEQ of PCDD and PCDF released per annum. Most concentrations of PCDD/F in the published literature and limit values in legislation are presented as I-TEQ (International Toxic Equivalents) using the NATO toxicity equivalency factors (I-TEF) established in 1988 (NATO/CCMS, 1988). The Stockholm Convention, however, requires to utilise state-of-the-art Toxic Equivalency Factors, which presently are the WHO-TEFs. The UNEP Toolkit states the difference between the I-TEFs and mammalian WHO-TEFs are minor and insignificant for the purposes of the Toolkit for estimating PCDD and PCDF emissions (UNEP, 2003). As previously mentioned, this inventory addresses emissions of PCDD and PCDF only and does not include emissions from dioxin-like PCB. Furthermore, the emission factors and estimates presented in this inventory and in the UNEP Toolkit represent order of magnitude release estimates. Therefore, the difference between the I-TEFs and WHO-TEFs for PCDD and PCDF are insignificant.

3. Methodology

The are five steps included in the application of the UNEP Toolkit are as follows:

1. Application of a screening matrix to identify main source categories
2. Checking of subcategories to identify existing activities and sources in the country
3. Gathering of detailed information on the processes and classifying processes into similar groups by applying the Standard Questionnaire
4. Quantification of identified sources with default/measured emission factors
5. Nation-wide application to establish full inventory and report results using guidance given in the standard format.

Table 3.1 provides an overview of the UNEP main source and subcategories.

The methodology used to compile this inventory follows the UNEP Toolkit guidelines and was performed as follows:

- Dioxin emission sources to air, water and land were identified in accordance with the classification provided in the UNEP Toolkit
- Activity data were collected on a national basis (e.g. material throughput, production data) from publicly available information sources for each emission source category
- Dioxin emission factors presented in the UNEP Toolkit judged suitable for Australian conditions were identified for each emission source category
- Dioxin emissions were estimated based on default UNEP emission factors and publicly available, nationally based, source activity data (i.e. this inventory is not a facility based inventory. Estimates of dioxin emissions were generated on a national level)
- Default emission estimates and report sections were supplied to industry peak bodies and government agencies for review and comment
- Estimated dioxin emissions were updated based on the response from industry peak bodies and government agencies.

Information was requested from selected industrial peak bodies and facilities on activity and emissions statistics for 2002. As the information was requested on a voluntary basis, this relied heavily on the cooperation of the industrial peak bodies and facilities. Where emissions data were made available, revised emission estimates were calculated based on these data to allow comparison with the toolkit estimates. The revised estimates based on measured data were considered more representative that the UNEP Toolkit based estimates and these emission estimates are used in the final total estimated dioxin emissions for 2002.

Prior to the completion of the report, 30 of the top 50 facilities on the National Pollutant Inventory were contacted and information was requested regarding dioxin measurement

data from each facility. Excerpts of the report were provided to the following industrial sectors:

- Cement industry
- Chemical industry
- Crematoria
- Ferrous and non-ferrous metal production
- Mineral products
- Power generation
- Petroleum industry
- Sewage and sewage treatment
- Waste disposal.

Industry bodies were requested to respond with any specific comments on the inventory for their given industry sector. In particular, industry bodies were requested to confirm activity data used in the emission estimates and supply dioxin emissions data if available.

UNEP recommend that the inventory should include the following information:

- A listing of all process subcategories that are carried out in the country
- The activity statistic for each category and a short description of how this was found or estimated
- The range of emission factors by process subcategory and the overall range of potential emissions (mass flow multiplied by low and high emission factors)
- More precise country estimates, where available, shown separately from the potential range of releases made using the UNEP Toolkit default emission factors, along with an explanation of how the result was achieved
- Potential emission ranges shown as a bar chart for each source based on the default emission factors
- In country estimates shown as points or ranges overlaid on the potential range.

This report presents the following information for each subcategory that is applicable to Australia:

- A brief description of the subcategory as it applies to Australia
- Available dioxin emission and subcategory activity data
- An estimate of dioxin emissions in 2002 based on the UNEP Toolkit methodology and emission factors
- A revised dioxin emission estimate based on dioxin measurement data where available.

Table 3.1 outlines the UNEP categories and subcategories of dioxin emissions included in this inventory.

Table 3.1 UNEP Main Source Categories and Subcategories

Waste Incineration	**Transport**
Municipal solid waste incineration	4-Stroke engines
Hazardous waste incineration	2-Stroke engines
Medical waste incineration	Diesel engines
Light-fraction shredder waste incineration	Heavy oil fired engines
Sewage sludge incineration	**Uncontrolled Combustion Processes**
Waste wood and waste biomass incineration	(Clean) Biomass burning
Combustion of animal carcasses	Waste burning and accidental fires
Ferrous and Non-Ferrous Metal Production	**Production and Use of Chemicals and Consumer Goods**
Iron ore sintering	Pulp and paper mills
Coke production	Chemical industry
Iron and Steelmaking	Petroleum industry
Iron foundries	Textile plants
Copper production	Leather plants
Aluminium production	**Miscellaneous**
Lead production	Drying of biomass
Zinc production	Crematoria
Brass production	Smoke houses
Magnesium production	Dry cleaning
Other non-ferrous metal production	Tobacco smoking
Shredders	**Disposal/Landfills**
Thermal wire reclamation	Landfills and waste dumps
Power Generation & Heating	Sewage and sewage treatment
Fossil fuel power plants	Composting
Biomass power plants	Open water dumping
Landfill, biogas combustion	Waste oil disposal (non-thermal)
Household heating and cooking (biomass)	
Domestic heating (fossil fuels)	
Production of Mineral Products	
Cement production	
Lime production	
Brick production	
Glass production	
Ceramics production	
Asphalt mixing	

3.1 Format of Emission Inventory Report

The following sections detail estimated emissions for each of the subcategories as identified in Table 3.1. For all relevant sectors a brief description is presented of the category, and any other relevant information is also detailed. If the sector is not relevant in an Australian context, this is stated and no information on dioxin emissions from such sources is presented. Those interested in these sectors should refer to the UNEP Toolkit.

Secondly, details are discussed of activity data available for the sector that can be used to generate dioxin emission estimates using available emission factors. In some sectors the available activity statistics must be manipulated to generate statistics compatible with the available emission factor units.

Thirdly, the activity statistics are employed with the UNEP Toolkit emission factors to generate a dioxin emission estimate. A range of emission estimates is normally provided, with a low, high and best estimate emission presented. The range may be based on a range of emission factors given in the toolkit or on a margin of error estimated based on estimated variances in approximate activity statistics provided or calculated.

If dioxin monitoring data were available for a particular sector, these may be used to help generate a revised estimate. However, as only a small number of measurements are generally available for a given sector, the toolkit factors may still be used to aid in the generation of a potential emission range. Using the activity data and the dioxin emission data for a given sector allows calculation of a revised emission factor that can be compared to the toolkit emission factors. As little dioxin monitoring data are available for the identified sectors in Australia, many of the sectors do not include a revised estimate. Where a revised estimate has been generated, this value, rather than the simple toolkit based emission estimate is used in calculating total dioxin emissions to a given media as presented in the summary tables.

4. Estimates of Dioxin and Furan Emissions 2002

4.1 Main Category 1 – Waste Incineration

Waste incineration is the combustion of waste materials in a furnace and does not apply to open or domestic burning (UNEP, 2003). Waste incineration is described by the following UNEP subcategories:

- Municipal solid waste incineration (Section 4.1.1)
- Hazardous waste incineration (Section 4.1.2)
- Medical waste incineration (Section 4.1.2)
- Light fraction shredder waste incineration (Section 4.1.3)
- Sewage sludge incineration (Section 4.1.4)
- Waste wood and waste biomass incineration (Section 4.1.5)
- Animal carcass incineration (4.1.6).

4.1.1 Municipal Solid Waste Incineration

Municipal Solid Waste (MSW) incineration is the combustion of municipal waste for the purpose of reducing the volume of municipal waste disposed in landfills.

Large scale municipal waste incineration is not performed in Australia. However, a similar process was identified at one facility in Australia. At this facility biomass pyrolysis is performed whereby the pre-screened municipal solid waste is heated inside a sealed unit preventing the waste from combusting. The heat drives off the moisture and volatile components of the waste, resulting in mass reduction. The gas generated is captured for combustion to produce electricity. Despite not being an incinerator the facility has been included in this category because it performs a similar function.

4.1.1.2 4.1.1.1 Available Activity Data

No activity data (i.e. the mass of municipal waste processed) was available for this facility. However, the facility has a licence to process 30,000 tonnes of waste per annum (Brightstar, 2003b). Therefore, the estimated material processed used to estimate total dioxin emissions is 25,000 tonnes.

Due to the uncertainty in the quantity of waste treated, the following range of waste material treated is employed in the dioxin estimates:

- Lower bound: 20,000 tonnes
- Upper bound: 30,000 tonnes.

It is noted that this facility ceased operation in 2003.

4.1.1.2 Toolkit Estimate of Emissions

The UNEP Toolkit describes four classes of emission factors ranging from Class 1 (low technology combustion with no air pollution control systems) to Class 4 (high technology combustion with sophisticated air pollution control systems).

The facility has published dioxin concentrations of 0.03 ng TEQ/Nm^3 (@ 11% O_2) (Brightstar, 2003a). The UNEP Toolkit Class 4 emission factor should be used if a regulatory value of 0.1 ng TEQ/Nm^3 (@ 11% O_2) is strictly enforced and the facility in question can be assumed to be in compliance (UNEP, 2003). Therefore, the facility will be treated as a high technology combustion with sophisticated air pollution control system facility, and the UNEP Toolkit Class 4 emission factor for MSW incinerators was used to estimate PCDD/F emissions to air.

The residue from this process is taken either to landfills or used as organic mulch. Therefore, some dioxin releases would occur through the residue formed in this process. The UNEP Toolkit provides emission factors for fly ash and bottom ash as residue. However, as the facility burns biogas (Brightstar, 2003a) and not municipal waste, there would be no residue in the form of fly ash or bottom ash expected from this facility. Dioxin emissions from disposal of the dried municipal waste are accounted for in Section 4.9 – Disposal/Landfills of this inventory.

Table 4.1 provides a summary of the dioxin emission factors that apply to Municipal Solid Waste Incineration.

Table 4.1 Emission Factors – Municipal Solid Waste Incineration [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Municipal Solid Waste Incineration	ND	0.5	ND	NA	NA	NA	NA	NA	NA

[a] Source UNEP, 2003
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.2 provides the Toolkit emission estimate for releases to air, water and land. The high and low estimates are based on the estimated range of material treated.

Table 4.2 UNEP Toolkit Estimate of Emissions – Municipal Waste Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Municipal Solid Waste Incineration	0.010	0.013	0.015	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.2 Hazardous Waste Incineration

Hazardous waste incineration is the combustion of wastes and residues that contain hazardous material, not including hospital waste, which is treated in a separate section.

Only a single facility was identified in this category. This facility operates a vertical, down-fired furnace burning natural gas or recovered fuel with wet (caustic) scrubbing to remove acid gases (Unilabs, 2001).

High temperatures and the presence of chlorinated hydrocarbons in hazardous waste make the incineration of hazardous waste susceptible to dioxin formation. Once formed, the flue gas stream carries the dioxins to the caustic scrubber employed to reduce emissions of particulates and dioxins (resulting in an accumulation of dioxins in the scrubber residue) (Unilabs, 2001).

4.1.1.2 Available Activity Data

With regard to the available activity data, i.e. the amount of hazardous waste incinerated in Australia in the year 2002, the latest activity data available is from the 2003 period, where the maximum hazardous waste incinerated was 2,000 tonnes and the minimum hazardous waste incinerated was 1,500 tonnes (personal communication. NSW Waste Services, 2004). The average value of 1,750 tonnes of hazardous waste incinerated has been taken as the best estimate for the activity data.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit describes four classes of emission factors ranging from Class 1 (low technology combustion with no air pollution control systems) to Class 4 (high technology combustion with sophisticated air pollution control systems).

The hazardous waste incinerator in Australia is designed to have a dioxin emission limit of less than 0.1 ng/m^3 (@ 11% O_2) (Unilabs, 2001) and is of relatively modern design with a sophisticated air pollution control system installed. Therefore, the Class 4 dioxin emission factors have been chosen to estimate dioxin emissions from hazardous waste incineration.

The UNEP Toolkit provides a discussion on dioxin release to the environment via water and solid residues rather than a clearly defined set of emission factors based on sector activity. This is due to the fact that the air pollution control devices employed at hazardous waste incinerators vary considerably with many of the larger systems having separate fly-ash collection devices - bag filters or electrostatic precipitators. Fly ash is generally considered to be the most heavily contaminated residue followed by wet scrubbers and possible third stage polishing devices (e.g. catalyser beds).

In Australia there is no data for contaminated aqueous wastes (wet scrubber blow-down) from the hazardous waste incinerator. However, the hazardous waste incinerator in Australia does not have separate collection of fly ash as the wet scrubber removes any entrained fly ash from the exhaust gas stream. In this instance, the predominant dioxin emission is aqueous discharges from the site and/or in surplus wastewater treatment plant sludge.

The UNEP Toolkit concludes its discussion on releases to water and as solid residues stating that in order to produce an estimate in the absence of consolidated residue data, it is reasonable to assume that releases as residues (via disposal of residues to water bodies/landfills) are of the same order of magnitude as releases to air. Therefore, the emission factors used to estimate dioxin emissions from hazardous waste incineration are presented in Table 4.3.

Table 4.3 Emission Factors – Hazardous Waste Incineration [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Hazardous Waste Incineration	ND	0.75	ND	NA	0.38	NA	NA	0.38	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.4 provides the Toolkit emission estimate for hazardous waste incineration releases to air, water and land. The high and low emission estimates are based on the estimated range of material incinerated.

Table 4.4 UNEP Toolkit Estimate of Emissions – Hazardous Waste Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Hazardous Waste Incineration	0.0011	0.0013	0.0015	0.00056	0.00066	0.00075	0.0006	0.0007	0.0008

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

Unilabs (2001) calculated a dioxin emission factor to air based on test data for the Australian hazardous waste incinerator. The dioxin emission factor to air determined was 2.59 µg TEQ/t HW burnt. The derived dioxin emission factor is greater than the UNEP Toolkit Class 4 emission factor to air.

Data on dioxin concentrations in scrubber liquor were not available. Therefore, to develop a revised estimate for releases to water and land, the methodology recommended in the UNEP Toolkit was used, assuming that releases to water and land via scrubber blow-down is the same order of magnitude as releases to air.

The derived emission factors based on measurement data (for air) and the UNEP assumption (for water and land) are presented in Table 4.5.

Table 4.5 Revised Emission Factors – Hazardous Waste Incineration [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Hazardous Waste Incineration	ND	2.59	ND	NA	0.38	NA	NA	0.38	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.6 provides the revised emission estimate for hazardous waste incineration emissions to air, water and land.

Table 4.6 UNEP Toolkit Estimate of Emissions – Hazardous Waste Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Hazardous Waste Incineration	0.0039	0.0045	0.0052	0.0019	0.0023	0.0026	0.0019	0.0023	0.0026

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.1.2 Medical Waste Incineration

Medical waste (MW) incineration is the combustion of all wastes generated from medical activity including but not limited to, hospitals, medical doctor, dentist or any other physician (UNEP, 2003). A MW incinerator generally has two chambers for combustion, the primary chamber where waste is heated and volatilised and a secondary chamber where combustion is completed (Unilabs, 2001).

Medical waste includes both infectious and non-infectious wastes. The types of materials burned at medical waste incinerators include (USEPA, 1995b; Unilabs, 2001):

- medical hospital waste
- quarantine waste
- security waste
- illicit materials and drugs
- pharmaceuticals
- miscellaneous regulated wastes
- veterinary waste
- crematorium waste
- waste generated at research facilities.

These medical wastes are typically incinerated for the following reasons (USEPA, 1995b):

- to render the waste innocuous
- a reduction in the waste volume
- to reduce the mass of the waste.

As for municipal waste incineration the composition of medical waste can vary considerably, resulting in highly variable emissions.

The three main types of medical waste incinerators are:

1. controlled-air incinerators (also known as starved-air)
2. excess-air incinerators
3. rotary kiln incinerators.

4.1.1.2 Available Activity Data

Sixteen biomedical waste incinerators in Australia were identified in the Unilabs study (2001) for Environment Australia. Seven represent hospital incinerators and nine are privately operated. The identified medical waste incinerators are summarised in Table 4.7.

Table 4.7 Identified Medical Incinerators Operating in Australia [a]

Incinerator Description	Number operating in Australia
Controlled air incinerator with wet scrubbing air pollution control system	3
Controlled air incinerator with dry air pollution control system	1
Rotary kiln with wet scrubbing air pollution control system	1
Excess air/batch type	1
Incinerators identified but no information available [b]	10

[a] Source: Unilabs (2001)

[b] Of the 10 unknown incinerators it is probable that 50% have ceased operation (Unilabs, 2001)

With regard to the available activity data, i.e. the amount of medical waste incinerated in Australia in the year 2002, the latest activity data available is from the 1998/1999 financial period (1 July 1998 to 30 June 1999). Table 4.8 provides a summary of Australian activity data for Medical Waste Incineration provided in the Unilabs report.

Table 4.8 Medical Waste Incineration Activity Data [a]

Incinerator Description	Age	Emission Factor (tonnes incinerated/annum)
Controlled air incinerator with wet scrubbing system	New	4,800
	Old	1,500
Controlled air incinerator with dry scrubbing system	-	936
Unknown technology but source identified	-	21,000

[a] Source: Unilabs (2001)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit describes four classes of emission factors ranging from Class 1 (uncontrolled batch type combustion with no air pollution control systems) to Class 4 (high technology, continuous combustion with sophisticated air pollution control systems).

Medical waste incinerators identified by Unilabs (2001) as “controlled air incinerator with wet scrubbing system – new” are incinerators with sophisticated air pollution control systems. Therefore, the Class 4 dioxin emission factors have been chosen to estimate dioxin emissions from these incinerators. All other identified medical waste incinerators have good air pollution control systems and are continuous in operation. Therefore, the UNEP Class 3 emission factors have been chosen to estimate dioxin emissions from these incinerators.

Dioxin emissions to water occur when wet scrubbers are employed for the removal of particulate matter and quench water is used to cool ashes (UNEP Toolkit, 2003). Measured concentrations of dioxins in scrubber water after medical waste incinerators

were not available. However, the predominant dioxin emission is aqueous discharges from the site and/or in surplus wastewater treatment plant sludge.

Dry scrubbing air pollution control systems would be expected to emit dioxins to land in the form of residue. The UNEP toolkit provides dioxin emission factors for residue emissions for dry air pollution control systems. The UNEP emission factors are used to estimate emissions to land from medical waste incinerators with dry scrubbing air pollution control systems. It is assumed that the incinerators operating with unknown air pollution control technology have dry air pollution control systems.

The emission factors used to estimate dioxin emissions from medical waste incineration are presented in Table 4.9.

Table 4.9 Emission Factors – Medical Waste Incineration [a, b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Class 3	ND	525	ND	NA	0	NA	ND	920	ND
Class 4	ND	1	ND	ND	75	ND	ND	75	ND

a Source: UNEP (2003)
b L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.10 provides the Toolkit emission estimate for hazardous waste incineration releases to air, water and land.

Table 4.10 UNEP Toolkit Estimate of Emissions – Medical Waste Incineration

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Class 3	-	12.3	-	-	0	-	-	21.6	-
Class 4	-	0.0048	-	-	0.36	-	-	0.36	-
Total	**-**	**12.3**	**-**	**-**	**0.36**	**-**	**-**	**21.9**	**-**

a L = Low Estimate; BE = Best Estimate; H = High Estimate

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

Unilabs (2001) calculated dioxin emission factors to air based on test data received from three medical waste incinerators. Data received represent a total of 20% of medical waste incinerators in Australia, but the data representation is probably greater due to the likelihood that some medical waste incinerator closures have occurred (Unilabs, 2001).

Unilabs used dioxin emission factors for the other twelve incinerators sourced from the report “A Review of Dioxin Emissions in the UK” (Her Majesty’s Inspectorate of Pollution, 1995).

The derived air emission factors based on measurement data and the international report are presented in Table 4.11.

Table 4.11 Air Emission Factors – Medical Waste Incineration [a, b]

Incinerator Description	Age	Emission Factor (µg TEQ/tonne)		
		L	BE	H
Controlled air incinerator with wet scrubbing system	New	-	4.62	-
	Old	-	46.8	-
Controlled air incinerator with dry scrubbing system	-	-	0.462	-
Unknown technology but source identified [b]	-	120	300	480

[a] Source: Unilabs (2001)

[b] Based on emission factors published in Her Majesty's Inspectorate of Pollution (1995). Best estimate emission factor taken to be the average of the high and low emission factors.

No dioxin measurement data were available for water or land emissions from hazardous waste incinerators. Therefore, the UNEP Toolkit estimated emissions to water and land are employed in the inventory.

The revised dioxin emission estimate for medical waste incineration is provided in Table 4.12

Table 4.12 Revised estimate of emissions - Medical Waste Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Medical Waste Incineration	2.61	6.39	10.2	-	0.36	-	-	21.9	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.1.3 Light Fraction Shredder Waste Incineration

Incineration of light fraction shredder waste was not carried out in Australia in 2002.

4.1.4 Sewage Sludge Incineration

Sewage sludge is one of the end products of the wastewater treatment process. The most common methods of sewage sludge disposal are to spread the sludge on land, deposit it in landfills or to incinerate it. This section deals solely with the emissions that result from the incineration of sewage sludge (UNEP, 2003).

Prior to incineration of the sludge, the sewage sludge is typically dewatered until 15-30% solids, at which point it will burn without supplemental fuel. Unburned residual ash is removed from the incinerator on a continuous basis and disposed. Portions of the non-combustible waste, as well as unburned VOCs, are transported from the incinerator through entrainment in the exhaust gas stream. Appropriate exhaust gas control devices reduce emissions of residual VOCs.

Several types of incinerators and incineration technologies are used for sewage sludge incineration, including:

- multiple-hearth furnaces (MHFs)
- fluidised-bed combustors (FBCs)
- electric incinerators

- co-incineration with refuse
- rotary kilns
- high-pressure wet-air oxidation.

4.1.1.2 Available Activity Data

Two sewage sludge incinerators were identified in Australia in the Unilabs (2001) report. One was identified as being a multiple hearth furnace, the other was not identified (Unilabs, 2001).

With regard to the available activity data, i.e. the amount of sewage sludge incinerated in Australia in the year 2002, the latest activity data available is from the 1998/1999 financial period sourced from the Unilabs report (2001). Table 4.13 outlines the available activity data for sewage sludge incineration.

Table 4.13 Sewage Sludge Incineration Activity Data [a]

Incinerator Description Emission Factor	Activity Data (tonnes/year)
Multiple hearth incinerator with wet scrubbing system	13,000
Unknown technology but source identified	10,000

[a] Source: Unilabs (2001)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit describes three classes of emission factors ranging from Class 1 (older furnaces, batch type operation with no or very little air pollution control equipment) to Class 3 (modern state of the art facilities that are continuous and have good technology air pollution control equipment).

The sewage sludge incinerator identified by Unilabs (2001) as "multiple hearth furnace with wet scrubbing system" is an incinerator with a sophisticated air pollution control system. Therefore, the Class 3 dioxin emission factors have been chosen to estimate dioxin emissions from this incinerator. The sewage sludge incinerator with unknown air pollution control technology has been estimated using the Class 2 dioxin emission factors.

Dioxin emission factors describing the dioxin concentration in scrubber effluent from sewage sludge incinerators were not available. However, since the wastewater from wet scrubbers is often treated and reintroduced into the wastewater plant, no dioxins are released from the incinerator to water (UNEP, 2003).

Dioxin emissions to land have been estimated using the UNEP emission factors for residue, assuming that the residue is directly placed onto or mixed with soil.

The emission factors used to estimate dioxin emissions from sewage sludge incineration are presented in Table 4.14.

Table 4.14 Emission Factors – Sewage Sludge Incineration [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Class 2	ND	4	ND	NA	0	NA	NA	0.5	NA
Class 3	ND	0.4	ND	NA	0	NA	NA	0.5	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.15 provides the Toolkit emission estimate for sewage sludge incineration releases to air, water and land.

Table 4.15 UNEP Toolkit Estimate of Emissions – Sewage Sludge Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Class 2	-	0.04	-	-				0.005	
Class 3	-	0.005	-	-				0.007	
Total	**-**	**0.045**	**-**	**-**	**0.00**	**-**		**0.012**	

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.1.1.2 Revised Emissions using Dioxin Measurement Data

Unilabs (2001) calculated a dioxin emission factor to air based on test data received from the multiple hearth sewage sludge incinerator. Unilabs calculated a dioxin emission factor of 0.135 µg TEQ/tonne sewage sludge incinerated. Emission testing data for the sewage sludge incinerator with unknown technology was not provided. Therefore, the UNEP Class 2 dioxin emission factors have been retained in the revised estimate.

No dioxin measurement data were available for water or land emissions from sewage sludge incinerators. Therefore, the UNEP Toolkit emission factors to water and land are employed in the inventory. The revised dioxin emission factors based on measurement data and the UNEP Toolkit are presented in Table 4.16.

Table 4.16 Emission Factors – Sewage Sludge Incineration [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Class 2	ND	4	ND	NA	0	NA	ND	0.5	ND
Class 3	ND	0.135	ND	NA	0	NA	ND	0.5	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

The revised dioxin emission estimate for medical waste incineration is provided in Table 4.17.

Table 4.17 Revised estimate of emissions – Sewage Sludge Incineration [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Sewage Sludge Incineration	-	0.042	-	-	0.00	-		0.012	

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.1.5 Waste Wood And Waste Biomass Incineration

Waste wood and waste biomass incineration is the combustion of waste biomass under controlled conditions that may have been treated or become mixed with treated or contaminated biomass. No information on combustion of contaminated wood is available, and it is understood that wood burned in large wood processing plants is uncontaminated wood. The combustion of clean biomass is covered in Section 4.6.

4.1.6 Animal Carcass Incineration

Incineration of animal carcasses was not carried out in Australia in 2002.

4.2 Main Category 2 – Ferrous And Non-Ferrous Metal Production

This category concerns the recovery of metals from ores and/or scrap. Primary metal production is considered to be those processes that obtain metal for the original ore and secondary metal production are those operations that obtain a refined metal from scrap (UNEP, 2003). Ferrous and non-ferrous metal production has been broken into the following categories:

- Metal ore sintering (Section 4.2.1)
- Coke production (Section 4.1.1.2)
- Iron and steel production and foundries (Section 4.2.3)
- Copper production (Section 4.2.4)
- Aluminium production (Section 4.2.5)
- Lead production (Section 4.2.6)
- Zinc production (Section 4.2.7)
- Brass and bronze production (Section 4.2.8)
- Magnesium production (Section 4.2.9)
- Other non-ferrous metal production (Section 4.2.10)
- Shredders (Section 4.2.11)
- Thermal wire reclamation (Section 4.2.12).

4.2.1 Metal Ore Sintering

This section covers the sintering of metal ores. The sintering process converts fine-sized raw materials, including iron ore, coke breeze, limestone, mill scale, and flue dust, into an agglomerated product, sinter, of suitable size for charging into a blast furnace. The raw materials are sometimes mixed with water to provide a cohesive matrix, and then placed on a continuous, travelling grate called the sinter strand. A burner hood, at the beginning of the sinter strand ignites the coke in the mixture, after which the combustion is self supporting and it provides sufficient heat, 1,300 to 1,480 °C, to cause surface melting and agglomeration of the mix. On the underside of the sinter strand is a series of windboxes that draw combusted air down through the material bed into a common duct, leading to a gas cleaning device. The fused sinter is discharged at the

end of the sinter strand, where it is crushed and screened. Undersize sinter is recycled to the mixing mill and back to the strand. The remaining sinter product is cooled in open air or in a circular cooler with water sprays or mechanical fans. The cooled sinter is crushed and screened for a final time, then the fines are recycled, and the product is sent to be charged to the blast furnaces. Generally, 2.3 tonnes of raw materials, including water and fuel, are required to produce 0.9 tonnes of product sinter (USEPA, 1995c).

Research has shown that dioxin formation in the sintering process occurs at the flame front as hot gases are drawn through the bed with a small portion of *de novo* formation in the gas collectors. Consistency in the operating process has been shown to limit dioxin formation (UNEP, 2003).

4.1.1.2 Available Activity Data

No information regarding the quantity of iron ore sinter produced was found during the literature search. Discussions with the Australian Bureau of Agricultural and Resource Economics (ABARE) indicated that assuming 100% conversion of iron to steel is reasonable. The annual production of steel in blast furnaces (i.e. from iron and not scrap) was estimated using data from the 2000 National Greenhouse Gas Inventory (NGGI). The 2000 NGGI indicates that 6,727 kilotonnes of iron and steel was produced in Australia (NGGIC, 2002 (Table 2C-1)). USEPA (1995c) indicates that about 1.4 tonnes of ore and/or sinter is required to produce 1.0 tonne of iron. It is then assumed that 1 tonne of iron is required to produce 1 tonne of steel. Therefore, to attain a reasonable estimate of sinter production, it is assumed that approximately 1 tonne of sinter is required to produce 1 tonne of steel (this accounts for any additional materials that may be used in the iron and steel process). Thus, an estimate of 6,727,000 tonnes of sinter is generated.

Manganese ore sinter produced was given as 168,000 tonnes per annum in the 2000/2001 financial period (MCA, 2003).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a range of emission factors for iron ore sintering depending on the amount of waste used in the feedstock and the level of air pollution control. For emissions to air, the emission factor ranges from 20 µg/tonne of sinter produced for plants that have a high use of waste (i.e. chlorinated contaminants) and limited process control to 0.3 µg/tonne of sinter produced for plants that have taken comprehensive steps to control dioxin emissions.

No emission factor is given for emissions to water or land, as emissions are not considered to be significant. The range of dioxin in solid residues is estimated to be 0.003 µg TEQ/tonne of sinter produced. The dioxins contained in the residue may become an emission to land if the solid residue is dumped directly to land. Furthermore, the dioxins contained in the residue may become an emission to water if wet scrubbers are employed for air pollution control.

The UNEP Toolkit does not provide emission factors for manganese ore sintering. However, the single manganese sintering plant operating in Australia has recently introduced new air pollution control equipment and emits approximately 0.5 g I-TEQ/year (MCA, 2003). Using the activity data, this equates to a dioxin emission

factor of 3 µg TEQ/tonne of sinter produced. This emission factor is used to estimate dioxin emissions from the manganese ore sintering plant and compares well to the UNEP dioxin emission factors for iron ore sintering.

Table 4.18 provides a summary of the UNEP dioxin emission factors that apply to Metal Ore Sintering.

Table 4.18 Emission Factors – Metal Ore Sintering [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Iron ore sintering	0.3	5	20	NA	NA	NA	NA	NA	NA
Manganese ore sintering	ND	3	ND	NA	NA	NA	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

The 0.3 µg TEQ/tonne emission factor for iron ore sintering is likely to significantly underestimate actual emissions from sinter production as the emission factor is intended to be used only for the highest technology plants where dioxin emissions have been specifically addressed and major changes to technology and plant operation have been made to reduce dioxin emissions. However, the low emission estimate should be considered as an indicator of the range of potential emissions from sinter production.

Table 4.19 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.19 UNEP Toolkit Estimate of Emissions – Metal Ore Sintering [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Metal ore sintering	3	34	135	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

Dioxin measurement data were provided for emissions to air for iron ore sintering measured in 1997. Recorded flue gas concentrations were between 1.5-3.4 ng I-TEQ/Nm^3, corresponding to derived emission factors of between 2.7 and 6.4 µg TEQ/tonne of sinter produced (based on typical gas emission rates of approximately 2000 Nm^3/tonne sinter).

In 2003, emission control technology (carbon packed bed technology) was installed and further dioxin testing was performed at the facility. The dioxin measurements made in 2003 were within the first five months of operation and ranged between 0.04 and 0.09 ng I-TEQ/Nm^3. The measured dioxin concentrations correspond to dioxin emission factors between 0.08 and 0.2 µg TEQ/tonne of sinter (based on typical gas emission rates of approximately 2,000 nm^3/tonne sinter). These emission factors correspond well to the default UNEP emission factor of 0.3 µg TEQ/tonne of sinter produced. For the inventory, the emission testing data from the 1997 period is used to estimate emissions to air from iron ore sintering as the dioxin inventory is based on the year 2002, prior to the emission control technology being installed and operational. The best estimate emission factor is taken to be the average of the highest and lowest derived measured

dioxin emission factor to air. The low emission factor is taken to be the default UNEP emission factor of 0.3 µg TEQ/tonne sinter in order to show the potential range of dioxin emissions from iron ore sintering in Australia supported by the 2003 dioxin measurement data. The 2003 emission test data were not used due to the limited nature of the testing program.

The derived dioxin emission factors based on the measurement data provided are presented in Table 4.20.

Table 4.20 Revised Emission Factors – Metal Ore Sintering [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Iron ore sintering	0.3	4.6	6.4	NA	NA	NA	NA	NA	NA
Manganese ore sintering	ND	3	ND	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.21 provides the revised emission estimate for metal ore sintering emissions to air, water and land.

Table 4.21 Revised Estimate of Emissions – Metal Ore Sintering [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Metal Ore Sintering	2.5	32	44	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.2.2 Coke Production

This section covers the production of coke from coal. Coking, the destructive distillation of coal occurs in coke ovens by exposing the coking coal to high temperatures in the absence of air. Each coke oven is lined with refractory bricks and consists of a coking chamber, a heating chamber and a regenerative chamber. Coke ovens generally operate in batteries of 10 to 100 and heat is supplied from gases combusted between the chambers to keep the oven walls over 1,100°C. The coal is heated for 12 to 20 hours after which the coking process is complete and all volatile mass has been removed from the coal. The gases produced by the coking process are captured and cleaned of its by-products. Approximately 40% of the gas is used in the oven battery for heating the ovens the rest is used in other steel making processes or sold.

4.1.1.2 Available Activity Data

Coke production data is based on data from the 2000 National Greenhouse Gas Inventory. The NGGI indicates that there was an estimated 22.32 PJ of energy used in coke production in 2000 (NGGIC, 2002). Assuming an average energy content of 29.5 GJ/tonne for coking coal, this equates to 757,000 t of coal used to produce coke. Approximately 3 tonnes of coal are required to produce 2 tonnes of coke (UNEP Toolkit, 2003). Therefore, it is estimated that 505,000 tonnes of total coke was produced in 2000.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides two classes of dioxin emission factors for coke production. Class 1 emission factors are applied to coke production facilities that have no air pollution controls and Class 2 emission factors are applied to facilities that are equipped with air pollution controls. It is assumed that all coke production facilities in Australia are equipped with some level of air pollution control, therefore, the UNEP Class 2 dioxin emission factors are used to estimate dioxin emissions to air.

The UNEP Toolkit provides an emission factor to water of 0.06 µg/tonne of coke produced. The dioxin emission to water occurs through the discharge of effluents from quenching or wet scrubbing. The UNEP Toolkit provides two emission factors, one for treated wastewater, 0.006 µg/tonne of coke produced (assuming the water treatment process is 90% effective), and one for untreated wastewater, 0.06 µg/tonne coke produced. The UNEP emission factors are presented in Table 4.22.

Table 4.22 Emission Factors – Coke Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Coke production	-	3	-	0.006	0.03	0.06	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.23 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.23 UNEP Toolkit Estimate of Emissions – Coke Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Coke production	-	0.2	-	0.003	0.02	0.03	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.2.3 Iron And Steel Production

This subcategory covers both primary and secondary production of iron and steel.

4.1.1.2 Available Activity Data

The total iron or steel produced in Australia was sourced from the 2000 National Greenhouse Gas Inventory and is estimated to be 6,727,000 tonnes (NGGIC, 2002). The total foundry production of iron or steel for 2002 was estimated at 50,000 tonnes (ITR, 2003). BHP (2003) estimate that approximately 1,900,000 tonnes of steel are recycled every year with approximately 1,450,000 tonnes of this being consumed in Australia. In addition to this scrap collection, the steel industry produces approximately 1,000,000 tonnes of scrap and this is recycled within the industry.

Therefore, the total iron or steel produced in iron and steel plants is estimated to be 6,677,000 tonnes per annum. Of this steel, 2,450,000 tonnes is generated from recycled scrap. The total iron or steel produced from foundries is estimated to be 50,000 tonnes per annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a range of dioxin emission factors depending on the type of technology employed and the feedstock. Dioxin emission factors to air range from 10 µg TEQ/tonne steel for plants with limited controls using contaminated scrap to 0.1 µg TEQ/tonne steel for plants using clean scrap and operating with good environmental controls. A very low emission factor of 0.01 µg TEQ/tonne steel is given for blast furnaces with air pollution control.

No emission factor is given for water, as this is not considered to be significant. The range for dioxin in solid residues ranges from 15 µg TEQ/tonne steel to 1.5 µg TEQ/tonne steel.

To arrive at a toolkit dioxin emission estimate for iron and steel production, the UNEP dioxin emission factors provided in Table 4.24 have been used.

Table 4.24 Emission Factors – Iron and Steel Production [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Iron and steel production	0.1	3	10	ND	ND	ND	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

The UNEP Toolkit provides a range of dioxin emission factors for ferrous foundries depending on the technology employed. Dioxin emission factors to air range from 10 µg TEQ/tonne steel for foundries with no air pollution control using a cold air cupola furnace or rotary drum furnace to 0.03 µg TEQ/tonne for foundries with fabric filters using a hot air cupola or induction furnace.

No emission factor is given for dioxin releases to water. Emission factors for solid residue range from 8 µg TEQ/tonne steel for cold air cupola furnaces with fabric filter air pollution control to 0.2 µg TEQ/tonne steel for foundries with no air pollution control.

To estimate the amount of emissions to land from landfilled residues, the dioxin emission factors for solid residue have been used.

To arrive at a toolkit dioxin emission estimate for ferrous foundries, the UNEP dioxin emission factors provided in Table 4.25 have been used.

Table 4.25 Emission Factors – Ferrous Foundries [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Ferrous foundries	0.03	4.3	10	NA	NA	NA	0.2	0.5	8

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.26 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.26 UNEP Toolkit Estimate of Emissions – Iron and Steel Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Iron and steel production	0.07	20	67	ND	ND	ND	NA	NA	NA
Ferrous foundries	0.002	0.3	0.5	NA	NA	NA	0.01	0.03	0.4

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.2.4 Copper Production

This section covers both primary and secondary production of copper. However, the occurrence of dioxin emissions is mainly associated with secondary copper production due to the presence of contaminants in the feedstock.

Two copper smelters and three copper refineries are currently operating in Australia (MCA, 2003). Copper concentrates from mining operations can be smelted using various methods to convert the concentrates to copper metal. One method used in Australia is to produce a copper matte by melting the copper concentrate with fluxes in a furnace that is poured into a converter containing more fluxes to produce blister copper. Another method is to flash smelt the copper, where the copper concentrate is introduced into a smelter with an oxygen enriched environment, causing the sulphur fraction of copper sulphides to burn and become sulphur dioxide leaving behind blister copper. Blister copper (98 to 99% pure copper) is then refined in anode furnaces and by electrolysis to produce pure refined copper (MCA, 2003).

Secondary copper production is similar to primary copper production described above but the raw material is oxidic or metallic requiring smelting in reducing conditions (UNEP, 2003).

4.1.1.2 Available Activity Data

Copper production data was based on the Australian Bureau of Statistics published activity data of 547,000 tonnes for the 2002/2003 financial period (1 July 2002 to 30 June 2003) (ABS, 2003b). The available activity data does not split the total copper produced between primary and secondary production. Therefore, it is assumed that secondary copper production has the same level of activity as was used in the 1998 dioxin emissions inventory of 20,000 tonnes (EA, 2002a).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP toolkit provides a range of emission factors to air for secondary copper production. The emission factors range from 800 µg TEQ/tonne of copper produced for facilities with basic technology to 5 µg TEQ/tonne of copper produced for facilities that have been optimised for dioxin control. The UNEP toolkit provides a dioxin emission factor of 0.01 µg TEQ/tonne of copper produced for all primary copper production.

No emission factors are provided for releases to water. Dioxin emissions to water may occur is water effluent is discharged from the facilities, however, no emission factors are available to quantify these emissions. Emission factors for solid residues are provided for secondary copper production ranging from 800 µg TEQ/tonne of copper produced for basic technology to well controlled facilities to 300 µg TEQ/tonne of

copper produced for facilities with high technology controls optimised for controlling dioxin emissions. There is no data available to estimate dioxin emissions to solid residue from primary copper production.

To estimate the amount of emissions to land from landfilled residues, the dioxin emission factors for solid residue have been used.

The UNEP toolkit dioxin emission factors used to estimate dioxin emissions from copper production are presented in Table 4.27.

Table 4.27 Emission Factors – Copper Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Primary copper production	ND	0.01	ND	ND	ND	ND	ND	ND	ND
Secondary copper production	5	50	800	ND	ND	ND	300	630	800

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

Table 4.28 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.28 UNEP Toolkit Estimate of Emissions – Copper Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Primary copper production	-	0.005	-	ND	ND	ND	ND	ND	ND
Secondary copper production	0.1	1	16	ND	ND	ND	6	13	16

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available; ND = No Data

4.2.5 Aluminium Production

This section covers secondary production of aluminium only. Dioxin emissions have been associated with the use of carbon anodes at primary aluminium production facilities, however, levels are generally thought to be low and the main interest is the thermal processing of scrap materials (UNEP, 2003). Secondary production of aluminium is conducted by remelting aluminium scrap in a variety of furnaces. Impurities in the scrap or from cleaning processes can result in dioxin formation (UNEP 2003).

4.1.1.2 Available Activity Data

Secondary aluminium production data was based on the Australian Bureau of Statistics published activity data of 69,142 tonnes for 2001 (ABS, 2002b). There is no information on the split by pollution control technology.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP toolkit provides a range of emission factors for dioxin emissions to air from the secondary aluminium production industry. The emission factors range from 150 µg TEQ/tonne aluminium produced for plants with minimal pre-treatment of scrap and simple dust removal to 0.5 µg TEQ/tonne of aluminium produced for modern plants

optimised for dioxin control. The UNEP Class 2 dioxin emission factor is used in this inventory for the 'best estimate' emission factor. The UNEP Class 2 emission factor should be where plants have fabric filters and afterburner air pollution control equipment.

No emission factor is given for releases to water, as this is not considered to be a significant release route.

Dioxin emission factors ranging from 100 to 400 µg TEQ/tonne aluminium produced are provided for solid residues.

The UNEP toolkit dioxin emission factors used to estimate dioxin emissions from secondary aluminium production are presented in Table 4.29.

Table 4.29 Emission Factors –Aluminium Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Aluminium production	0.5	35	150	ND	ND	ND	100	250	400

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.30 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.30 UNEP Toolkit Estimate of Emissions – Aluminium Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Aluminium production	0.06	4.5	19	ND	ND	ND	13	32	51

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

4.2.6 Lead Production

This section covers secondary production of lead only. Dioxin emissions from primary lead production using direct smelting are low and are not considered further (UNEP, 2003). Data on dioxin emissions from primary lead production using sinter/smelting are not available (UNEP, 2003).

Secondary lead is recovered from scrap material in a variety of furnaces. A major source of scrap for secondary lead production is recycled batteries. The recycling of batteries requires the separation of the lead from the plastic cases. Use of PVC in the production of the plastic cases for batteries provides a source for the formation of dioxins. Organic material in the scrap can also lead to dioxin formation (UNEP, 2003).

4.1.1.2 Available Activity Data

Secondary lead production is estimated at 68,000 tonnes (Pasminco, 2003; MIM, 2003).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP toolkit provides three classes of dioxin emission factors to air ranging from Class 1 (lead production from scrap (i.e. car batteries) containing PVC), Class 2 (lead production from PVC, chlorine free scrap with air pollution controls) to Class 3 (lead production from PVC, chlorine free scrap with fabric filters and scrubber air pollution

control equipment). The dioxin emission factors to air range from 80 µg TEQ/tonne aluminium produced (Class 1) to 0.5 µg TEQ/tonne aluminium produced (Class 3).

No emission factor is given for releases to water as there is not enough data available and no dioxin release to land is expected from secondary lead production.

The UNEP toolkit dioxin emission factors used to estimate dioxin emissions from secondary lead production are presented in Table 4.31.

Table 4.31 Emission Factors –Lead Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Lead production	0.5	8	80	ND	ND	ND	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.32 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.32 UNEP Toolkit Estimate of Emissions – Lead Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Lead production	0.03	0.5	5	ND	ND	ND	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = Not Data

4.2.7 Zinc Production

This section covers all production of zinc. Zinc in Australia is produced using two main processes, electrolysis and smelting. Zinc concentrate from mining operations is roasted to remove sulphur and then leached to form a zinc sulphate solution. This is purified and undergoes electrolysis to separate the zinc. The smelting process involves sintering the metal first and then smelting to produce zinc vapour that is condensed to extract zinc metal (repeated several times to achieve purity) (MCA, 2003).

Dioxin emissions from zinc production have not been well studied but may be significant (UNEP, 2003).

4.1.1.2 Available Activity data

Zinc production data was based on the Australian Bureau of Statistics published activity data of 496,000 tonnes for the 2002/2003 financial period (1 July 2002 to 30 June 2003) (ABS, 2003b). There was no available information available concerning the types of pollution control equipment employed.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a range of emission factors depending on the air pollution control technology employed. The emission factors range from 1,000 µg TEQ/tonne of zinc produced for furnaces using scrap feedstock materials from the steel industry to recover zinc and have no air pollution controls to 5 µg TEQ/tonne of zinc produced for high technology facilities using comprehensive pollution controls such as fabric filters with lime and active carbon injection.

No emission factor is given for releases to water as there is not enough data available and no dioxin release to land is expected from zinc production.

The UNEP toolkit dioxin emission factors used to estimate dioxin emissions from zinc production are presented in Table 4.33.

Table 4.33 Emission Factors –Zinc Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Zinc production	5	100	1,000	ND	ND	ND	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.34 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.34 UNEP Toolkit Estimate of Emissions – Zinc Production

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Zinc production	2.5	50	500	ND	ND	ND	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

4.2.8 Brass And Bronze Production

No significant thermal recovery of brass was carried out in Australia in 2002.

4.2.9 Magnesium Production

Magnesium production was not carried out in Australia in 2002.

4.2.10 Other Non-Ferrous Metal Production

Metals included in this section include nickel, tin, silver and gold. The production of these metals has not been investigated as to the dioxin forming potential. However, as the process of production involves smelting these have been included in the inventory.

4.1.1.2 Thermal Non-Ferrous Metal Production Activity

The total production of other non-ferrous metals in Australia is provided in Table 4.35.

Table 4.35 Activity Data – Other Non-Ferrous Metal Production

Metal	Production data (tonnes/year)	Source
Nickel	206,000	ABARE (2003)
Silver	644,000	ABS (2003a)
Gold	350,000	ABS (2003a)
Tin	791,000	ABS (2003a)
Total	**1,991,000**	

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides two classes of emission factors for thermal non-ferrous metal production. The UNEP Class 1 dioxin emission factors are for facilities producing metals from contaminated scrap with little or no air pollution control. The UNEP Class 2 emission factor are for processes using clean feedstock that are equipped

with air pollution control equipment. Metal production in Australia is assumed to occur at facilities with a high level of air pollution control. Therefore, the UNEP Class 2 dioxin emission factors have been used to estimate emissions from other non-ferrous metal production.

The UNEP toolkit dioxin emission factors used to estimate dioxin emissions from other non-ferrous metal production are presented in Table 4.36.

Table 4.36 Emission Factors – Non-Ferrous Metal Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Non-ferrous metal production	-	2	-	ND	ND	ND	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.37 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.37 UNEP Toolkit Estimate of Emissions – Non-Ferrous Metal Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Non-ferrous metal production	-	4	-	ND	ND	ND	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = Not Data

4.2.11 Shredders

Shredders are used to reduce scrap metal into small fragments that can be used in the recycled metal industry. The bulk of the material used in shredders in Australia are end of life vehicles (ELV) (Environment Australia, 2002c). Emissions from shredders can be produced by contaminated material that is heated by the shredding process. Dioxin is released in a by-product of the process (UNEP, 2003).

4.1.1.2 Available Activity Data

Environment Australia estimated that there are approximately 455,000 tonnes of metal processed per annum by shredders in Australia (Environment Australia, 2002). The report adds the warning that these figures are based on unconfirmed numbers. However, this data is the best available activity data, and is used to estimate dioxin emissions from shredders in this inventory.

4.1.1.2 UNEP Toolkit Estimate of Emissions

Very little dioxin emissions data are available from shredders (UNEP, 2003). The UNEP Toolkit presents a single class of emission factors for dioxin emissions to air from shredders.

The UNEP toolkit emission factors are presented in Table 4.38.

Table 4.38 Emission Factors – Shredders[a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Shredders	-	0.2	-	ND	ND	ND	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

Table 4.39 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.39 UNEP Toolkit Estimate of Emissions – Shredders[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Shredders	-	0.09	-	ND	ND	ND	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

4.2.12 Thermal Wire Reclamation

No significant thermal wire reclamation was carried out in Australia in 2002.

4.3 Main Category 3 - Power Generation And Heating

This section concerns the use of combustion processes to produce electricity or heating. Subcategories in this section are as follows:

- Fossil fuel power plants (Section 4.3.1)
- Biomass power plants (Section 4.3.1)
- Landfill biogas combustion (Section 4.3.3)
- Household heating and cooking with biomass (Section 4.3.4)
- Household heating and cooking with fossil fuels (Section 4.3.4).

4.3.1 Fossil Fuel Power Plants

This subcategory covers fossil fuel electricity generation for distribution through the national grid and also fuel usage in boilers for industrial heating and processing.

4.1.1.2 Available Activity Data

Activity data relating to fuel used for electricity generation for the 2001/2002 financial period (July 2001 to June 2002) were provided by the Electricity Supply Association of Australia (ESAA, 2003).

Information on the quantity of fuel used in industrial combustion was sourced from the 2001 National Greenhouse Gas Inventory.

The estimated 2002 activity data for fossil fuel power plants are presented in Table 4.40.

Table 4.40 Fuel Consumption Activity Data for Fossil Fuel Power Plants

Fuel	Electricity Generation (TJ/a)	Industrial (TJ/a)	Total (TJ/a)
Black Coal	1,143,373	93,115 [a]	1,236,488
Brown Coal	685,487	55,825 [a]	741,312
Briquettes	1,319	-	1,319
Heavy fuel oil [b]	2,449	56,039 [d]	58,488
Light fuel oil [c]	5,454	124,801 [d]	130,255
Natural Gas	160,845	348,410	509,255

a The amount of black coal combusted by the industrial sector was estimated based on the proportion of black coal to total coal combusted by the electricity generation sector. Likewise the amount of brown coal combusted by the industrial sector was estimated based on the proportion of brown coal to total coal combusted by the electricity generation sector.

b The amount of heavy fuel oil combusted is taken to be the amount of oil combusted for steam generation.

c The amount of light fuel oil combusted is taken to be the amount of oil combusted in internal combustion engines and gas turbines.

d The amount of heavy fuel oil combusted by the industrial sector was estimated based on the total petroleum-based fuel combusted by the industrial sector and by applying the proportion of heavy fuel oil combusted by the electricity generation sector. Likewise, the amount of light fuel oil combusted by the industrial sector was estimated based on the proportion of light fuel oil combusted by the electricity generation sector.

No activity data were available for co-fired waste boilers.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides specific emission factors for dioxin releases to air based on the type of fuel combusted. No emission factors are presented for water emissions as this release route is expected to be insignificant. The UNEP Toolkit presents a dioxin emission factor for solid residues from coal fired boilers of 14 µg/TJ coal combusted. The solid residue emission factor is used to estimate the total emissions to land from fossil fuel power plants.

The UNEP dioxin emission factors are presented in Table 4.41.

Table 4.41 Emission Factors – Fossil Fuel Electric Power Generation [a,b]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Coal fired	-	10	-	ND	ND	ND	-	14	-
Heavy fuel oil	-	2.5	-	ND	ND	ND	-	-	-
Light fuel oil/natural gas	-	0.5	-	ND	ND	ND	-	-	-

a Source: UNEP (2003)

b L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

The sum of black coal, brown coal and briquettes combusted by fossil fuel power plants provided in Table 4.41 is used as the total activity for 'coal' fired combustion to arrive at an estimate for dioxin emissions.

Table 4.42 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.42 UNEP Toolkit Estimate of Emissions – Fossil Fuel Electric Power Generation [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Coal fired	-	19.8	-	NA	NA	NA	-	27.7	-
Heavy fuel oil	-	0.15	-	NA	NA	NA	-	-	-
Light fuel oil/natural gas	-	0.32	-	NA	NA	NA	-	-	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Emission Data

Australian dioxin emission testing data were provided by the ESAA for six NSW fossil fuelled power plants burning black coal and three Victorian fossil fuelled power plants burning brown coal.

Recorded median flue gas concentrations were in the following ranges:

Black coal: 0.0016-0.0910 ng I-TEQ/Nm^3 (6 power stations tested)

Brown coal: 0.0020-0.0067 ng I-TEQ/Nm^3 (3 power stations tested).

The dioxin concentrations presented above include all congener non-detects at the analytical detection limit. Therefore, the emission estimates generated from these figures are likely to overestimate actual emissions.

The derived dioxin emission factors based on the measurement data provided are presented in Table 4.43.

Table 4.43 Revised Emission Factors – Coal Fired Power Plants [a]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Black Coal	0.6	10.1	34.7	NA	NA	NA	ND	ND	ND
Brown Coal[5]	1.6	1.8	5.3	NA	NA	NA	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

No dioxin emissions measurement data were available for heavy fuel oil, light fuel oil or natural gas and emissions to solid residue for coal combustion. Therefore, the UNEP Toolkit emission factors have been retained for the revised emission estimate. Total revised emissions to air, water and land are presented in Table 4.44. Comparison to the UNEP estimates in Table 4.42 shows a reduction in emissions to air of approximately 30%.

It is noted that some of the ash produced from coal fired boilers is reused in the cement industry.

[5] Dioxin testing performed by HRL Technology, Pty Ltd, Victoria

Table 4.44 Revised Estimate of Emissions – Fossil Fuel Power Plants [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Black Coal	0.74	12.49	42.91	NA	NA	NA	-	17.30	-
Brown Coal	1.19	1.33	3.93	NA	NA	NA	-	10.38	-
Heavy fuel oil	0.15	0.15	0.15	NA	NA	NA	-	-	-
Light fuel oil/natural gas	0.32	0.32	0.32	NA	NA	NA	-	-	-
Total	**2.39**	**14.3**	**47.3**					**27.7**	

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.3.1 Biomass Power Plants

The combustion of biomass is often used in Australian industries to achieve the dual purpose of waste removal and electricity generation. However, because this power generation is associated with a particular industry the combustion activity is covered under that industries activity such as pulp and paper manufacturing. Therefore not all electricity generation by biomass has been included in this category to avoid double counting emissions.

4.1.1.2 Available Activity Data

Biomass combustion from electricity suppliers was based on data from the Electricity Supply Association of Australia (ESAA). The Electricity Supply Association of Australia indicates that there was an estimated 859 TJ of energy consumed by electricity suppliers (ESAA, 2003).

Electricity contributions from the combustion of bagasse from the sugar industry were estimated at 400 GWh/yr (Roarty, M., 2000). This is equivalent to 1,440 TJ/year.

Thus, total activity of biomass energy generation is estimated at 2,190 TJ/annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides emission factors for clean wood fired boilers of 50 µg TEQ/TJ to air and 15 µg TEQ/TJ to solid residues. No emission factor is presented for water as this release route is expected to be insignificant.

The UNEP Toolkit emission factors are presented in Table 4.45.

Table 4.45 Emission Factors – Biomass Power Plants [a,b]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Biomass power plants	-	50	-	NA	NA	NA	ND	15	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.46 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.46 UNEP Toolkit Estimate of Emissions – Biomass Power Plants [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Biomass power plants	-	0.1	-	NA	NA	NA	-	0.033	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.3.3 Landfill and Biogas Combustion

The anaerobic decomposition of landfill biomass results in the production of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), water (H_2O) and a number of other combustible gases. Combustible gases make up approximately 50% of the gases produced.

4.1.1.2 Available Activity Data

Landfill and biogas combustion data was based on the 2001 National Greenhouse Gas Inventory published activity data of 9,500 TJ (NGGIC, 2003).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a single dioxin emission factor to air for landfill/biogas combustion in boiler, turbines and flares. Dioxin releases to water or land are no expected from this process. The UNEP dioxin emission factors are presented in Table 4.47.

Table 4.47 Emission Factors – Landfill and Biogas Combustion [a,b]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Landfill/biogas combustion	-	8	-	NA	NA	NA	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.48 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.48 UNEP Toolkit Estimate of Emissions – Landfill and Biogas Combustion

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Landfill/biogas combustion	-	0.08	-	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.3.4 Household Heating and Cooking (Biomass)

This subcategory covers all residential heating and cooking using biomass as the fuel.

4.1.1.2 Household Heating and Cooking – Biomass Activity

Information on the consumption of biomass was taken from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The total reported wood/wood waste combusted by the residential sector was 79,780 TJ (equivalent to 4,900,000 tonnes, assuming an average heat content of 16.2 GJ/tonne).

Environment Australia reviewed annual firewood consumption in Australia and derived activity estimates between 3-5.5 Mt (Environment Australia, 2002c). The report notes that the figure could be as low as 3 million tonnes based on estimated shortfalls from deliveries made (i.e. estimated that for every tonne of firewood sold only 770 kg are being delivered).

For this report the following activity data will be used to estimate emissions from residential biomass combustion:

Best estimate: 79,780 TJ/a (4,900,000 t/a)

Low estimate: 48,700 TJ/a (3,000,000 t/a)

High estimate: 89,300 TJ/a (5,500,000 t/a).

Respondents to the survey conducted by Environment Australia for the report on Emissions from Domestic Solid Fuel Burning Appliances (Environment Australia, 2002b), suggest that only 2.1% of respondents used waste wood as a fuel source on a regular basis. No further breakdown was given as to whether the waste wood was likely to have been treated by PCP or paint. Given that no PCP treated wood is being produced in Australia it is likely that the percentage of contaminated wood combusted in household stoves is very small. Therefore, all biomass combusted in residential appliances has been treated as virgin wood.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides an emission factor to air for the combustion of biomass in household heating and cooking of 100 µg TEQ/TJ of biomass burned. No release to water is expected. An emission factor is given for solid residue of 20 µg TEQ/TJ of biomass burned. The solid residue is treated as an emission to land in the inventory.

The UNEP dioxin emission factors are presented in Table 4.49.

Table 4.49 Emission Factors – Household Heating and Cooking (Biomass) [a,b]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Household heating and cooking (biomass)	-	100	-	NA	NA	NA	NA	20	NA

[a] Source: UNEP (2003)

[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.50 provides the Toolkit emission estimate for releases to air, water and land. The high and low emission estimates are based on the estimated range of activity data.

Table 4.50 UNEP Toolkit Estimate of Emissions – Household Heating and Cooking (Biomass) [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Household heating and cooking (biomass)	4.9	8.0	9.0	NA	NA	NA	1.0	1.6	1.8

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate using Measurement Data

A recent Australian study into dioxin emissions to air from domestic solid fuel burning apparatus (Environment Australia, 2002a) suggest a best estimate emission factor for household heating of 4.1 µg TEQ/tonne of Air Dry fuel burnt. Assuming an average heat content of 16.2 GJ/t provides an emission factor of 253 µg TEQ/t of Air Dry (ADt) fuel burnt. This is a higher figure than provided by the UNEP toolkit, but is within the range of factors discussed of 0.2 µg TEQ/tonne and 4700 µg TEQ/tonne (UNEP, 2003). No emission testing was conducted to establish emission factors from PCP treated or otherwise contaminated wood. For all other media the UNEP toolkit emission factor were applied in the revised estimate. Table 4.51 provides a summary of the revised dioxin emission factors for household heating and cooking - biomass.

Table 4.51 Emission Factors – Household Heating and Cooking (Biomass) [a]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/TJ)		
	L	BE	H	L	BE	H	L	BE	H
Household heating and cooking (biomass)	-	253	-	NA	NA	NA	NA	20	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.52 provides the revised emission estimate for releases to air, water and land. The high and low emission estimates are based on the estimated range of activity data.

Table 4.52 Revised Estimate of Emissions – Household Heating and Cooking (Biomass) [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Household heating and cooking (biomass)	12.3	20.2	22.6	NA	NA	NA	1.0	1.6	1.8

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.3.4 Domestic Heating And Cooking (Fossil Fuels)

This subcategory covers all residential heating and cooking using coal, oil and natural gas as the fuel.

4.1.1.2 Available Activity Data

Information on the domestic consumption of fossil fuels was taken from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The total activity data provided by the National Greenhouse Gas Inventory are provided in Table 4.53.

Table 4.53 Domestic Heating and Cooking with Fossil Fuels – Activity Data [a]

Fuel	Energy Consumed (TJ/a)
Coal	160
Oil	19,810
Natural gas	122,380

[a] Source: NGGIC (2003)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit reports that emissions to air from coal burning are fairly consistent and range between 1 to 7 µg TEQ/tonne of coal burnt. The UNEP Toolkit recommends an emission factor of 2 µg TEQ/tonne of coal burnt equivalent to approximately 70 µg TEQ/TJ of coal combusted (based on a heating value of 28 MJ/kg for coal). This emission factor is used to generate the best estimate of emissions while the upper and lower emission estimates are based on the range of 1 to 7 µg TEQ/tonne of coal burnt provided by the UNEP Toolkit.

The UNEP Toolkit reports that dioxin emissions from oil burning range from 0.04 to 2 µg TEQ/tonne of oil burnt. The UNEP Toolkit recommends an average dioxin emission factor of 0.5 µg TEQ/tonne oil burnt is used to estimate emissions. This emission factor is equivalent to approximately 10 µg TEQ/TJ of oil combusted (based on an average heating value of 44 MJ/kg for oil). The upper and lower emission estimates are based on the range of 0.04 to 2 µg TEQ/tonne of oil burnt provided by the UNEP Toolkit.

The UNEP Toolkit reports that dioxin emission from gas combustion range between 0.04 to 0.07 ng TEQ/m^3 of natural gas combusted. The UNEP toolkit recommends an average value of 0.05 ng TEQ/m^3 be used to generate the best estimate from domestic combustion of natural gas. Based on an average heat value of 38 MJ/m^3 this emission factor is equivalent to approximately 1.3 µg TEQ/TJ of natural gas combusted. The upper and lower emission estimates are based on the range of 0.04 to 0.07 ng TEQ/m^3 of natural gas combusted provided by the UNEP Toolkit.

The UNEP Toolkit also reports dioxin content in coal fly ash ranging from 4 to 42,000 ng TEQ/kg ash generated. An emission factor of 5,000 ng/kg fly ash is recommended for a first estimate of dioxin emissions. Fly ash emissions entrained in flue gas emitted to air would be included in the toolkit emission factor for air emissions. Other fly ash emissions would adhere to the inside of the chimney and be disposed to landfill after chimney cleaning.

No information on the quantity of fly ash generated from coal combustion for domestic heating and cooking is available. The methodology employed in the Ireland inventory (Hayes and Marnane, 2002) is used to estimate the amount of fly ash generated from domestic combustion of coal. Assuming that coal has an average ash content of 5%, consisting of approximately 1-3% fly ash, then the annual generation of fly ash collected in chimneys is estimated to be between 2.5 to 7.5 tonnes (based on 5,000 tonnes of residential coal combusted). Assuming that fly ash residue is collected and disposed of in landfills, then these figures can be used to estimate dioxin emissions to land.

The UNEP Toolkit dioxin emission factors to air, water and land are presented in Table 4.54.

Table 4.54 Emission Factors – Household Heating and Cooking (Fossil Fuels) [a, b]

Category	Air emission factor (µg TEQ/TJ)			Water emission factor (µg TEQ/TJ)			Land emission factor (µg TEQ/t ash residue)		
	L	BE	H	L	BE	H	L	BE	H
Coal	35	70	245	NA	NA	NA	-	5	-
Oil	0.8	10	40	NA	NA	NA	-	-	-
Natural gas	1.1	1.3	1.8	NA	NA	NA	-	-	-

a Source UNEP (2003)

b L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.55 provides the Toolkit emission estimate for releases to air, water and land.

Table 4.55 UNEP Toolkit Estimate of Emissions – Household Heating and Cooking (Fossil Fuels)

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Coal	0.006	0.01	0.039	NA	NA	NA	1.3	2.5	3.8
Oil	0.02	0.2	0.79	NA	NA	NA	-	-	-
Natural gas	0.14	0.16	0.22	NA	NA	NA	-	-	-
Total	**0.16**	**0.37**	**1.1**				**1.3**	**2.5**	**3.8**

a Source: UNEP(2003)

b L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.4 Main Category 4 - Production Of Mineral Products

This section details dioxin emission estimates from the production of mineral products. The following subcategories have been identified as possible sources of dioxin emissions:

- Cement production (Section 4.4.1)
- Lime production (Section 4.4.2)
- Brick production (Section 4.4.3)
- Glass production (Section 4.4.4)
- Ceramics (Section 4.4.5)
- Asphalt mixing (Section 4.4.6).

4.4.1 Cement Production

This subcategory describes dioxin emission estimates from the production of cement.

4.1.1.2 Available Activity Data

The Australian Cement Industry Federation (CIF) provided activity data relating to clinker and cement production for the year 2002. The total clinker produced during 2002 was 6,355,000 tonnes. It is reported that 335,000 tonnes of clinker were produced using alternative fuels and 6,020,000 tonnes of clinker were produced using standard fuels. The total cement produced during 2002 was 7,496,656 tonnes.

Dry and wet kilns are used to produce cement in Australia. The majority of cement kilns in Australia are dry kilns.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a range of dioxin emission factors depending on the type of cement production facility involved and the operating temperature of the particulate control device. The majority of cement kilns operating in Australia are dry kilns and typically the operating temperatures of air pollution control equipment in Australian facilities are below 200°C. Therefore, the UNEP dioxin emission factor to air of 0.05 µg TEQ/tonne cement applies.

No emission factor is given for releases to water, as dioxin emissions to water are not expected from cement production.

The UNEP Toolkit provides a dioxin emission factor of 0.003 µg TEQ/tonne cement for solid residues from cement production. Cement kiln dust is either used as a by-product for various other industries or landfilled. An example of cement kiln dust by-product use is for soil conditioners. Therefore, the UNEP dioxin emission factor for solid residues is used to estimate the total dioxin emission to land from cement production.

Table 4.56 presents the UNEP Toolkit dioxin emission factors for cement production.

Table 4.56 Emission Factors – Cement Production [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Cement production	-	0.05	-	NA	NA	NA	-	0.003	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.57 provides the emission estimate for releases to air, water and land.

Table 4.57 UNEP Toolkit Estimate of Emissions – Cement Production

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Cement production	-	0.4	-	NA	NA	NA	-	0.02	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

Australian dioxin emission testing data were provided by the CIF for all Australian cement kilns. The emissions testing data provided were the results of repeated measurements over the period 1991 – 2003 and were obtained from all cement kilns in Australia using a range of process conditions, primary fuels and raw materials. Both wet and dry processes are represented as were plants using gas, coal and alternative fuels.

All measured dioxin concentrations for the period 1991-2003 were well below 0.1 ng TEQ/Nm^3 (@ 11% O_2) indicating a high level of dioxin control at Australian cement production facilities (UNEP, 2003).

The derived dioxin emission factors based on measurement data are presented in Table 4.58.

Table 4.58 Emission Factors – Cement Production [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Standard fuel	0.035	0.076	0.13	NA	NA	NA	ND	ND	ND
Alternative fuel	0.025	0.069	0.16	NA	NA	NA	ND	ND	ND

[a] Source: CIF (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

No measurement data were available for dioxin concentrations in cement kiln dust. Therefore, the UNEP Toolkit emission factor has been retained for the revised dioxin estimate.

Table 4.59 provides the revised emission estimate for releases to air, water and land.

Table 4.59 UNEP Toolkit Estimate of Emissions – Cement Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Cement production	0.22	0.48	0.84	NA	NA	NA	-	0.02	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

The derived dioxin emissions based on measurement data are in good agreement with the emission estimates using the UNEP Toolkit.

4.4.2 Lime Production

Lime is produced in essentially the same manner as cement. The most significant difference is that the main raw material is limestone only.

4.1.1.2 Available Activity Data

Activity data for the total amount of lime produced in Australia was sourced from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The 2001 NGGI estimates that 1,489,000 tonnes of lime were produced in 2001. For the purposes of this inventory this is assumed to be consistent with the expected activity in 2002. The production of lime using waste derived fuel is estimated based on the proportion of cement produced using waste derived fuel and is estimated at 78,000 tonnes. The amount of lime produced using standard fuel is estimated at 1,411,000 tonnes.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit suggests as emission factor of 0.07 µg TEQ/tonne lime for facilities with particulate emission controls and 10 µg TEQ/tonne lime for facilities with little or no particulate emission control. Facilities operating in Australia have sophisticated particulate emission control. Therefore, the 0.07 µg TEQ/tonne lime is used to estimate dioxin emissions to air from lime production in Australia.

No emission factor is given for releases to water, as there are generally no emissions to water from lime production.

No emission factor is provided for releases to land/solid residue, as no data is available to derive a dioxin emission factor.

Table 4.60 presents the UNEP Toolkit dioxin emission factors for lime production.

Table 4.60 Emission Factors – Lime Production [a, b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Lime production	-	0.07	-	NA	NA	NA	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.61 provides the emission estimate for releases to air, water and land.

Table 4.61 UNEP Toolkit Estimate of Emissions – Lime Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Lime production	-	0.10	-	NA	NA	NA	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available; ND = No Data

4.4.3 Brick Production

Bricks are made from a wide range of clays and shales with a very fine particle size. The raw material is fed into a crusher and then moved to a press or extruder where it is formed into a brick or block column. The brick or brick column gets cut and the bricks are arranged in layers. Automatic haulage systems and transfer cars move the bricks to the kiln for firing. Bricks are produced by firing clay in tunnel kilns at temperatures between 1,000-1,200 °C. Although there are many different kiln types, three basic types are widely used in Australia, mostly fuelled by natural gas (CBPI, 2003). These are described as follows:

- Down draught kilns - these kilns rely on heated air to be introduced into the air space above the 'green' bricks. The heated air is then drawn down through the bricks and out of the stack producing a drying effect
- Hoffman kilns - these kilns fire the bricks by moving hot air around the periphery. The fire can be moved by a series of vents along the kiln firing a new set of bricks with each move. Bricks are preheated by exhaust gases from the firing process and air drawn into the kiln is used to cool the finished bricks
- Tunnel kilns - These kilns are continuously fired and bricks are moved on trolleys through the kiln.

4.1.1.2 Available Activity Data

Brick production data was based on the Australian Bureau of Statistics published activity data of 1,604,000 tonnes for 2002 (ABS, 2003a).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides dioxin emission factors to air ranging from 0.2 µg TEQ/tonne brick for kilns without particulate air pollution control to 0.02 µg TEQ/tonne brick for kilns with particulate air pollution control. Gaseous emissions from brick kilns are not usually controlled unless there is a high fluorine content in the raw material when typically a limestone dry scrubber would be employed (USEPA, 1997). The range of emission factors presented in the UNEP Toolkit has been used to estimate the

range of dioxin emissions from brick production. The best estimate emission is based on the average between the two emission factors. However, as emissions from brick kilns are not usually controlled, dioxin emissions are likely to be towards the upper end of the range estimated in Table 4.60.

No dioxin release to water from brick production is expected (UNEP, 2003). Furthermore, no dioxin emission factor to land/solid residue is provided, as no data are available to estimate an emission factor.

Table 4.62 presents the UNEP Toolkit dioxin emission factors for brick production.

Table 4.62 Emission Factors – Brick Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Brick production	0.02	0.1	0.2	NA	NA	NA	ND	ND	ND

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.63 provides the emission estimate for releases to air, water and land.

Table 4.63 UNEP Toolkit Estimate of Emissions – Brick Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Brick production	0.03	0.2	0.3	NA	NA	NA	ND	ND	ND

[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

4.4.4 Glass Production

Traditionally, glass is manufactured from sand, limestone, dolomite and soda and a number of other materials may be added to provide colour, clarity and/or purification. However, in Australia the major raw material for glass manufacture is crushed recycled glass, called cullet (Eastwaste, 2003).

The glass manufacturing process can be described as follows. Raw material is fed into a furnace and melted at about 1500 °C. Molten glass is then poured into moulds and if appropriate, air is blown through them to give them shape (Eastwaste, 2003). The glass is then slowly cooled to prevent stress fracturing. Any chlorine or fluorine in the raw materials has the potential to contribute to dioxin production (UNEP, 2003).

4.1.1.2 Available Activity Data

Glass production activity data is estimated at 850,000 tonnes per annum based on data from Hassan (2002).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides dioxin emission factors to air ranging from 0.2 µg TEQ/tonne glass for facilities without particulate air pollution control and where controls on facility process are not stringent to 0.015 µg TEQ/tonne glass produced for facilities with particulate air pollution control and careful control over combustion conditions and material inputs are practiced.

No dioxin emission factors to water or land are provided in the UNEP toolkit due to lack of emissions testing data.

The level of process control practiced in Australia at glass production facilities is unknown. However, most glass manufacturing facilities use fabric filters to control particulate emissions (Environment Australia, 1998b). Therefore, the range of dioxin emission factors to air were used to estimate the potential range of emissions from glass manufacturing. The best estimate is based on the mean of the presented range in the UNEP Toolkit.

Table 4.64 presents the UNEP Toolkit dioxin emission factors for glass production.

Table 4.64 Emission Factors – Glass Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Glass production	0.015	0.1	0.2	ND	ND	ND	ND	ND	ND

[a] Source: UNEP (2003)

[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

Table 4.65 provides the emission estimate for releases to air, water and land.

Table 4.65 UNEP Toolkit Estimate of Emissions – Glass Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Glass production	0.013	0.09	0.2	ND	ND	ND	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.4.5 Ceramics Production

Ceramics are heat resistant or refractory materials generated by high heats in furnaces. The two basic raw ingredients are kaolinite and montmorillonite, (Environment Australia, 1998). Although there is not enough information to consider the production of ceramics as a source of dioxin formation, the similarity in process to brick production and the high temperatures involved has resulted in this category being included in the inventory (UNEP, 2003).

4.1.1.2 Available Activity Data

No activity data was found for the 2002 period for this subcategory. Therefore, activity data used in the previous inventory of 10,000,000 tonnes based on activity data from 1994 (PAE, 2002c) were used for this inventory.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit does not provide dioxin emission factors for ceramics production, as not enough information is available. The UNEP Toolkit suggests that the emission factors presented for brick production are used to estimate the emissions from ceramics production.

Table 4.66 presents the UNEP Toolkit dioxin emission factors for ceramics production.

Table 4.66 Emission Factors – Ceramics Production [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Ceramic production	0.02	0.1	0.2	NA	NA	NA	ND	ND	ND

a Source: UNEP (2003)

b L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.67 provides the emission estimate for releases to air, water and land.

Table 4.67 UNEP Toolkit Estimate of Emissions – Ceramics Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Ceramics production	0.2	1	2	NA	NA	NA	ND	ND	ND

a L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available; ND = No Data

4.4.6 Asphalt Mixing

Asphalt consists of two raw materials. Bitumen, a thick tarry substance, and an aggregate, commonly gravel of various grades. The process of asphalt mixing involves heating and drying the aggregate using temperatures between 160-175 °C (AAPA, 2003). The bitumen is then applied while the aggregate is still hot. This usually takes place in the same heating chamber as was used for heating the aggregate.

4.1.1.2 Available Activity Data

Activity data for the total amount of bitumen used in Australia was sourced from 2000 National Greenhouse Gas Inventory (NGGIC, 2002). The 2000 NGGI estimates that 337,860 tonnes of bitumen was used in 2000. For the purposes of this inventory this activity rate is assumed to be consistent with the expected activity in 2002. No information was available on the types of pollution control technologies used by facilities in Australia.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides two classes of emission factors to estimate dioxin emissions from asphalt mixing. The recommended dioxin emission factors to air for facilities with either fabric filters or wet scrubber particulate control is 0.007 µg TEQ/tonne of asphalt whereas the recommended emission factor for facilities without air pollution control is 0.07 µg TEQ/tonne of asphalt.

Dioxin releases to water are not expected and as such the UNEP Toolkit does not provide emission factors.

A dioxin emission factor is provided for solid residues from asphalt mixing for facilities with air pollution control. The emission factor is not based on dioxin measurement data but on the assumption that 90% of dioxins in the flue gas are captured in the air pollution control device and the flue gas contains the same concentration of dioxins as facilities without air pollution control. The estimated dioxin emission factor to solid residues is 0.06 µg TEQ/tonne of asphalt. This emission factor has been used to estimate the total dioxin emissions to land.

As the types of pollution control technologies installed on Australian asphalt mixing facilities are unknown, the range of dioxin emission factors to air is used to estimate the possible range of emissions from asphalt mixing. The best estimate dioxin emission factor is taken to be the mean of the two emission factors presented in the UNEP Toolkit. Likewise, the dioxin emission factor to land is used to estimate the maximum emissions to land from asphalt mixing. Asphalt mixing facilities without air pollution control devices are expected to have zero emissions to land, therefore, this emission factor is used to estimate dioxin emissions to land. The best estimate emission factor is the mean of the two emission factors.

Table 4.68 presents the UNEP Toolkit dioxin emission factors for asphalt mixing.

Table 4.68 Emission Factors – Asphalt Mixing [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Asphalt mixing	0.007	0.1	0.07	NA	NA	NA	0.0	0.03	0.06

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.69 provides the emission estimate for releases to air, water and land.

Table 4.69 UNEP Toolkit Estimate of Emissions – Asphalt Mixing [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Asphalt mixing	0.002	0.01	0.02	NA	NA	NA	0	0.01	0.02

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.5 Main Category 5 – Transport

This category covers emissions from fuel combustion during transportation. Transportation has been broken down into the following categories:

- 4-Stroke engines (Section 4.5.1)
- 2-Stroke engines (Section 4.5.2)
- Diesel engines (Section 4.5.3)
- Heavy oil fired engines (Section 4.5.4).

4.5.1 4-Stroke Engines

4-stroke engines are commonly used in passenger cars and in medium and large engine capacity motorcycles. Since 1986, all petrol vehicles in sold in Australia have been fitted with catalytic converters.

4.1.1.2 Available Activity Data

Activity data for the amount of petrol fuel consumed in 4-stroke internal combustion engines were sourced from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). All gasoline fuel combusted by the transportation sector in Australia in 2002 was unleaded petrol. The 2001 National Greenhouse Gas Inventory provided activity statistics for the total energy consumed (PJ/a). The total fuel mass consumed was

derived assuming an average unleaded petrol energy content of 39.1 MJ/L (API, 2004) and an average density of 0.72 kg/L. The total activity data provided by the 2001 National Greenhouse Gas Inventory are presented in Table 4.70.

Table 4.70 Fuel consumed by 4-stroke engines [a]

Vehicle type	Fuel type	Fuel consumed (PJ/a)	Fuel consumed (tonnes/a)
With catalyst	Unleaded petrol	539.9	9,943,000
Without catalyst	Unleaded petrol	65.3	1,203,000

[a] Source: NGGIC (2003)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit suggest an emission factor to air of 2.2 µg TEQ/tonne fuel combusted in leaded fuelled vehicles and 0.1 µg TEQ/tonne of fuel combusted in unleaded fuelled vehicles without catalysts and 0 µg TEQ/tonne of fuel combusted in unleaded vehicles with catalysts.

No emission factors are provided for releases to water or land, as these release routes are negligible.

Table 4.71 presents the UNEP Toolkit dioxin emission factors for 4-stroke engine combustion in the transportation sector.

Table 4.71 Emission Factors – 4-Stroke Engines [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Leaded fuel	-	2.2	-	NA	NA	NA	NA	NA	NA
Unleaded fuel without catalyst	-	0.1	-	NA	NA	NA	NA	NA	NA
Unleaded fuel with catalyst	-	0	-	NA	NA	NA	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

Table 4.72 provides the emission estimate for releases to air, water and land.

Table 4.72 UNEP Toolkit Estimate of Emissions – 4-Stroke Engines [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
4-stroke engines	-	0.12	-	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

In 2002, Environment Australia commissioned a study to estimate the total dioxin emissions from motor vehicles (PAE, 2002). Measurement data from Australia and from around the world were used to derive dioxin emission factors for various vehicle types. The derived emission factors are presented in Table 4.73. The Australian dioxin emission factors are converted to the same units as the UNEP Toolkit emission factors assuming an average fuel consumption rate of 12.4 L/100 km (ABS, 1998) and assuming an average fuel density of 0.74 kg/L.

Table 4.73 Derived Dioxin Emission Factors Based on Australian and Overseas Dioxin Measurement Data

Vehicle type	Fuel	Emission factor range (pg I-TEQ/km)	Emission factor range (µg TEQ/tonne)
Non-catalyst passenger cars, light-commercial vehicles and motorcycles	Leaded petrol	10-280	0.1-3.1
Non-catalyst passenger cars, light-commercial vehicles and motorcycles running on unleaded petrol	Unleaded petrol	2-20	0.02-0.2
Catalyst passenger cars, light-commercial vehicles and motorcycles running on unleaded petrol	Unleaded petrol	1-3	0.01-0.03

The Australian derived dioxin emission factors are in good agreement with the UNEP Toolkit emission factors.

The dioxin emission factors used to estimate emissions from 4-stroke petrol fuelled vehicles are presented in Table 4.74. The best estimate dioxin emission factor is taken to be the average between the high and low derived emission factors.

Table 4.74 Derived Dioxin Emission Factors

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Leaded fuel	0.1	1.6	3.1	NA	NA	NA	NA	NA	NA
Unleaded fuel without catalyst	0.02	0.1	0.2	NA	NA	NA	NA	NA	NA
Unleaded fuel with catalyst	0.01	0.02	0.03	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.75 provides the emission estimate for releases to air, water and land.

Table 4.75 Revised Estimate of Emissions – 4-Stroke Engines[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Unleaded fuel without catalyst	0.02	0.1	0.2	NA	NA	NA	NA	NA	NA
Unleaded fuel with catalyst	0.1	0.2	0.3	NA	NA	NA	NA	NA	NA
Total	**0.12**	**0.32**	**0.54**	-	-	-	-	-	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.5.2 2-Stroke Engines

2-stroke petrol powered internal combustion engines are commonly used in small boats, motorcycles, lawnmowers and other small machinery.

4.1.1.2 Available Activity Data

For the purposes of this study it was assumed that all petrol consumed in motorcycles and off-road vehicles provided in the 2001 National Greenhouse Gas Inventory was consumed in 2-stroke internal combustion engines. The total petrol combusted provided was 77,700 tonnes/annum (NGGIC, 2003).

There is a high degree of uncertainty associated with this estimate. Therefore, a margin of error of ±20% has been applied to account for the possible range of activity data giving the following range of activity data:

- Lower bound: 62,200 tonnes/annum
- Upper bound: 93,300 tonnes/annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a default dioxin emission factor to air of 2.5 µg TEQ/tonne of fuel combusted.

Dioxin emissions to water and land are expected to be negligible and hence no dioxin emission factors are provided in the UNEP Toolkit.

The default UNEP emission factor to air is used to estimate dioxin emissions from 2-stroke engines. The range of dioxin emissions presented is based on the range of activity data estimated for 2-stroke engines.

Table 4.76 presents the UNEP Toolkit dioxin emission factors for 2-stroke engine combustion in the transportation sector.

Table 4.76 Emission Factors – 2-Stroke Engines [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
2-stroke engines	-	2.5	-	NA	NA	NA	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.77 provides the emission estimate for releases to air, water and land.

Table 4.77 UNEP Toolkit Estimate of Emissions – 2-Stroke Engines [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
2-stroke engines	0.16	0.19	0.23	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.5.3 Diesel Engines

Diesel engines are commonly used in heavy trucks, light trucks, buses, heavy construction equipment, boats and a smaller proportion of passenger cars.

4.1.1.2 Available Activity Data

Activity data for the amount of diesel fuel consumed in Australia were sourced from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The 2001 National Greenhouse Gas Inventory provided activity statistics for the total energy consumed (PJ/a). The total fuel mass consumed was derived assuming an average diesel energy content of 35.6 MJ/L (API, 2004) and an average density of 0.84 kg/L. The total activity data provided by the 2001 National Greenhouse Gas Inventory are presented in Table 4.78.

Table 4.78 Fuel consumed by Diesel Engines[a]

Vehicle Class	Fuel consumed (PJ/a)	Fuel consumed (tonnes/a)
Light duty vehicles (passenger cars and light trucks)	62.0	1,462,000
Heavy duty vehicles (medium duty and heavy duty vehicles)	195.8	4,620,000
Buses	21.0	496,000
Other	33.6	623,600

[a] Source: NGGIC (2003)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The recommended UNEP Toolkit emission factor to air for diesel fuel combustion is 0.1 µg TEQ/tonne of fuel combusted.

Emissions to water are expected to be negligible. However, particulate emissions from diesel engines are expected to contain dioxins. Dioxin emissions from diesel engines in the form of particulate would be expected to be a land emission. However, there is no data available to estimate a dioxin emission factor.

The recommended dioxin emission factor of 0.1 µg TEQ/tonne of fuel combusted is used to estimate emissions from diesel combustion in the transportation sector. Table 4.79 provides the emission estimate for releases to air, water and land.

Table 4.79 UNEP Toolkit Estimate of Emissions – Diesel Engines[a,b]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Diesel engines	-	0.72	-	NA	NA	NA	ND	ND	ND

[a] Source: UNEP (2003)

[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

In 2002, Environment Australia commissioned a study to estimate the total dioxin emissions from motor vehicles (PAE, 2002). Measurement data from Australia and

from around the world were used to derive dioxin emission factors for various vehicle types. The derived emission factors are presented in Table 4.80. The Australian dioxin emission factors are converted to the same units as the UNEP Toolkit emission factors assuming an average fuel consumption rate of 18 L/100 km for light duty vehicles (Diesel NEPM), a average fuel consumption rate of 40 L/100 km for heavy duty vehicles and buses (Diesel NEPM) and assuming an average fuel density of 0.84 kg/L.

Table 4.80 Derived Dioxin Emission Factors Based on Australian and Overseas Dioxin Measurement Data

Vehicle type	Emission factor range (pg I-TEQ/km)	Emission factor range (µg TEQ/tonne)
Light-duty vehicles running on diesel (passenger cars, LCVs)	6- 50	0.04-0.3
Heavy-duty vehicles running on diesel (trucks)	15-650	0.04-1.9
Buses running on diesel	12-530	0.04-1.6

The dioxin emission factor provided in the UNEP Toolkit is within the range of emission factors derived for Australian conditions, however, the UNEP Toolkit is toward to low end of the derived range.

The dioxin emission factors used to estimate emissions from diesel engines are presented in Table 4.81. The best estimate dioxin emission factor is taken to be the average between the high and low derived emission factors.

Table 4.81 Derived Dioxin Emission Factors – Diesel Engines [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
LDV [b]	0.04	0.2	0.3	NA	NA	NA	ND	ND	ND
HDV [c]	0.04	1.0	1.9	NA	NA	NA	ND	ND	ND
Buses [d]	0.04	0.8	1.6	NA	NA	NA	ND	ND	ND

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available
[b] LDV: Light-duty vehicles running on diesel (passenger cars, LCVs)
[c] HDV: Heavy-duty vehicles running on diesel (trucks)
[d] Buses running on diesel

Emissions from diesel fuel consumed in vehicle classes not described in Table 4.81 are estimated using the default UNEP Toolkit dioxin emission factor.

Table 4.82 provides the emission estimate for releases to air, water and land.

Table 4.82 Revised Estimate of Emissions – Diesel Engines [a]

	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
LDV [b]	0.06	0.3	0.4	NA	NA	NA	ND	ND	ND
HDV [c]	0.2	4.6	8.8	NA	NA	NA	ND	ND	ND
Buses [d]	0.02	0.4	0.8	NA	NA	NA	ND	ND	ND
Other	0.06	0.06	0.06	NA	NA	NA	ND	ND	ND
Total	**0.33**	**5.4**	**10.1**	-	-	-	-	-	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available; ND = No Data
[b] LDV: Light-duty vehicles running on diesel (passenger cars, LCVs)
[c] HDV: Heavy-duty vehicles running on diesel (trucks)
[d] Buses running on diesel

4.5.4 Heavy Oil Fired Engines

Heavy fuel oil (HFO) is commonly used for transportation in ships and for the heating of organic liquid storage tanks and stationary power generation. Power stations are considered in section 3.3.1 and are not be included in this subcategory.

4.1.1.2 Available Activity Data

Activity data for the amount of heavy fuel oil combusted in Australia were sourced from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The 2001 National Greenhouse Gas Inventory estimates that 37.4 PJ/annum of heavy fuel oil is combusted by marine vessels. Assuming an average fuel oil energy content of 40.1 MJ/L and an average density of 0.86 kg/L, the total mass of fuel oil combusted in 2001 is estimated to be 802,100 tonnes/annum.

Although much of the consumption of heavy fuel oil used on shipping is likely to take place outside of Australia (i.e. en route to destination), emissions from this source are included in the inventory, as this study will form a portion of a larger international dioxin emissions inventory.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The availability of emission factors is very limited for heavy fuel oil combustion (UNEP, 2003). The UNEP Toolkit presents a default emission factor to air of 4 µg TEQ/tonne of fuel combusted for all types of heavy fuel oil combustion. Emissions to land are not expected from this source and, hence, an emission factor is not provided in the UNEP Toolkit. Dioxin emissions are expected in the form of solid residue from heavy fuel oil combustion. However, currently there is not enough data available to derive an emission factor. Dioxin emissions in the solid residue formed from heavy fuel oil combustion would be expected to be an emission to water or land, depending on the disposal method employed.

Table 4.83 presents the UNEP Toolkit dioxin emission factors for heavy oil fired engine combustion in the transportation sector.

Table 4.83 Emission Factors – Heavy Oil Fired Engines [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Heavy oil fired engines	-	4	-	NA	NA	NA	NA	NA	NA

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.84 provides the emission estimate for releases to air, water and land.

Table 4.84 UNEP Toolkit Estimate of Emissions – Heavy Oil Fired Engines [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Heavy oil fired engines	-	3	-	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.6 Main Category 6 - Uncontrolled Combustion Processes

This category covers all combustion activity that does not occur in controlled devices such as incinerators, stoves or boilers. Uncontrolled combustion processes has been broken up into the following categories:

- Biomass burning (Section 4.6.1)
- Waste burning and accidental fires (Section 4.6.2).

4.6.1 Biomass Burning

This subcategory covers the burning of biomass occurring in the open. This includes forest fires, as well as burning of grassland and harvest residues.

4.1.1.2 Available Activity Data

All activity data for biomass burning were taken from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The mass of material combusted has been estimated using the algorithms presented in the National Greenhouse Gas Inventory Methodology Workbook 5.1 Non CO_2 emissions from the Biosphere (Environment Australia, 1998). For savanna fire, prescribed forests and wildfires, the total estimated mass combusted is calculated using the following formula:

$$MC_{jk} = A_{ij} \times M_{jk} \times Z_{jk}$$

where:

MC_{jk}	=	Annual estimated mass of biomass combusted for fire class k in state j	(tonnes/a)
A_{jk}	=	Mean annual area burned over 10 years from the inventory year (-8 to the inventory year +1)	(ha/a)
M_{jk}	=	Mean fuel load for fire class k and state j	(tonnes/ha)
Z_{jk}	=	Combined burning efficiency which accounts for the proportion of the scar which burns and the proportion of fuel exposed to fire which is volatilised for state j and fire class k	(-)

For agricultural residue burning the total biomass combusted is estimated using the following formula. For the inventory the standard categories of wheat and coarse grains and sugar cane are used. Coarse grains are defined as wheats, oats, barley, rye, rice, maize, sorghum, triticale and millet. The total estimated mass combusted is calculated using the following formula:

$$MC_{jk} = P_{jk} \times R_{jk} \times S_{jk} \times DM_{jk} \times F_{jk} \times Z_{jk}$$

where:

MC_{jk}	=	Annual estimated biomass combusted emissions for crop k in state j	(g/a)
P_{ij}	=	Mean annual production of crop k averaged over 3 years bracketing the inventory year (year-1 to year +1) in state j	(tonnes/a)
R_{jk}	=	Residue to crop ratio for state j and crop class k	(-)
S_{jk}	=	Fraction of residue remaining at the time of burning for state j and	(-)

		crop class k	
DM_{jk}	=	Dry matter content for state j and crop class k	(-)
F_{jk}	=	Fraction of crop production which is burned for state j and crop class k	(-)
Z_{jk}	=	Combined burning efficiency that accounts for the proportion of the crop in the field which burns and the proportion of fuel exposed to fire which is volatilised for state j and crop class k.	(-)

All parameters for the above equations were sourced from the 2001 National Greenhouse Gas Inventory (NGGIC, 2003). The total estimated biomass combusted in Australia is provided Table 4.85.

Table 4.85 Total Estimated Biomass Combusted [a]

Fire type	Total mass combusted (tonnes/annum)
Savanna & temperate grassland	216,173,000
Prescribed burning - forest fuel	3,505,000
Wildfires - forest fuel	10,588,000
Agricultural residue burning - wheat	3,492,000
Agricultural residue burning - coarse grains	6,044,000
Agricultural residue burning - sugar cane	653,300

a Source: NGGIC (2003)

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a default emission factor to air of 5 µ TEQ/tonne of material combusted for forest fires, grassland fires and moor fires and a default emission to land of 4 µg TEQ/tonne of material combusted. The default UNEP Toolkit emission factor to air for agricultural residue burning is 0.5 µg TEQ/tonne of material combusted and 10 µg TEQ/tonne of material combusted for emissions to land.

The UNEP emission factors were combined with the activity data to generate a default dioxin emission estimate from biomass burning in Australia.

Table 4.86 provides the emission estimate for releases to air, water and land.

Table 4.86 UNEP Toolkit Estimate of Emissions – Biomass Burning [a,b]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Savanna & temperate grassland	-	1,080	-	NA	NA	NA	-	900	-
Prescribed burning - forest fuel	-	20	-	NA	NA	NA	-	14	-
Wildfires - forest fuel	-	50	-	NA	NA	NA	-	42	-
Agricultural residue burning - wheat	-	2	-	NA	NA	NA	-	35	-
Agricultural residue burning - coarse grains	-	3	-	NA	NA	NA	-	60	-
Agricultural residue burning - sugar cane	-	0.3	-	NA	NA	NA	-	7	-
Total	**-**	**1,200**	**-**	**-**	**-**	**-**	**-**	**1,020**	**-**

a Source: UNEP (2003)

b L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.1.1.2 Revised Estimate Using Dioxin Measurement Data

DEH commissioned a project to determine the levels of dioxin emissions from bushfires in Australia (Meyer and Beer, 2004). The study measured dioxin emissions from various classes of biomass fires including cane fires, prescribed fires in forests, wildfires and savanna fires. There were no field measurements made for agricultural burning of cereal residues. Therefore, it was judged that emission factors derived for dioxin emissions to air for sugar cane burning could be used to estimate emissions from burning of cereal crops (Meyer and Beer, 2004).

Details of the dioxin measurements are as follows (Meyer and Beer, 2004):

- Cane fire in south east Queensland
- Two wildfire in north east Victoria
- Savanna fire in Darwin and Kakadu
- Prescribed fire measurements in south-west Western Australia in the Jarra/Kirri forests, Central Victoria in Messmate forests and south east Queensland in coastal woodland.

The emission measurements were assumed to be lognormally distributed and minimum and maximum emission factors were estimated corresponding to the 2.5 percentile and the 97.5 percentile (i.e. interval corresponding to the 95% confidence limit).

As many of the toxic congener concentrations were close to or below the detection limit, the emission factors were calculated for the lower bound (non detects set to zero concentration), middle bound (non detects set to half level of detection) and upper bound (non detects set to level of detection). Emission factors were calculated for total PCDDs, PCDFs and PCBs. Analysis of the results shows that the emission estimates derived from lower bound, middle bound and upper bound emission factors changes the mean emission estimate but has little effect on the upper 95% confidence limit and lower limit estimate (Meyer and Beer, 2004). This shows that the emission estimates are not significantly affected by the sample size and analytical sensitivity (Meyer and Beer, 2004). The middle bound emission factors are used to estimate dioxin emissions from biomass burning in the inventory and are presented in Table 4.87.

Table 4.87 Estimate Factors – Biomass Burning [a]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Savanna & temperate grassland	0.17	1.05	3.76	NA	NA	NA	-	4	-
Prescribed burning - forest fuel	0.34	0.85	2.03	NA	NA	NA	-	4	-
Wildfires - forest fuel	0.12	0.44	1.24	NA	NA	NA	-	4	-
Agricultural residue burning - wheat	0.16	0.82	2.25	NA	NA	NA	-	10	-
Agricultural residue burning - coarse grains	0.16	0.82	2.25	NA	NA	NA	-	10	-
Agricultural residue burning - sugar cane	0.16	0.82	2.25	NA	NA	NA	-	10	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

No dioxin measurement data were available for emissions to land. Therefore, the default UNEP emission factors to land were retained for the revised emission estimate. Table 4.88 provides the revised emission estimate for releases to air, water and land.

Table 4.88 Revised Estimate of Emissions – Biomass Burning [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Savanna & temperate grassland	36	230	810	NA	NA	NA	-	900	-
Prescribed burning - forest fuel	1.2	3.0	7.1	NA	NA	NA	-	14	-
Wildfires - forest fuel	1.3	4.7	13	NA	NA	NA	-	42	-
Agricultural residue burning - wheat	0.56	2.9	7.9	NA	NA	NA	-	35	-
Agricultural residue burning - coarse grains	0.97	5.0	14	NA	NA	NA	-	60	-
Agricultural residue burning - sugar cane	0.11	0.54	1.5	NA	NA	NA	-	7	-
Total	**49**	**240**	**820**	**-**	**-**	**-**	**-**	**1,020**	**-**

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.6.2 Waste Burning and Accidental Fires

This subcategory includes landfill fires, accidental fires in houses and factories, uncontrolled domestic waste burning, accidental fires in vehicles and open burning of wood (construction/demolition).

4.1.1.2 Available Activity Data

<u>Landfill Fires</u>

Studies in New Zealand, the United States and Ireland have based emission estimates from landfill fires on data from landfill experiments performed in Sweden. The Swedish study produced an average emission factor of 1,000 μg Nordic-TEQ per tonne of waste burnt. This emission factor is the default UNEP emission factor for landfill fires. Using this emission factor it was estimated that the dioxin emissions from landfill fires in Sweden was 35 g Nordic-TEQ/yr (Persson and Bergström, 1991).

The New Zealand, United States and Ireland inventories used this figure on a pro-rata basis to derive an annual estimate of emissions by assuming a direct correlation of emissions to population size in New Zealand and Sweden, United States and Ireland and Sweden. The population size in Sweden was 8,822,000 (1995 data as per US EPA, 1998) and the Australian population in 2002 was 19,633,000 (ABS, 2003b).

Therefore, using the pro-rata approach based on population, the activity data necessary to estimate dioxin emissions from landfill fires is the population of Australia. The dioxin emission factor corresponding to the measured emission factor of 1,000 μg Nordic-TEQ per tonne of waste burnt assuming that the rate of landfill fires is directly proportional to population is 4.0 μg TEQ/person.

Uncontrolled Domestic Waste Burning

No activity data were available for uncontrolled domestic waste burning. It is noted that all State and Territory Governments have banned domestic waste burning. Backyard barrel burning is permitted in the USA and it is considered a major source of dioxin emissions.

Accidental Building Fires

The total number of fires in structures (domestic, commercial and industrial buildings) were sourced for New South Wales and Victoria from the New South Wales Fire Brigade (NSWFB) Annual Report (NSWFB, 2002) and the Country Fire Authority (CFA) Annual Report 2002 (CFA, 2002) respectively for the 2001/2002 financial period (1 July, 2001 to 30 June 2002). No data were available for the other Australian States and Territories. Therefore, the total number of fires in structures were estimated based on the number of fires reported for NSW and Victoria and scaling the total number in direct total proportion to the population of Australia in comparison to the total population of NSW and Victoria. The estimated number of fires in structures in Australia is shown in Table 4.89.

Table 4.89 Estimated Number of Fires in Structures

Region	**Number of Fires**	**Population** [c]
NSW	7,784 [a]	6,640,000
Victoria	3,046 [b]	4,873,000
Australia	*19,241* [d]	19,663,000

[a] Source: NSWFB, 2002
[b] Source: CFA, 2002
[c] Source: ABS, 2003b
[d] Estimated value

The mass of combustible material consumed in fires can be estimated based on the size of the fire. The New Zealand Emission Inventory (Buckland et al., 2000) classifies fires in the following manner, based on the total number of reported domestic, commercial and industrial building fires:

- 90% of fires are small, consuming 100-250 kg of material per fire
- 90% of the remaining fires are moderate consuming 1-2.5 tonnes of material per fire
- 90% of the remaining fires are large, consuming 10-25 tonnes of material per fire
- The remaining fires are very large, consuming 250-1,000 tonnes of material per fire.

This methodology was applied to fire statistics for Australia. The range of material consumed in each fire allows a range of activity statistics for this subcategory as follows:

- Lower estimate: 10,000 tonnes/annum
- Upper estimate: 32,200 tonnes/annum.

Accidental Vehicle Fires

The total number of vehicle fires were sourced for New South Wales and Victoria from the New South Wales Fire Brigade (NSWFB) Annual Report (NSWFB, 2002) and the Country Fire Authority (CFA) Annual Report 2002 (CFA, 2002) respectively for the 2001/2002 financial period (1 July, 2001 to 30 June 2002). No data were available for the other Australian states and territories. Therefore, the total number of vehicle fires were estimated based on the number of fires reported for NSW and Victoria and scaling the total number in direct total proportion to the population of Australia in comparison to the total population of NSW and Victoria. The estimated number of vehicle fires in Australia is shown in Table 4.90.

Table 4.90 Estimated Number of Vehicle Fires

Region	Number of Fires	Population [c]
NSW	6,488 [a]	6,640,000
Victoria	2,104 [b]	4,873,000
Australia	*14,674* [d]	19,663,000

[a] Source: NSWFB, 2002
[b] Source: CFA, 2002
[c] Source: ABS, 2003b
[d] Estimated value

Open Burning of Construction Wood

No activity data were available for the open burning of construction wood.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides a default emission factor to air of 1,000 µg TEQ/tonne of material burnt for landfill fires. Using data from the Swedish study that the emission factor is based on and, assuming that the rate of landfill fires is directly proportional to population between countries, the 1,000 µg TEQ/tonne of material burnt is equivalent to 4.0 µg TEQ/person.

The UNEP Toolkit assigns a default emission factor for accidental fires on houses and factories of 400 µg TEQ/tonne of material burnt. The default emission factor to land for accidental fires in houses and factories is also 400 µg TEQ/tonne of material burnt.

The default UNEP emission factor to air for uncontrolled domestic waste burning is 300 µg TEQ/tonne of waste burnt and the default emission factor to land is 600 µg TEQ/tonne of material burnt.

The UNEP Toolkit provides an emission factor to air of 94 µg TEQ/vehicle fire and 18 µg TEQ/vehicle fire for emissions to land.

The UNEP Toolkit provides a default emission factor to air of 60 µg TEQ/tonne of material burnt and 10 µg TEQ/tonne of material burnt.

The UNEP Toolkit emission factors to air, water and land are outlined in Table 4.91.

Table 4.91 Emission Factors – Waste Burning and Accidental Fires [a,b]

Category	Air emission factor (µg TEQ/tonne)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne)		
	L	BE	H	L	BE	H	L	BE	H
Landfill fires	-	1,000	-	ND	ND	ND	ND	ND	ND
Accidental building fires	-	400	-	ND	ND	ND	-	400	-
Domestic waste burning	-	300	-	ND	ND	ND	-	600	-
Accidental vehicle fires		94 [c]	-	ND	ND	ND	-	18 [c]	-
Open burning of wood		60	-	ND	ND	ND	-	10	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data
[c] Emission factor units = µg TEQ/vehicle burnt

Table 4.92 provides the revised emission estimate for releases to air, water and land.

Table 4.92 UNEP Toolkit Estimate of Emissions – Waste Burning and Accidental Fires [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Landfill fires	-	79	-	ND	ND	ND	ND	ND	ND
Accidental building fires	4	8	13	ND	ND	ND	4	8.4	13
Domestic waste burning	ND	ND	ND	ND	ND	ND	ND	ND	ND
Accidental vehicle fires	1.4	1.4	1.4	ND	ND	ND	0.3	0.3	0.3
Open burning of wood	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total	**84**	**88**	**93**				**4.3**	**8.7**	**13.3**

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data

4.7 Main Category 7 - Production and use of Chemicals and Consumer Goods

This category concerns the potency of the chemicals and consumer goods production sector to generate dioxins (UNEP, 2003). Production and use of chemicals and consumer goods has been broken into the following categories:

- Pulp and paper production (Section 4.7.1)
- Chemical industry (Section 4.7.2)
- Petroleum industry (Section 4.7.3)
- Textile production (Section 4.7.4)
- Leather refining (Section 4.7.5).

4.7.1 Pulp and Paper Production

Some pulp and paper mill facilities (i.e. those using a chemical pulping process) combust lignin to generate electricity. In addition, bark, woodchips and other material are often burnt in boilers to produce steam and, in some instances, electricity.

4.1.1.2 *Available Activity Data*

Pulp and Paper Production

The production of paper involves pulping (reducing to fibres) of biomass raw material (or recycled paper) followed by pressing the pulp to produce a sheet of fibres. Various chemicals are added to affect the quality and properties of the paper (UNEP, 2003).

During the 2000/2001 financial period (1 July 2000 to 30 June 2001), the pulp and paper industry in Australia produced 2,897,000 tonnes of paper (APIC, 2003a). Of this, 395,000 tonnes were produced using mechanical pulping (pers comm. APIC, 2004) and 1,554,000 tonnes of paper were produced from recycled pulp (APIC, 2003a).

The remaining 948,000 tonnes of paper are produced using chemical pulping, by either the Sulphite process or by the Kraft (or sulphate) process. No data were available to estimate the mass of paper produced using each technology, however, the UNEP Toolkit states that approximately 10% of the world's pulp is produced by the Sulphite process. Therefore, it is estimated that 94,800 tonnes of paper were produced using the Sulphite process, whereas 853,000 tonnes of paper were produced using the Kraft process.

The UNEP Toolkit requires that the activity data is further segregated into new technology and old technology processes. No information was available to estimate the mass of paper produced using old and new technologies. For the inventory it was estimated that 10% of all paper produced by chemical pulping were produced using old technologies.

The estimated activity rates for pulp and paper production in Australia are presented in Table 4.93.

Table 4.93 Estimated Activity Data for Pulp and Paper Production

Classification	Activity Data (ADt/annum) [a]
Kraft pulp and paper - old technology	85,320
Kraft pulp and paper - new technology	767,880
Sulphite papers - old technology	9,480
Sulphite papers - new technology	85,320
Mechanical pulping	395,000
Recycling pulp	1,554,000
Total	**2,897,000**

[a] ADt = Air dried tonnes

Electricity Production

During the 2001/2002 financial period (1 July 2001 to 30 June 2002), the pulp and paper industry in Australia recovered 9,472 TJ of energy from black liquor and 3,467 TJ of energy from waste wood (APIC, 2003a). Assuming average energy contents of 15 GJ/tonne for black liquor and 16.2 GJ/tonne for wood, the total estimated fuel combusted was estimated using the following equation:

$$TA_i = \frac{\left(\dfrac{ER_i}{EC_i}\right)}{EF}$$

where:

TA_i	=	Total mass of substance i combusted to produce electricity in Australian pulp and paper facilities	(tonnes)
ER_i	=	Energy recovered from the combustion of substance i in Australian pulp and paper facilities	(GJ)
EC_i	=	Energy content of substance i combusted	(GJ/t)
EF	=	Efficiency of energy recovery.	(%)

Assuming an average efficiency of energy recovery (EF) of 30%, the estimated fuel combusted to produce electricity in Australian pulp and paper facilities are:

Black liquor = 2,105,000 tonnes/year

Bark = 713,400 tonnes/year.

Obernberger (2003) indicates that ash content by dry weight can vary between 6% for bark and 0.3% for softwoods.

Therefore, assuming that the average ash content by dry weight is 3.2%, the estimated total ash residue produced from the combustion of black liquor and bark is:

Ash produced = 90,200 tonnes/year.

4.1.1.2 UNEP Toolkit Estimate of Emissions

Pulp and Paper Production

The UNEP Toolkit provides default emission factors to water, residue (sludge) and to products (produced paper). Sludges removed from the pulp and paper industry generally are disposed on land, taken to landfill or incinerated. It is assumed for the inventory that all sludge generated from the pulp and paper industry is disposed on land or taken to landfill. Dioxin emissions to products from the pulp and paper industry are also considered an emission to land in this inventory.

The emission factors provided in the UNEP Toolkit for the pulp and paper industry are presented in Table 4.94 and Table 4.95.

Table 4.94 Emission Factors – Pulp and Paper Production - Effluents and Sludges [a,b]

Category	Air emission factor (μg TEQ/Adt[c])			Water emission factor (μg TEQ/Adt[c])			Land emission factor (μg TEQ/Adt[c])		
	L	BE	H	L	BE	H	L	BE	H
Kraft pulp and paper - old technology	NA	NA	NA	-	4.5	-		4.5	
Kraft pulp and paper - new technology	NA	NA	NA	-	0.06	-		0.2	
Sulphite papers - old technology	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulphite papers - new technology	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mechanical pulping	NA	NA	NA	ND	ND	ND	ND	ND	ND
Recycling pulp	NA	NA	NA	ND	ND	ND	ND	ND	ND

a Source: UNEP (2003)
b L = Low Estimate; BE = Best Estimate; H = High Estimate; ND = No Data; NA = Not Available;
c ADt = Air dried tonnes

Table 4.95 Emission Factors – Pulp and Paper Production - Pulp and Paper Products

Category[a]	Air emission factor (µg TEQ/Adt[c])			Water emission factor (µg TEQ/Adt[c])			Land emission factor (µg TEQ/Adt[c])		
	L[b]	BE	H	L	BE	H	L	BE	H
Kraft pulp and paper - old technology	NA	NA	NA	NA	NA	NA	-	8	-
Kraft pulp and paper - new technology	NA	NA	NA	NA	NA	NA	-	0.5	-
Sulphite papers - old technology	NA	NA	NA	NA	NA	NA	-	1	-
Sulphite papers - new technology	NA	NA	NA	NA	NA	NA	-	0.1	-
Mechanical pulping	NA	NA	NA	NA	NA	NA	-	NA	-
Recycling pulp	NA	NA	NA	NA	NA	NA	-	10	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available
[c] ADt = Air dried tonnes

Table 4.96 provides the UNEP Toolkit emission estimate for releases to air, water and land from pulp and paper products.

Table 4.96 UNEP Toolkit Estimate of Emissions – Pulp and Paper Production[a]

Category	Air emission (g TEQ/annum)			Water emission (g TEQ/annum)			Land emission (g TEQ/annum)		
	L	BE	H	L	BE	H	L	BE	H
Kraft pulp and paper - old technology	NA	NA	NA	-	0.38	-	-	1.1	-
Kraft pulp and paper - new technology	NA	NA	NA	-	0.05	-	-	0.6	-
Sulphite papers - old technology	NA	NA	NA	NA	NA	NA	NA	0.009	NA
Sulphite papers - new technology	NA	NA	NA	NA	NA	NA	NA	0.009	NA
Mechanical pulping	NA	NA	NA	ND	ND	ND	ND	NA	ND
Recycling pulp	NA	NA	NA	ND	ND	ND	ND	16	ND
Total	**-**	**-**	**-**	**-**	**0.43**	**-**	**-**	**17.2**	**-**

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available; ND = No Data

Electricity Production

The UNEP Toolkit provides default emission factors to air and residue for black liquor boilers and bark boilers used in pulp and paper production for electricity generation. Dioxin releases to ash (i.e. residue) are considered as emissions to land in this inventory.

The UNEP Toolkit emission factors to air, water and land are outlined in Table 4.97.

Table 4.97 Emission Factors – Pulp and Paper Production - Electricity Generation[a,b]

Category	Air emission factor (µg TEQ/tonne feed)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne ash)		
	L	BE	H	L	BE	H	L	BE	H
Black liquor boilers	-	0.07	-	NA	NA	NA	-	1,000	-
Bark boilers	-	0.4	-	NA	NA	NA	-	1,000	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.98 provides the revised emission estimate for releases to air, water and land from electricity generation during pulp and paper production.

Table 4.98 UNEP Toolkit Estimate of Emissions – Pulp and Paper Production - Electricity Generation [a]

Category	Air emission (g TEQ/annum)			Water emission (g TEQ/annum)			Land emission (g TEQ/annum)		
	L	BE	H	L	BE	H	L	BE	H
Black liquor boilers	-	0.1	-	NA	NA	NA	-	70	-
Bark boilers	-	0.3	-	NA	NA	NA	-	20	-
Total		**0.4**					**-**	**90**	**-**

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.7.2 Chemical Industry

Historically, the first observations of contamination with dioxins and furans were from the manufacture of chlorinated phenols and their derivatives. In particular, pesticides such as 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and pentachlorophenol (PCP) were found to be contaminated with dioxins and furans. High PCDF contamination was also found in polychlorinated biphenyls (PCB) (UNEP, 2003). PCBs along with some of the more toxic 'POPS' (persistent organic pollutants) pesticides are banned in Australia, although their presence is likely to be detected in the environment for many years due to their persistence.

The following processes are identified as sources of dioxins:

- Production of PCP
- Production of PCB
- Production of chlorinated pesticides
- Production of chloranil
- Production of chlorine
- Production of ECD (ethylene chlorine or 1,2-dichloroethane)/VCM (vinyl chloride monomer)/PVC (polyvinyl chloride).

4.1.1.2 Available Activity Data

<u>Production of PCP and PCB</u>

PCP/PCB production does not occur in Australia.

<u>Production of Chlorinated Pesticides</u>

The manufacturer of chlorinated pesticides in Australia has stated that dioxins produced by the facility are destroyed before release into the environment, using a 'Plascon' device (developed by CSIRO). This technology operates on the principal of pyrolysis and can attain temperatures of between 5,000 and 6,000 °C, ensuring 100% destruction. Dioxin formation is avoided by the use of pyrolysing conditions.

<u>Production of Chloranil</u>

No activity data were available for the production of chlorinal in Australia.

Production of Chlorine

Significant dioxin formation can occur in the chlorine production process if graphite anodes are used (UNEP, 2003). Many industrialised countries replaced the graphite anodes in the 1970's (UNEP, 2003). It is assumed that the use of graphite anodes to produce chlorine in Australia is negligible and hence, dioxin emissions from chlorine production are also negligible.

Production Of EDC/VCM/PVC

It appears that there is one facility in Australia involved in the production of EDC/VCM/PVC. The facility produces PVC only, importing the other products. Activity data for the 2002 period of 82,000 tonnes of PVC produced were obtained from the facilities annual report (Australian Vinyls, 2002).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides default emission factors for the production of PVC. The default emission factors are presented in Table 4.99.

Table 4.99 Emission Factors – Chemical Production - PVC Production [a,b]

Category	Air emission factor (µg TEQ/tonne feed)			Water emission factor (µg TEQ/tonne)			Land emission factor (µg TEQ/tonne ash)		
	L	BE	H	L	BE	H	L	BE	H
PVC production	-	0.00084	-	-	0.03		-	0.1	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate

Table 4.100 provides the revised emission estimate for releases to air, water and land.

Table 4.100 UNEP Toolkit Estimate of Emissions – Chemical Production - PVC Production [a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
PVC production	-	0.00007	-	-	0.003	-	-	0.009	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate

4.7.3 Petroleum Industry

The only potential source of dioxin formation in petroleum refining is in the regeneration of catalysts. No activity data were available and the UNEP Toolkit does not provide default emission factors.

Emissions from the petroleum industry are not included in this inventory.

4.7.4 Textile Production

The UNEP Toolkit indicates that little data are available on dioxin emissions to air, land and water from the textile industry, but indicates that measurable dioxin concentrations are likely to be found in the product.

Sources of dioxins in textile products are due to:

- Use of chlorinated chemicals, especially PCP, to protect the raw material (cotton, wool or other fibres, leather etc.)

- Use of dioxin-contaminated dyes (e.g. chloranil based dyes)
- Formation of dioxins during finishing processes.

Emissions from the textile industry are not included in this inventory.

4.7.5 Leather Production

The UNEP Toolkit indicates that it has been reported that leather products have contained measurable dioxin concentrations. Based on the observed congener profile, it can be assumed that PCP is the source for the contamination (UNEP, 2003). PCP is banned in Australia, therefore, dioxin emissions in leather products are assumed to be negligible.

4.8 Main Category 8 - Miscellaneous

Miscellaneous is used to quantify all emission sources that do not fit into any of the categories described elsewhere.

The following categories are included in the miscellaneous category:

- Drying of biomass (Section 4.8.1)
- Crematoria (Section 4.8.2)
- Smoke Houses (Section 4.8.3)
- Dry cleaning (Section 4.8.4)
- Tobacco smoking (Section 0).

4.8.1 Drying Of Biomass

The UNEP Toolkit indicates that dioxin emissions can occur from the drying of biomass if contaminated wood is used as fuel. The drying of biomass using combustion does not widely take place in Australia, as most wood chip and green fodder are air dried. Furthermore, the combustion of contaminated wood does not commonly occur in Australia. Therefore, dioxin emissions from the drying of biomass are expected to be insignificant.

4.8.2 Crematoria

Crematoria are used to reduce human bodies to ash for the purposes of burial. They are typically fired by natural gas.

4.1.1.2 Available Activity Data

During the 1998/1999 financial period (1 July 1998 to 30 June 1999) the number of cremations performed annually in Australia was approximately 60,000 (Unilabs, 2001). This was the most recent available data supplied to Unilabs by the Australian Cemeteries and Crematoria Association and this figure had remained static for the previous 10 years (Unilabs, 2001).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit describes three classes of emission factors ranging from Class 1 (low technology combustion with no air pollution control systems) to Class 3 (high technology combustion with sophisticated air pollution control systems). Class 1 emission factors should be used if combustion conditions are poor (e.g. temperatures below 850 °C), uncontrolled combustion air flow and if plastic and other decorative materials are burned together with the coffin. Class 2 emission factors should be applied if the combustion conditions are securely over 850°C, combustion air flow is controlled, no plastics or other decorative materials are combusted and some dust removal is in place. Class 3 emission factors should be applied if there are state of the art air pollution control systems in place (UNEP, 2003). It is assumed that all crematories operating in Australia have well controlled combustion conditions and some form of air pollution control. Therefore, the UNEP Class 1 emission factors are used to derive the low estimate, the UNEP Class 2 emission factors are used to derive a high estimate of dioxin emissions. The mean of the Class 1 and Class 2 emission factors is used to derive the best estimate of dioxin emissions.

A single emission factor is provided in the UNEP Toolkit for dioxin emissions in residue. The disposal route for this material is uncertain. For the purposes of this inventory disposal to land is assumed.

The UNEP emission factors to air, water and land are outlined in Table 4.101.

Table 4.101 Emission Factors – Crematoria[a,b]

Category	Air emission factor (µg TEQ/cremation)			Water emission factor (µg TEQ/cremation)			Land emission factor (µg TEQ/cremation)		
	L	BE	H	L	BE	H	L	BE	H
Crematoria	0.4	5	10	NA	NA	NA	-	2.5	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.102 provides the emission estimate for releases to air, water and land.

Table 4.102 UNEP Toolkit Estimate of Emissions – Crematoria[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Crematoria	0.02	0.3	0.6	NA	NA	NA	-	0.2	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.8.3 Smoke Houses

Smoke houses use the combustion of biomass to produce smoke in a closed chamber to preserve food. Dioxin emissions to air from the combustion products of biomass and to land from ash disposal are possible. No activity data are available for smoke houses in Australia. It is assumed that smoke house activity is small and dioxin emissions are negligible.

4.8.4 Dry Cleaning

The main source of dioxins from the dry cleaning process is from the actual textile being cleaned, which may have dioxin contamination due to manufacturing methods

(Hayes and Marnane, 2000). The dry cleaning process itself does not generate any dioxins. During the dry cleaning process, dioxins can be extracted from contaminated textiles and transferred into the solvent. The solvent is distilled for recovery and reuse and consequently dioxins can be concentrated in the residues, however, these residues would not be disposed of directly to water or land.

Tobacco Smoking

Tobacco smoking is regarded as a minor source of dioxin emission to air, with the smoker normally regarded as the most exposed individual due to inhalation of smoke.

4.1.1.2 Available Activity Data

For the 2001 period the Australian Institute of Health and Welfare (AIHW) estimated that the number of smokers (over the age of 14) was approximately 3.6 million and that the mean number of cigarettes smoked per week was 109.4 per person (AIHW, 2002). This equates to an estimated activity rate of 394 million cigarettes smoked per week or 20,500 million cigarettes smoked per year in Australia. It is estimated that the margin of error on the estimated activity rate is ±20%.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The default UNEP Toolkit emission factor of 0.1 pg TEQ/cigarette is used to estimate dioxin emissions to air from cigarette smoking. The range of activity data estimates is used to estimate the range of dioxin emissions. In theory there would be an emission to land through cigarette ash. However, it is likely that the contribution to land would be insignificant (UNEP, 2003). Therefore, dioxin emissions to land are assumed to be negligible.

The UNEP emission factors to air, water and land are outlined in Table 4.103.

Table 4.103 Emission Factors – Tobacco Smoking [a]

Category	Air emission factor (pg TEQ/cigarette)			Water emission factor (pg TEQ/cigarette)			Land emission factor (pg TEQ/cigarette)		
	L	BE	H	L	BE	H	L	BE	H
Tobacco smoking	-	0.1		NA	NA	NA	-	2.5	-

[a] Source: UNEP (2003)
[b] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.104 provides the emission estimate for releases to air, water and land.

Table 4.104 UNEP Toolkit Estimate of Emissions – Tobacco Smoking[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Tobacco smoking	0.001	0.002	0.003	NA	NA	NA	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.9 Main Category 9 - Disposal/Landfills

This section covers dioxin emissions from waste disposal to land or water, i.e. non-thermal waste management.

The following categories are included in the miscellaneous category:

- Landfills and waste dumps (Section 4.9.1)
- Sewage and Sewage treatment (Section 4.9.2)
- Open water dumping (Section 4.9.3)
- Composting (Section 4.9.4)
- Waste oil disposal (Section 4.9.5).

4.9.1 Landfills and Waste Dumps

Landfills and waste dumps are places where waste is disposed of by burying in the ground or piling on the surface. A landfill is considered a controlled engineered waste storage site with respect to inputs/types of wastes, location of different types of waste and management (gas and water collection etc.).

4.1.1.2 Available Activity Data

No estimate of leachate emissions to groundwater in Australia was identified. The New Zealand (Buckland et al., 2000) and Ireland Emissions Inventories (Hayes and Marnane, 2000) use a methodology to estimate leachate production from landfills based on rainfall, mass of material landfilled, and the size of the landfill.

For the 1996/1997 financial period (1 July 1996 to 30 June 1997), the Australian Bureau of Statistics (ABS) estimated that 21.2 million tonnes of solid wastes were received and disposed at landfills nationwide. Assuming that the volume of landfilled waste has grown by 5% annually, the estimated landfilled waste in 2002 is estimated at 27.7 million tonnes of waste per annum. Assuming a density for landfill waste of 500 kg/m^3 (Buckland et al., 2000; Hayes and Marnane, 2000), the volume of landfilled waste is estimated at 55,000,000 m^3/annum. No information was available regarding the number of landfills operating in Australia or the estimated waste acceptance rates for each landfill.

To estimate the volume of leachate generated from rainfall infiltration through the landfill cover, the following assumptions were made:

- Site area. The refuse volume was estimated by assuming a minimum landfill depth of 10 metres and a maximum landfill depth of 20 metres
- The mean annual rainfall for Australia was obtained from the Australian Bureau of Meteorology
- Percentage rainfall infiltration. It was assumed that between 10 and 20% of rainfall would generate leachate at landfills. This assumption assumes that 20% of rainfall will generate leachate for small and medium sized landfills as these sites generally have poorer cover, and 10% of rainfall will generate

leachate for large landfills which tend to have more highly engineered covers.

The total volume of leachate produced from new refuse placed annually is between 139,000 and 555,000 m^3/a.

To estimate the leachate generated from waste already in place an estimate of the total landfilled waste must be made. The quantity of waste landfilled is assumed to have grown by approximately 5% per annum. Based on this, a rough estimate of the quantity of waste landfilled over the past fifty years can be approximated at 1,000,000,000 m^3. Assuming that the refuse is distributed at an average landfill depth of 10 to 20 metres and assumptions for rainfall and rain infiltration are as previously given, the estimated volume of leachate generated from the refuse in place in closed and operating landfills is 2,500,000-10,100,000 m^3/a.

Therefore, the total estimated leachate from landfills is as follows:

- Lower estimate: 2,700,000 m^3/annum
- Upper estimate: 10,700,000 m^3/annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The default UNEP Toolkit emission factor to water of 30 pg TEQ/L for non-hazardous landfilled waste is used to estimate dioxin emissions from landfills and waste dumps. The range of emission estimates are based on the low and high estimate of leachate produced from landfills and the best estimate is the mean of the low and high estimate. There is significant uncertainty in the estimated emissions from landfills.

Table 4.105 provides the emission estimate for releases to air, water and land.

Table 4.105 UNEP Toolkit Estimate of Emissions – Landfills and waste dumps[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Landfills and waste dumps	NA	NA	NA	0.08	0.2	0.3	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.9.2 Sewage and Sewage Treatment

Sewage in this case is the wastewater arising from human sanitation and any associated industrial wastes that are treated in the same systems. Sludge describes the solid component of the wastewater that is often extracted during the sewage treatment process.

4.1.1.2 Available Activity Data

<u>Wastewater</u>

The Australia State of the Environment Report 2001 (EA, 2001) estimates that for the year 2000, 1,823,614 ML of waste wastewater was disposed of to coastal waters, inland waters and land.

Sludge

Sludge disposal routes in Australia were sourced from Priestley (1984) and are provided in Table 4.106.

Table 4.106 Sewage Sludge Disposal Routes[a]

Disposal Route	Total Quantity of Sludge (tonnes of dry solids/a)	% of Total
Agriculture	27,000	9
Landfill or stockpile	228,000	76
Incineration	6,000	2
Ocean	39,000	13
Total	300,000	100

[a] Source: Priestley (1984)

In 2002, ocean sewage sludge disposal was not permitted. It is assumed that the majority of this material was disposed used for agriculture. Therefore, the total sludge disposed to land in 2002 can be estimated at 330,000 tonnes. ([agriculture + landfill + ocean] x 2002 population (19 million)/1984 population (17 million)).

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit emission factors for sewage sludge from urban environments are used to estimate dioxin emissions to air, water and land.

The UNEP emission factors to air, water and land are provided in Table 4.107.

Table 4.107 Emission Factors – Sewage and sewage treatment[a,b]

Category	Air emission factor (pg TEQ/L)			Water emission factor (pg TEQ/L)			Land emission factor (µg TEQ/tonne dry matter)		
	L	BE	H	L	BE	H	L	BE	H
Sewage and sewage treatment	NA	NA	NA	-	0.5	-	-	100	-

[a] Source: UNEP (2003)
[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.108 provides the emission estimate for releases to air, water and land.

Table 4.108 UNEP Toolkit Estimate of Emissions – Sewage and sewage treatment[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Sewage and sewage treatment	NA	NA	NA	-	0.9	-	-	33	-

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.9.3 Open Water Dumping

This subcategory relates to discharges from households, offices and other small businesses as well as run-off from contained land (e.g. parking lots) (UNEP, 2003).

4.1.1.2 Available Activity Data

The Australia State of the Environment Report 2001 (EA, 2001) estimates that the average volume of stormwater discharge annually is about 3,000,000 ML/annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides three emission factors for open water dumping as follows:

- Class 1: Mixed domestic and industrial water dumping (5 pg TEQ/L)
- Class 2: Urban environments (0.5 pg TEQ/L)
- Class 3: Remote environments or where controls are in place for open water dumping (0.1 pg TEQ/L).

The Class 1 and Class 3 emission factors are used to estimate the range of dioxin emissions from open water dumping whereas the Class 2 emission factor is used to generate the best estimate of dioxin emissions from open water dumping.

Table 4.109 provides the emission estimate for releases to air, water and land.

Table 4.109 UNEP Toolkit Estimate of Emissions – Open water dumping[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Open water dumping	NA	NA	NA	0.3	1.5	15	NA	NA	NA

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

4.9.4 Composting

Composting is a popular method of disposal for wastes originating from kitchen activities, gardening, park and other public/private area maintenance, agriculture and forestry. Basically, any organic material can be composted and this disposal process generally has a high degree of acceptance by the public. The composting process results in a loss of about 50% of the weight basis of the input material (UNEP, 2003).

4.1.1.2 Available Activity Data

Three forms of composting typically occur in Australia as follows:

- Home composting
- Industrial composting on-site
- Composting in metropolitan centres by local councils.

Activity data for composting by local councils in metropolitan centres and on-site industrial composting were not available. Home composting activity data were obtained from published statistics from the Australian Bureau of Statistics and from information obtained from New South Wales Department of Environment and Conservation.

The Australian Bureau of Statistics reported that in 1996, 45% of Australian households were estimated to compost (ABS, 2002) at an average rate of 460 kg of compost generated per household per year (ABS, 1998). The ABS also estimated that the number of households in 2002 was 7,393,000. Therefore, the total compost generated in Australia in the year 2002 is 1,520,000 tonnes. The UNEP Toolkit states that the average moisture content of compost is approximately 30% (UNEP, 2003). Therefore, the total compost (dry matter) generated in 2002 is estimated to be 1,062,000 tonnes.

The New South Wales Department of Environment and Conservation (NSWDEC) reports that 29% of households in the Greater Sydney Region were reported (by the former NSW Waste Board) to participate in home composting in 1999 (NSWDEC, 2004). This is significantly less than the participation rate reported by ABS. Furthermore, EcoRecycle Victoria (2000) estimates that of participating home composting households, an average of approximately 260 kg of organic waste is composted per household per year. Using the UNEP Toolkit estimate of 30% for the average moisture content, these statistics generate a total estimated compost (dry matter) in 2002 of 390,000 tonnes.

Therefore, the total estimated mass of home compost generated is as follows:

- Lower estimate: 390,000 tonnes/annum
- Upper estimate: 1,062,000 tonnes/annum.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit provides three emission factors for composting as follows:

- Class 1: Composting organic matter (100 µg TEQ/tonne (dry matter))
- Class 2: Garden/kitchen waste (15 µg TEQ/tonne (dry matter))
- Class 3: Green materials from non-impacted environments (5 µg TEQ/tonne dry matter).

The Class 1 emission factor was derived from materials that may contain high levels of compost, such as the content of vacuum cleaners or any fine particulates such as house dust, soil from contaminated land entering with vegetable and other plant leftovers, leaves from alleys impacted by traffic using leaded petrol, greens from cemeteries or other pesticide treated organic wastes (UNEP, 2003). These materials are not be expected in home composting, therefore, the Class 2 and Class 3 emission factors are used along with the high and low estimates for home compost activity rates to estimate the range of dioxin emissions from composting. The best estimate is taken to be the average of the high and low estimates.

The UNEP emission factors to air, water and land are provided in Table 4.110.

Table 4.110 Emission Factors – Composting[a,b]

Category	Air emission factor (µg TEQ/ tonne dry matter)			Water emission factor (µg TEQ/ tonne dry matter)			Land emission factor (µg TEQ/ tonne dry matter)		
	L	BE	H	L	BE	H	L	BE	H
Composting	NA	NA	NA	NA	NA	NA	5	10	15

a Source: UNEP (2003)

a L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

Table 4.111 provides the emission estimate for releases to air, water and land.

Table 4.111 UNEP Toolkit Estimate of Emissions – Composting[a]

Category	Air emission (g TEQ/a)			Water emission (g TEQ/a)			Land emission (g TEQ/a)		
	L	BE	H	L	BE	H	L	BE	H
Composting	NA	NA	NA	NA	NA	NA	3.6	7.3	11

[a] L = Low Estimate; BE = Best Estimate; H = High Estimate; NA = Not Available

It is noted that the emission estimate for composting is very uncertain and must be treated as an order of magnitude estimate only. Australian dioxin testing of compost materials would increase the reliability of this estimate.

4.9.5 Waste Oil Treatment (Non-Thermal)

This section covers the disposal of waste oils that are not covered under transformers containing PCBs which are dealt with under reservoirs.

4.1.1.2 Available Activity Data

The Department of the Environment and Heritage estimates that over 500,000 tonnes of oil is sold in Australia every year and that approximately half of this volume is recycled (DEH, 2003). Therefore, it is estimated that approximately 250,000 tonnes of waste oil is treated in Australia annually.

4.1.1.2 UNEP Toolkit Estimate of Emissions

The UNEP Toolkit does not provide an emission factor for oil treatment, as there are insufficient data on dioxin emissions.

5. RESULTS

Table 5.1 presents summary best estimate dioxin emissions for each category included in the inventory.

The category with the highest estimated emission is uncontrolled combustion (i.e. biomass burning, waste burning and accidental fires). Uncontrolled combustion is estimated to contribute to nearly 70% of total emissions to air and over 80% of total emissions to land. Disposal and landfilling is estimated to be the largest source of dioxin emissions to water, contributing over 75% of total emissions.

Uncontrolled combustion processes, which are significantly influenced by emissions from grass fires, contribute approximately 75% of all dioxin emissions in Australia. This high estimate results from the combustion of a large mass under uncontrolled conditions associated with higher dioxin formation potential.

The other major emission categories, in order of decreasing emissions, are:

1. Ferrous and non ferrous metal production
2. Production of chemicals and consumer goods
3. Power generation and heating
4. Disposals/Landfilling
5. Waste Incineration.

Table 5.1 Summary of Best Estimate Dioxin Emissions to Air, Water and Land in Australia for 2002

Source Categories	**AIR**		**WATER**		**LAND**	
	Best estimate (g TEQ/a)	Total Contribution to Air Emissions (%)	Best estimate (g TEQ/a)	Total Contribution to Water Emissions (%)	Best estimate (g TEQ/a)	Total Contribution to Land Emissions (%)
Waste Incineration	6.5	1.30	0.36	10.58	21.9	1.72
Ferrous and Non-ferrous Metal Production	112	22.45	0.02	0.44	44.4	3.48
Power Generation and Heating	35	7.05	0.00	0.00	31.8	2.49
Mineral Products	1.9	0.37	0.00	0.00	0	0.00
Transportation	9.1	1.83	0.00	0.00	0	0.00
Uncontrolled Combustion Processes	330	66.84	0.00	0.00	1030	80.75
Production of Chemicals and Consumer Goods	0.43	0.09	0.43	12.64	110	8.40
Miscellaneous	0.31	0.06	0.00	0.00	0.15	0.01
Disposal/Landfilling	0.00	0.00	2.61	76.34	40.3	3.15
TOTAL	**500**	**100**	**3.42**	**100**	**1,300**	**100**

Table 5.2 summarises the best estimate dioxin emissions by UNEP emission source subcategory.

Table 5.2 Emission Estimates by Subcategory

Source Category	Annual Estimated Release (g TEQ/a)			
	Air	Water	Land	Total [a]
Biomass burning	240	0	1,020	1,270
Pulp and paper production	0.4	0.4	110	110
Waste burning and accidental fires	88	0	8.7	97
Zinc production	50	0	0	50
Fossil fuel power plants	14.3	0	27.7	42.0
Aluminium production	4.45	0	31.80	36.26
Sewage and sewage treatment	0	0.9	33	34
Metal ore sintering	32	0	0	32
Medical waste incineration	6.39	0.36	21.9	28.7
Household heating and cooking with biomass	20.2	0	1.6	21.8
Iron and steel production plants	20.3	0	0.03	20.3
Copper production	1	0	13	14
Composting	0	0	7.3	7.3
Diesel engines	5.4	0	0	5.4
Other non-ferrous metal production	4	0	0	4
Heavy oil fired engines	3	0	0	3
Domestic heating and cooking with fossil fuels	0.4	0	2.5	2.9
Open water dumping	0	1.5	0	1.5
Ceramics production	1	0	0	1
Lead production	0.5	0	0	0.5
Cement production	0.48	0	0	0.48
Crematoria	0.3	0	0.15	0.46
4-Stroke Engines	0.3	0	0	0.3
Landfills and waste dumps	0	0.2	0	0.2
2-Stroke engines	0.2	0	0	0.2
Coke production	0.15	0.02	0	0.17
Brick	0.16	0	0	0.16
Biomass Power Plants	0.11	0	0.03	0.14
Lime	0.10	0	0	0.10
Shredders	0.09	0	0	0.09
Glass	0.09	0	0	0.09
Landfill and biogas combustion	0.07	0	0	0.07
Sewage sludge incineration	0.04	0	0.01	0.05
Asphalt mixing	0.02	0	0	0.02
Municipal solid waste incineration	0.013	0	0	0.013
Chemical industry	0	0.003	0.009	0.011
Hazardous waste incineration	0.005	0.002	0.002	0.009
Tobacco smoking	0.002	0	0	0.002
Total	**500**	**3.4**	**1,300**	**1,800**

[a] Total may not exactly equal the sum of emissions to air, water and land due to rounding error

Figure 5.1, Figure 5.2 and Figure 5.3 show the estimated dioxin emissions and the range of dioxin emissions from each subcategory included in the inventory to air, water and land respectively.

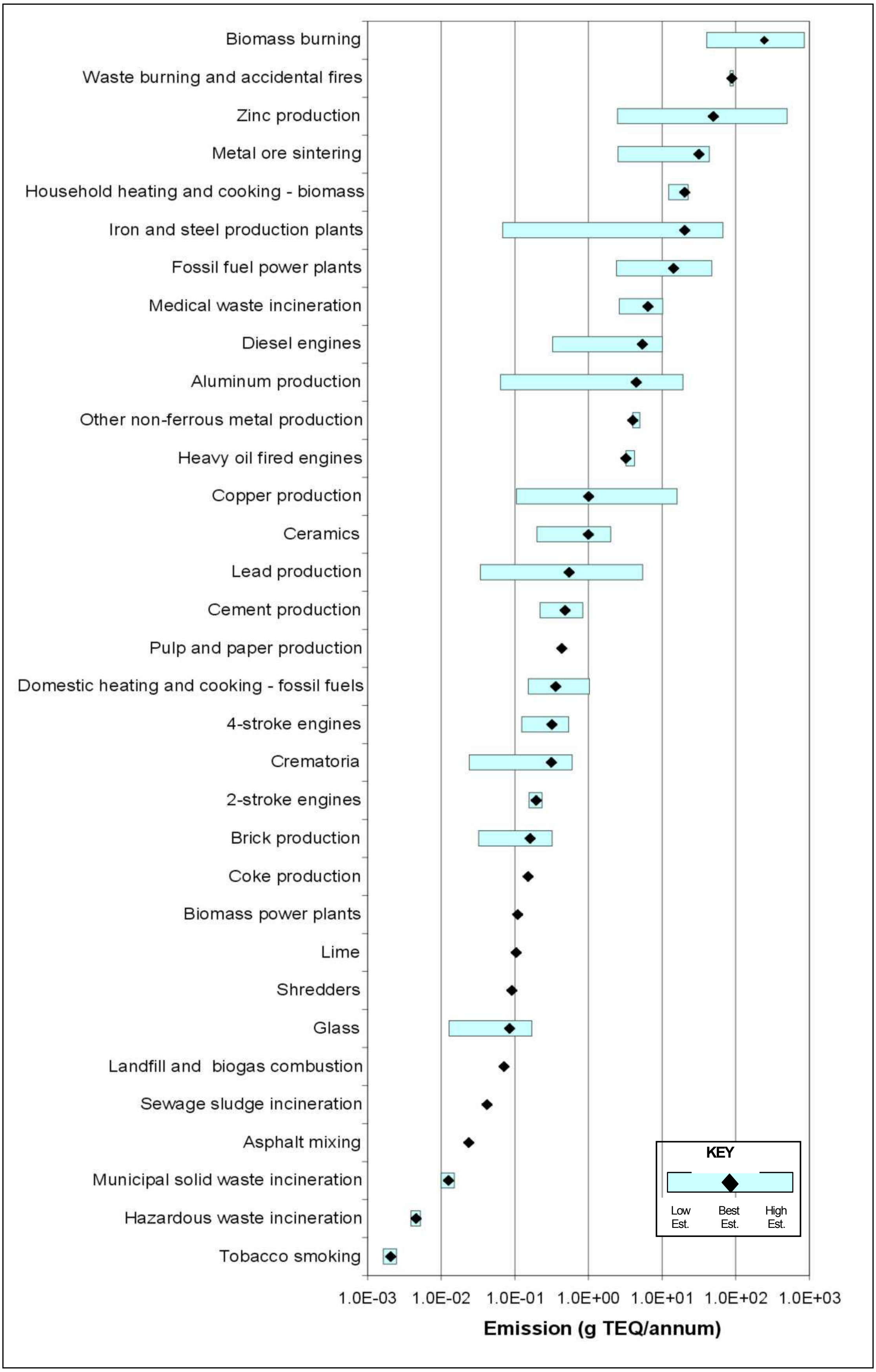

Figure 5.1 Estimated Dioxin Emissions to Air, Australia, 2002

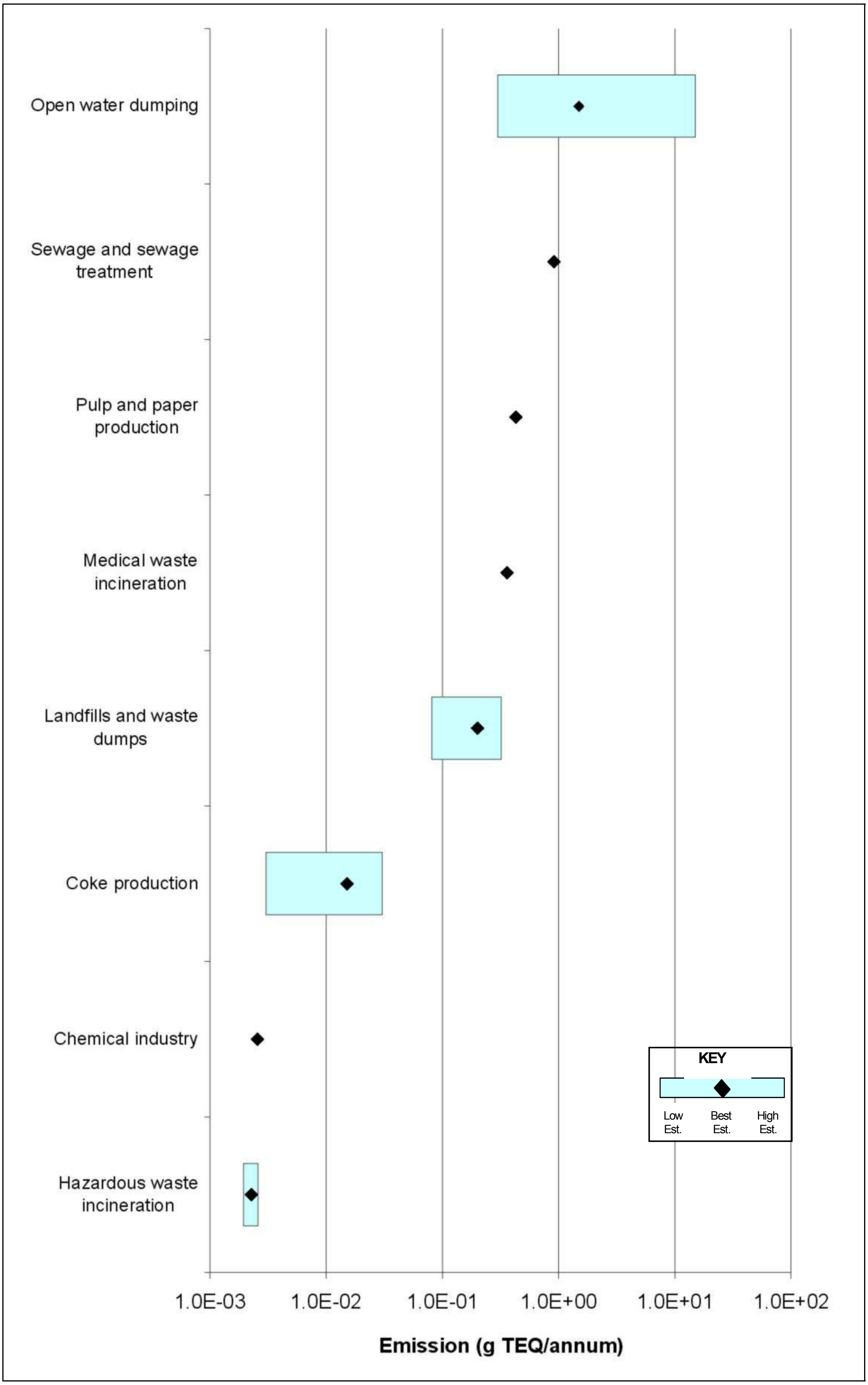

Figure 5.2 Estimated Dioxin Emissions to Water, Australia, 2002

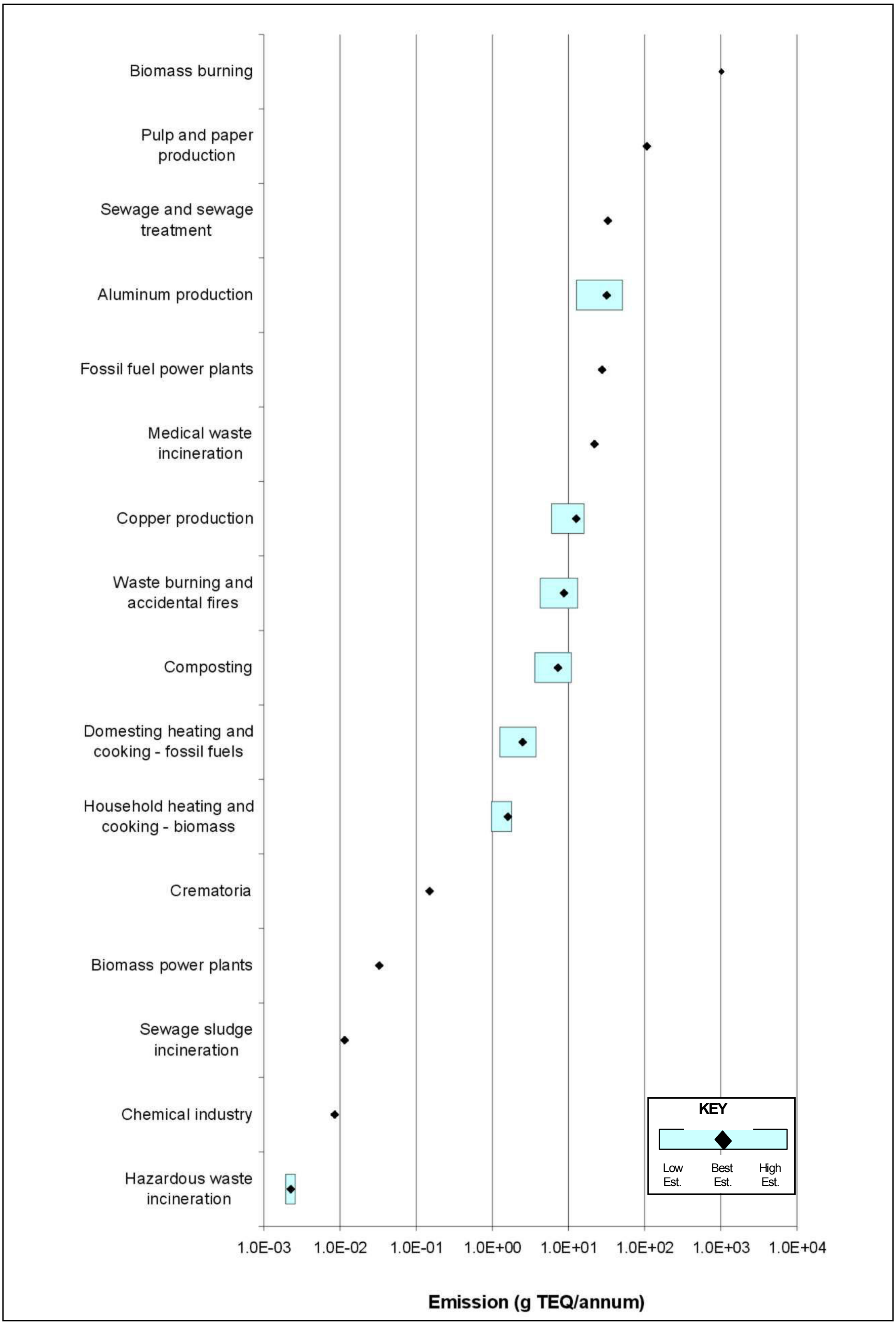

Figure 5.3 Estimated Dioxin Emissions to Land, Australia, 2002

6. Limitations of study

There are many limitations to the emission estimates presented in this inventory. The limitations of the study are discussed below:

- The most significant limitation is the lack of source test data for Australian sources, resulting in a heavy reliance on default UNEP Toolkit emission factors based on international dioxin measurement data. Emission factors as a tool for estimating emissions are inherently prone to uncertainties as they are typically based on limited testing of a source population. When applying these international emissions data to Australian sources this uncertainty is increased due to potential differences in process technologies, operating conditions and practices and pollution control equipment
- In addition to the above point, some UNEP Toolkit emission factors were originally derived using assumed conversion factors to supplement data gaps. Examples of this include assumed fuel heat values, densities and flue gas conversion rates (i.e. m3/tonne) to derive emission factors. This adds further to the uncertainties in the original emission factors
- The emission factors for a large number of sources span several orders or magnitude. This is indicative of the potentially large variations that are observed within a particular emission source category. With such large ranges it becomes difficult to identify significant dioxin contributors, particularly if the upper bound indicates that the source may be significant, while the lower bound indicates a minor contribution. As the estimated emission ranges indicate, a source thought to be significant may in fact be quite minor. Better source characterisation and source test data will enable greater confidence in smaller ranges
- Some source categories may have such variable process technologies, operational conditions etc. that it may be difficult to reliably predict emissions from these sources using limited data. Better characterisation of industry will enable the identification of these industry types. Industries where little variation is encountered could perhaps base emission factors upon more limited test data. This type of characterisation would initially be important for sources considered potentially large emitters
- Emission factors for many industries are based on test data taken during very short sample periods. The emission results are likely to be reflective of relatively good combustion and operational practice and therefore may not be indicative of likely emissions during process upsets and/or abnormal operation.

Considering these limitations, it is stressed that the emission estimates as determined by this study are **INDICATIVE** only of the likely dioxin releases by various sources in Australia. The estimates have been developed based on the best information currently available.

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