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Department of the Environment

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Volume 1

The Australian Government Submission to the United Nations Framework Convention on Climate Change

Australian National Greenhouse Accounts

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Executive summary

ES.1 Background Information on Greenhouse Gas Inventories

This is Australia's *National Inventory Report 2012,* submitted under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP). The *National Inventory Report 2012* contains national greenhouse gas emission estimates for the period 1990-2012, compiled under the rules for reporting applicable to the UNFCCC. It also contains estimates for 2008 - 2012 compiled using the reporting rules applicable to the Kyoto Protocol.

The report has been prepared in accordance with the UNFCCC *Reporting Guidelines on Annual Inventories,* agreed by the Conference of Parties at its eighth (decision 18/CP.8), ninth (decision 13/CP.9) and eleventh sessions (decision 14/CP.11), and set out in document FCCC/SBSTA/2006/9 and the supplementary reporting requirements under Article 7 of the Kyoto Protocol (Decision 15/CMP.1).

The *National Inventory Report 2012* has been compiled using methods which conform to the international guidelines adopted by the UNFCCC (IPCC 1997, 2000 and 2003). The methodologies used to estimate Australia's inventory have been improved over time and will continue to be refined as new information emerges, and as international practice evolves. The impact on greenhouse gas emission estimates of refinements to methodologies adopted for this inventory has been reported in Chapter 10 (Volume 3).

The responsibility for Australia's greenhouse emissions reporting has been assigned to the Department of the Environment (DE, 'the Department'). The Department undertakes all aspects of activity data co-ordination, emissions estimation, quality control, the preparation of the reports and their submission to the UNFCCC on behalf of the Australian Government.

In addition to this r*eport*, the Department publishes a range of supporting emissions estimates that, together, constitute the *Australian National Greenhouse Accounts*, including:

- *Quarterly Updates of Australia's National Greenhouse Gas Inventory*, which provides a summary of the Kyoto Protocol account, updated on a quarterly basis;
- an overview of the *State and Territory Greenhouse Gas Inventories*; and
- the *National Inventory by Economic Sector,* comprising emission estimates by economic sector rather than by IPCC sectors as in this report.

These documents are available on the Department's website at www.environment.gov.au/. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

ES.2 Summary of the National Emission and Removal Related Trends

ES.2.1 Greenhouse Gas Inventory - UNFCCC

Australia's total greenhouse gas emissions, excluding the *land use, land use change and forestry* (*LULUCF*) sector, were estimated to be 543.6 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2012. This represents an increase of 2.1 Mt, or 0.4%, on net emissions recorded in 2011, and an increase of 31.0% (128.7 Mt CO_2-e) above 1990 levels (Table ES.1).

Australia's total greenhouse gas emissions, including net emissions from the *LULUCF* sector, were 558.8 Mt CO_2-e in 2012. Overall, total emissions have increased by 13.3 Mt CO_2-e, or 2.4%, on net emissions recorded in 1990. By 2012, the net *land use, land use change and forestry* emissions had decreased from 130.5 Mt CO_2-e in 1990 to 15.2 Mt CO_2-e in 2012.

Table ES.01: Australia's net greenhouse gas emissions by sector under the UNFCCC

Sector and Subsector	Emissions Mt CO_2-e			Per cent change
	1990	2011	2012	1990-2012
1 All energy (combustion + fugitive)	286.7	409.9	413.4	44.2%
Stationary energy	194.6	282.6	283.2	45.5%
Transport	60.3	88.5	90.2	49.7%
Fugitive emissions from fuel	31.9	38.9	39.9	25.2%
2 Industrial Processes	24.7	34.1	31.2	26.5%
3 Solvent and other product use[(a)]	IE	IE	IE	NA
4 Agriculture	86.5	84.6	87.4	1.0%
6 Waste	17.0	13.0	11.7	-31.4%
Total net emissions (excluding *LULUCF*)	**415.0**	**541.5**	**543.6**	**31.0%**
5 *Land use, land use change and forestry*	130.5	-60.6	15.2	-88.4%
Total net emissions (including *LULUCF*) [(b)]	**545.5**	**480.9**	**558.8**	**2.4%**

(a) Included elsewhere - emissions are included in *industrial processes* for confidentiality reasons.

(b) These totals and trend do not reflect Australia's emissions and removals under the Kyoto Protocol accounting framework.

The decreasing trend in emissions from *LULUCF* since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland* and *grassland*. Changes in *LULUCF* emissions from year to year are affected by other factors, principally natural disturbances such as wildfires. Emissions from wildfires contribute a large proportion of Australia's total net emissions in some years.

ES.2.1.1 Major Inventory Developments and Recalculations

The inventory is developed in accordance with an Inventory Improvement Plan. Some of the major method improvements that have resulted in recalculations to the national inventory are listed below:

- Revisions to *land use, land use change and forestry* emission estimates as part of ongoing inventory improvements and in response to expert review team recommendations.
- Application of higher tier data collected under the National Greenhouse and Energy Reporting (NGER) System including for estimating fugitive emissions from open cut coal mines sector.
- Revisions to natural gas combustion reported in the *Australian Energy Statistics* (AES) that improve time series consistency with NGER data from 2008-09.

ES.2.2 Kyoto Protocol

Australia's initial assigned amount under the Kyoto Protocol (KP) is equivalent to 591.5 Mt CO_2-e for each year of the first commitment period (2008-2012). The initial assigned amount is fixed and is the value that Australia's KP emissions account will be compared with for the first commitment period.

Under the KP accounting rules Parties must report emissions from the Article 3.1 (Annex A) sectors, namely the *energy*, *industrial processes*, *solvents*, *agriculture* and *waste* sectors. Only a subset of the *LULUCF* sector emissions and removals are included in the account. These include deforestation, afforestation and reforestation activities that have occurred since 1990 (Article 3.3 activities), which are mandatory, and forest, cropland or grazing land management and revegetation (Article 3.4 activities), which can be elected by the Party. Australia has not elected to account for any Article 3.4 activities for the first commitment period.

The total net emissions associated with the KP account for Article 3.1 sectors and Article 3.3 *LULUCF* activities were 582.7 Mt CO_2-e in 2008, 570.8 Mt CO_2-e in 2009, 565.0 Mt CO_2-e in 2010, 553.6 Mt CO_2-e in 2011 and 554.6 Mt CO_2-e in 2012. There have been no transfers of KP units from international sources under Articles 6, 12 and 17.

Table ES.02: Emissions and removals associated with Articles 3.1 and 3.3 of the Kyoto Protocol, 2008–2012

Sector and Subsector	2008 emissions Mt CO_2-e	2009 emissions Mt CO_2-e	2010 emissions Mt CO_2-e	2011 emissions Mt CO_2-e	2012 emissions Mt CO_2-e
Article 3.1 – Annex A sectors					
1 Energy	411.7	413.3	411.4	409.9	413.4
2 Industrial Processes	33.1	30.9	33.9	34.1	31.2
3 Solvent and other product use[(a)]	IE	IE	IE	IE	IE
4 Agriculture	86.6	83.8	81.5	84.6	87.4
6 Waste	13.2	13.2	13.4	12.9	11.7
Inventory Total	**544.6**	**541.2**	**540.2**	**541.5**	**543.6**
Article 3.3 – KP *LULUCF* activities[(b)]	38.2	29.7	24.8	12.1	10.9
Afforestation/ Reforestation [(c)]	-18.6	-19.1	-22.9	-26.4	-21.9
Deforestation	56.7	48.8	47.7	38.5	32.8
Kyoto Protocol Total	**582.7**	**570.8**	**565.0**	**553.6**	**554.6**

(a) Included elsewhere - emissions are included in *industrial processes* for confidentiality reasons.

(b) Australia has elected to account for Article 3.3 activities on an annual basis.

(c) Accounting quantity in accordance with paragraph 4 of annex to decision 16/CMP.1.

While this report is primarily focused on estimates for the 1990-2012 period preliminary estimates are available for the period July 2012 – June 2013. The preliminary estimate for emissions from Annex A sectors in 2013 is 543.2 Mt CO_2-e. This result is similar to the estimate for 2012.

A full report on the holdings and transactions of Kyoto units from the national registry and the calculation of the KP-*LULUCF* accounting quantity are provided in Chapter 12.

ES.3 Overview of Source and Sink Category Emission Estimates and Trends

ES.3.1 Greenhouse Gas Inventory

The *energy* sector was the largest source of greenhouse gas emissions in 2012 comprising 76.0% (413.4 Mt CO_2-e) of total net emissions (excluding *LULUCF*). *Energy* emissions increased by 44.2% between 1990 and 2012 and increased by 0.8% between 2011 and 2012 (Table ES.2).

For the *energy* subsectors in 2012:

- *stationary energy* was the main contributor to total net emissions, excluding *LULUCF*, (52.1%) and increased by 0.2% between 2011 and 2012;
- *transport* emissions (16.6% of total net emissions, excluding *LULUCF*) increased by 1.9% between 2011 and 2012; and
- *fugitive emissions from fossil fuels* (7.3% total net emissions, excluding *LULUCF*) increased by 1.9% between 2011 and 2012.

Industrial processes made up 5.7% (31.2 Mt CO_2-e) of the total net emissions (excluding *LULUCF*) for 2012 and decreased by 8.5% between 2011 and 2012.

Agriculture emissions made up 16.1% (87.4 Mt CO_2-e) of total net emissions (excluding *LULUCF*) in 2012 and increased by 3.3% between 2011 and 2012.

The *waste* sector contributed 2.2% (11.7 Mt CO_2-e) of the total net emissions (excluding *LULUCF*) in 2012 and decreased by 9.5% between 2011 and 2012.

The *land use, land use change and forestry* sector was a net source of 15.2 Mt CO_2-e in 2012 and emissions increased from a net sink of 60.6 Mt CO_2-e in 2011.

A full overview of emission estimates by source and sink is given in Chapter 2. More detailed information on the emission results for individual sectors has been reported in the introductions to Chapters 3 - 6.

ES.3.2 KP-*LULUCF* Activities

In 2012, *afforestation/reforestation* activities on unharvested land units contributed a net sink of 22.2 Mt CO_2-e while harvested land units contributed a net source of 10.7 Mt CO_2-e. *Deforestation* activities were a net source of 32.8 Mt CO_2-e in 2012.

Australia has elected to account for the Article 3.3 activities on an annual basis. In accordance with the harvested forest sub-rule (paragraph 4 of the annex to decision 16/CMP.1) in calculating the *afforestation/reforestation* accounting quantity for 2008 – 2012 the emissions on harvested land units have been set to zero where the emissions are greater than the removals on those land units.

ES.4 Other Information (e.g. indirect greenhouse gases)

The National Inventory Report also presents estimates of emissions of indirect greenhouse gases, including NO_x, CO, NMVOC and SO_2. For these gases, no Global Warming Potentials are available to enable their conversion to carbon dioxide equivalent (CO_2-e) emissions. Consequently these emissions sources are not able to be aggregated, nor are they covered by the reporting provisions of the Kyoto Protocol. Estimates of Australia's emissions from NO_x, CO, NMVOC and SO_2 are presented in Chapter 2.

Acknowledgements

The Department of the Environment wishes to acknowledge the many individuals and organisations that contributed to the development of the national methods over the years. Although the list of all who have provided input is too long to include here, the Department of the Environment recognises the contributions of those involved in the preparation of the inventory.

National Greenhouse Gas Inventory Committee

Mr Rob Sturgiss	Australian Government
Dr Ian Galbally	CSIRO
Ms Kylie Goodwin	Victoria
Ms Libby Doughty	Tasmania
Mr Matt Riley	New South Wales
Ms Megan Surawski	Queensland
Mr Andrew Thiele	South Australia
Mr Michael Bruvel	Northern Territory
Mr Paul Sutton	Australian Capital Territory
Ms Sarah Gill	Western Australia

National Inventory User Reference Group

Mr Mike Grundy	CSIRO
Mr Alex Gosman	Australian Industry Greenhouse Network
Mr Andrew Macintosh	ANU Centre for Climate Law and Policy
Dr Hugh Saddler	Pitt and Sherry Pty Ltd
Mr Mick Stephens	Australian Forest Products Association
Ms Deborah Kerr	National Farmers' Federation

Department of the Environment

National Inventory Team for the compilation of emission estimates and drafting of the National Inventory Report in the Energy, Industrial Processes, Solvents, and Waste sectors.

Forest & Inventory Model Unit, Agriculture Unit, Geospatial Analysis Unit and Dr Mick Meyer (CSIRO) for the compilation of emission estimates and drafting of the National Inventory Report in the Agriculture and Land Use, Land Use Change and Forestry sectors.

The resources and expertise of the following Commonwealth agencies have also significantly contributed to the National Inventory Report:

Australian Bureau of Agricultural and Resource Economics and Sciences;

Australian Bureau of Statistics;

Bureau of Resources and Energy Economics;

Department of Agriculture (formerly the Department of Agriculture, Forestry and Fisheries);

Department of Infrastructure and Regional Development (formerly the Department of Infrastructure and Transport);

Department of Industry (formerly the Department of Resources, Energy and Tourism);

Geoscience Australia.

General Notes

Units

The units mainly used in this inventory are joules (J), grams (g), tonnes (t), metres (m) and litres (L), together with their multiples. Standard metric prefixes used in this inventory are:

kilo (k) = 10^3 (thousand)

mega (M) = 10^6 (million)

giga (G) = 10^9

tera (T) = 10^{12}

peta (P) = 10^{15}

Emissions are generally expressed in gigagrams (Gg) in the inventory tables, as called for under international guidelines, and in megatonnes (Mt) in the text of the inventory report:

gigagram (Gg) = 1,000 tonnes = 1 kilotonne (kt)

megatonne (Mt) = 1,000,000 tonnes = 1,000 Gg

Gases

CF_4	perfluoromethane (a perfluorocarbon)
C_2F_6	perfluoroethane (a perfluorocarbon)
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
HFCs	hydrofluorocarbons
N_2O	nitrous oxide
NMVOC	non-methane volatile organic compounds
NO_x	oxides of nitrogen
PFCs	perfluorocarbons
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide

Global Warming Potentials

CO_2 = 1	HFC-23 = 11,700
CH_4 = 21	HFC-125 = 2,800
N_2O = 310	HFC-134a = 1,300
CF_4 = 6,500	HFC-143a = 3,800
C_2F_6 = 9,200	SF_6 = 23,900

Conversion Factors

From element basis to molecular mass	From molecular mass to element basis
$C \rightarrow CO_2$: x 44/12 = 3.67	$CO_2 \rightarrow C$: x 12/44 = 0.27
$C \rightarrow CH_4$: x 16/12 = 1.33	$CH_4 \rightarrow C$: x 12/16 = 0.75
$N \rightarrow N_2O$: x 44/28 = 1.57	$N_2O \rightarrow N$: x 28/44 = 0.64

Indicators

In the tables, the following standard indicators are used:

NO (not occurring) when the activity or process does not occur in Australia

NA (not applicable) when the activity occurs in Australia but the nature of the process does not result in emissions or removals

NE (not estimated) where it is known that the activity occurs in Australia but there are no data or methodology available to derive an estimate of emissions

IE (included elsewhere) where emissions or removals are estimated but included elsewhere in the inventory

C (confidential) where reporting at a disaggregated level could lead to the disclosure of confidential information

PART 1:

ANNUAL INVENTORY SUBMISSION

1. Introduction and Inventory Context

1.1 Background Information on Greenhouse Gas Inventories

1.1.1 Inventory reporting

The United Nations Framework Convention on Climate Change (UNFCCC) was ratified by Australia in 1992 and entered into force in March of 1994. One of the principal commitments made by the ratifying Parties under the Convention was to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs).

Australia's *National Inventory Report 2012* provides estimates of Australia's net greenhouse gas emissions for the period 1990-2012. This report and associated common reporting format (CRF) tables[1] are submitted to the UNFCCC to fulfil Australia's reporting obligations under the Convention.

Australia's ratification of the Kyoto Protocol (KP) came into force in March 2008 and this inventory submission also constitutes Australia's annual submission under the Kyoto Protocol.

The report has been prepared in accordance with the *UNFCCC Reporting Guidelines on Annual Inventories* agreed by the Conference of Parties at its eighth (decision 18/CP.8), ninth (decision 13/CP.9) and eleventh sessions (decision 14/CP.11), and set out in document FCCC/SBSTA/2006/9 and the supplementary reporting requirements under Article 7 of the KP (Decision 15/CMP.1).

The emission estimates provided in this report have been compiled in accordance with the *Intergovernmental Panel on Climate Change* (IPCC) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997); IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000); and the *Good Practice Guidance on Land Use, Land Use Change and Forestry (IPCC 2003)*. The aim is to ensure that the estimates of emissions are accurate, transparent, consistent through time and comparable with those produced in the inventories of other countries.

1.1.2 Gases

The *National Inventory Report* covers sources of greenhouse gas emissions, and removals by sinks, resulting from human (anthropogenic) activities for the major greenhouse gases; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Also covered in ancillary fashion for reporting under the UNFCCC are the indirect greenhouse gases; carbon monoxide (CO), oxides of nitrogen (NO_X), and non-methane volatile organic compounds (NMVOCs). Sulphur dioxide (SO_2), an aerosol precursor, is also included because emissions of this gas influence global warming.

The *National Inventory Report* presents emissions for each of the major greenhouse gases as carbon dioxide equivalents (CO_2-e) using the 100-year global warming potentials (GWPs) contained in the 1995 IPCC *Second Assessment Report* (IPCC 1996)[2]. As greenhouse gases vary in their radiative activity, and in their atmospheric residence time, converting emissions into CO_2-e allows the integrated effect of emissions of the various gases to be compared.

[1] Australia's CRF tables are available on the web at http://ageis.climatechange.gov.au/QueryCRFTable.aspx

[2] GWPs used are, 1 for CO_2, 21 for CH_4, 310 for N_2O, 6,500 for the PFC perfluoromethane (CF_4), 9,200 for the PFC perfluoroethane (C_2F_6), and 23,900 for SF_6. GWPs are not available for the indirect greenhouse gases, and in accordance with the UNFCCC reporting guidelines, are reported but are not included in the inventory total.

1.1.3 Sectors

Emissions and removals have been grouped under six sectors that have been defined by the IPCC. These represent the main human activities that contribute to the release or capture of greenhouse gases into, or from, the atmosphere:

- *Energy*
- *Industrial processes*
- *Solvent and other product use*
- *Agriculture*
- *Land use, land use change and forestry* (*LULUCF*)
- *Waste*

Under the KP, only a subset of the *LULUCF* sector emissions and removals are open to being included in the account. These include *deforestation*, *afforestation and reforestation* activities that have occurred since 1990 (Article 3.3 activities which are mandatory) and *forest, cropland or grazing land management and revegetation* (Article 3.4 activities which can be elected by the Party). Australia has not elected to account for any Article 3.4 activities for the first commitment period.

1.1.4 Reporting year

The Australian inventory is reported for Australian fiscal years as key data sources, such as the National Greenhouse and Energy Reporting (NGER) System and national energy and agricultural statistics obtained from national statistical agencies (the Australian Bureau of Agricultural and Resource Economics and Sciences, the Bureau of Resources and Energy Economics and the Australian Bureau of Statistics), are published on this basis. The year 2012 refers to the Australian fiscal year from 1 July 2011 to 30 June 2012, and a similar format is used for other years to ensure that time series consistency is maintained. The estimates of emissions and removals in the *LULUCF* sector, where inventory-specific monitoring systems have been put in place, are produced on a calendar year basis. The use of fiscal year data is consistent with *Good Practice* as the use of these data conforms to the normal practice of Australia's national statistical agencies and leads to more accurate emissions estimates.

1.1.5 Structure of the National Inventory Report

The structure of this *National Inventory Report* has been organised to conform to the *UNFCCC Reporting Guidelines on Annual Inventories* (FCCC/SBSTA/2006/9) and the supplementary reporting requirements under Article 7 of the Kyoto Protocol (Decision 15/CMP.1).

The *National Inventory Report* provides estimates of Australia's total net emissions in 2012 and identifies trends in emissions between 1990 and 2012 for each of the sectors and for the main greenhouse gases. It also provides, *inter alia*, comprehensive information on estimation methodologies and data quality; details of recalculations of emissions estimates and background on the national system and the inventory preparation processes in order to facilitate international review and comparisons with the inventories of other countries.

National System

In accordance with Article 5, paragraph 1 of the Kyoto Protocol, Australia has put in place a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. The guidelines for national systems (annex to Decision 19/CMP.1) detail the characteristics of a national inventory system (Table 1.1). Sections 1.2 to 1.8 of the *National Inventory Report* describe the main components of Australia's national system.

Supplementary Kyoto Protocol reporting requirements

Chapters 11 to 15 of the *National Inventory Report* contain the supplementary Kyoto Protocol reporting information on emissions and removals from the *LULUCF* Article 3.3 activities, Kyoto units, minimisation of adverse impacts in accordance with Article 3.14 and changes to the national system and registry.

1.1.6 National Greenhouse Accounts

In addition to this report, the Department of the Environment (DE) publishes a range of supporting emission estimates that, together, constitute the *Australian National Greenhouse Accounts*. In addition to the *National Inventory Report*, the Department also prepares:

- *Quarterly Updates of Australia's National Greenhouse Gas Inventory*, which provides a summary of the Kyoto Protocol account and preliminary estimates of the Kyoto Protocol account updated on a quarterly basis;
- an overview of the *State and Territory Greenhouse Gas Inventories*; and
- the *National Inventory by Economic Sector,* comprising emission estimates by economic sector (rather than by IPCC sectors, as in this report).

They provide additional information with respect to Australia's emissions on both a regional and industry basis and are available on the Department's website: http://www.climatechange.gov.au/climate-change/emissions.

Table 1.1: Reporting of national system characteristics against the guidelines for national systems (Annex to Decision 19/CMP.1)

GENERAL FUNCTIONS		
Paragraph number	**Description of national inventory system characteristic**	**Section cross reference**
10a	Establish and maintain institutional, legal and procedural arrangements	1.2
10b	Ensure sufficient capacity for timely function of national systems functions	1.2
10a	Technical competence of staff	1.2
SPECIFIC FUNCTIONS		
Paragraph number	**Description of national inventory system characteristic**	**Section cross reference**
12a	Designate a single national entity	1.2
12b	Make available postal and electronic addresses of national entity	1.2
12c	Information on actors, institutional, legal and procedural arrangements	1.2
12d	Elaborate a QA/QC plan	1.6
12e	Establish process for official consideration	1.2
13	Improve quality of the inventory	1.6, 10
14a	Identify key source categories	1.5, Annex 1
14b	Prepare estimates in accordance with methods described by the IPCC	1.4
14c	Collect sufficient activity data to support the methods	1.3
14d	Estimate inventory uncertainty	1.7, Annex 7
14e	Information on recalculations	10
14g	Information on general inventory QC (tier 1) procedures in accordance with the QA/QC plan	1.6
15a	Information on specific QC (tier 2) procedures	1.6

SPECIFIC FUNCTIONS		
15b	Information on QA procedures including provision for basic review of the inventory by personnel not involved in the inventory development	1.2, 1.6
15c	Information on provision for more extensive review for key source categories	1.6
15d	Information on how 15(b) and 15(c) relate to evaluation of inventory planning process in order to meet quality objectives	1.3.1
16a	Information on how information is archived	1.3.2
16b	Information on what information is archived	1.3.2

1.2 Institutional Arrangements

1.2.1 Single national entity

In accordance with the guidelines for national systems (Decision 19/CMP.1 Annex paragraph 12(a)), the responsibility for Australia's national inventory has been assigned to a single agency, the Department of the Environment (DE, 'the Department'), under the Administrative Arrangements Orders of the Australian Government.

On 18 September 2013, the Australian Government announced changes to the makeup of Australian Government Department's including the incorporation of climate change sections of the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE) into the DE. All of the functions within the former DIICCSRTE responsible for inventory compilation have moved into the DE as part of these updated administrative arrangements.

The Department is responsible for all aspects of activity data co-ordination, emissions estimation, quality control, improvement planning, preparation of the reports, and the submission of reports to the UNFCCC on behalf of the Australian Government.

The designated representative with overall responsibility for the national inventory is:

Assistant Secretary
National Inventory Systems and International Reporting Branch
Department of the Environment
Australian Government
GPO Box 787
Canberra ACT 2601
AUSTRALIA
nationalgreenhouseaccounts@environment.gov.au

1.2.2 Capacity for timely performance of the general and specific functions of the national system

The guidelines for national systems (Decision 19/CMP.1 Annex paragraph 10(b)) require that there is sufficient capacity for the timely performance of national inventory system functions. The production of high quality and timely greenhouse gas inventories is a resource-intensive process. To meet these objectives of quality and timeliness Australia has invested significant financial and human resources through the development of capital assets, training of DE staff and the contracting of expert consultants as needed.

IT software systems

Estimation of emissions is conducted by the Department, utilising the Australian Greenhouse Emissions Information System (AGEIS) and, for the *LULUCF* sector, the Full Carbon Accounting Model (FullCAM) (see Figures 1.1 and 1.2).

The AGEIS has been designed to meet the requirements for national inventory systems and is an integral part of the inventory preparation and publishing processes. In particular, it fully integrates quality control procedures into the compilation process as well as centralising emissions estimation, inventory compilation and reporting, and data storage activities. The AGEIS provides high transparency levels for the inventory, with emissions data for the set of *National Greenhouse Accounts* publicly accessible through an interactive web interface: http://ageis.climatechange.gov.au/.

The AGEIS is continuing to be expanded and refined to support the range of *National Greenhouse Accounts* in accordance with the *AGEIS Strategic Plan*. Recent investment includes the integration of uncertainty calculations within the AGEIS and construction of a range of QC tools, including the automatic population of carbon balances to enhance and automate existing actions.

While the AGEIS is used for final preparation of the *National Greenhouse Accounts*, the inventory uses the Full Carbon Accounting Model (FullCAM) to estimate emissions and removals from the *LULUCF* sector and KP-*LULUCF* activities. FullCAM has been progressively developed to provide a greenhouse gas accounting capability for *Land use Land use Change and Forestry*. The progressive development of the model is set around priorities according to the scale of emissions from either the land use activity or carbon pool. To date the fully spatially explicit process-based ecosystems modelling capability has been completed for the conversion of forests to other land uses (e.g. cropping and grazing), conversion of lands to forest, croplands remaining croplands and the grassland component of grasslands remaining grasslands.

Figure 1.1: Department of the Environment inventory asset structures and relationships

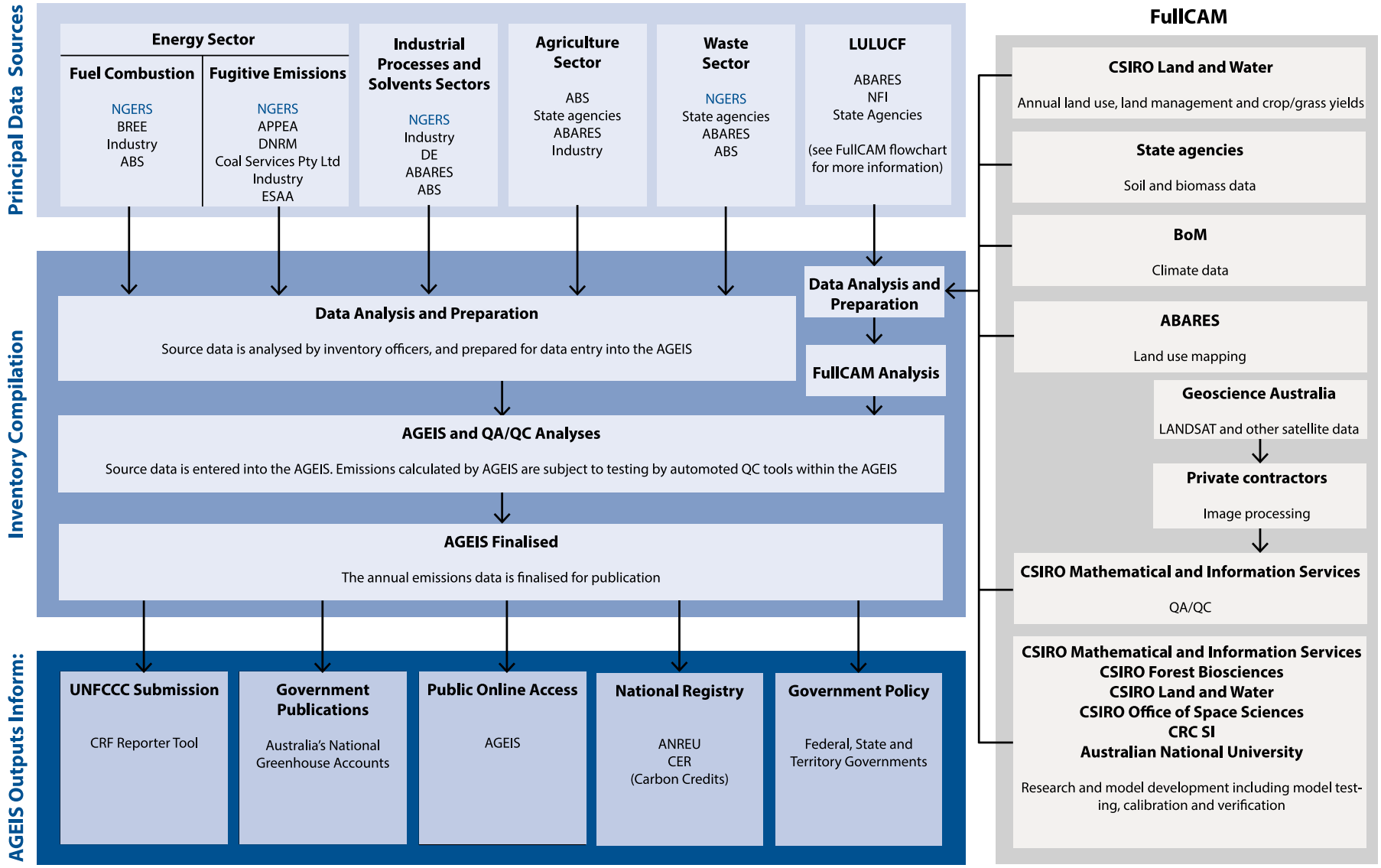
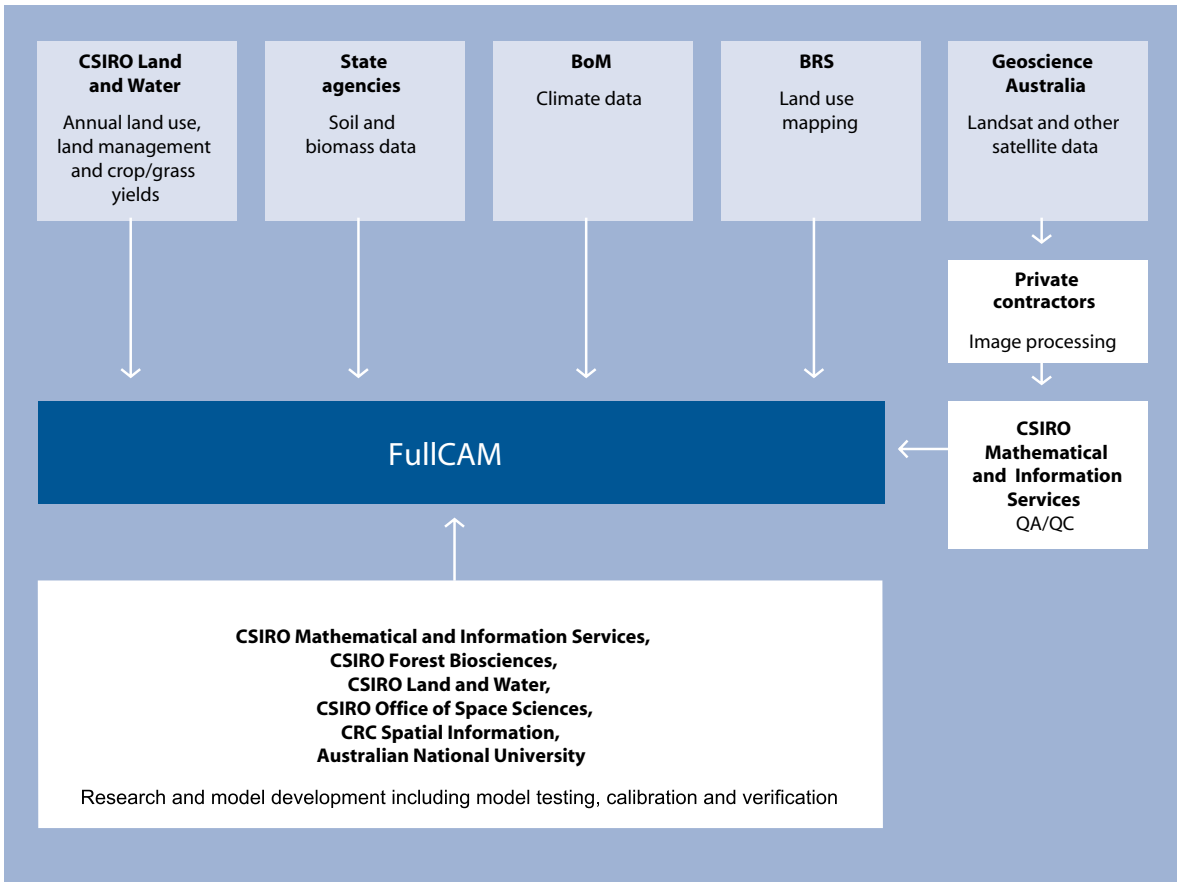


Figure 1.2: FullCAM institutional arrangements



1.2.3 Technical competence of staff

DE staff and external consultants have extensive experience in inventory preparation. The Department aims to maximise the number of staff that have undergone the UNFCCC reviewer training and participated in UNFCCC Expert Review processes. All senior staff are qualified reviewers and have been accepted onto the UNFCCC Roster of Experts. The Department has strongly supported the participation of Australian experts in the UNFCCC review process as this experience helps staff identify areas for improvement in Australia's inventory preparation. Where particular technical expertise is not available within the Department, expert consultants are engaged to undertake analysis and review work.

1.2.4 Process for Official Consideration and Approval of the Inventory

The *National Inventory Report*, in place since the 1990s, is prepared by the Department and is subject to the oversight of the Department's National Inventory and Projections Executive Committee. The draft *National Inventory Report* is considered by the National Greenhouse Gas Inventory Committee (NGGI C), which comprises representatives of the Australian, state and territory governments, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

In 2011-12, the Department expanded its formal external review arrangements by adding a new consultation group, the National Inventory Users Group. This group comprises key domestic users of the National Inventory data and includes Australia's premier science organisation, academics, sectoral experts from the consulting sector and industry representatives. The National Inventory User Group meets once or twice a year to prioritise and oversee inventory improvements.

This NGGI C and National Inventory Users Group are the principal mechanisms for formal external review of the report prior to its release.

The *National Inventory Report* is also circulated prior to submission to other Australian Government departments and agencies, and relevant state experts, through the NGGI C.

Release of each year's inventory and submission to the UNFCCC is approved by the Secretary of the Department.

1.3 Brief Description of the Process of Inventory Preparation

1.3.1 Inventory Preparation

Key steps in the annual inventory preparation process (with indicative dates in parentheses) are determined by the needs of the system and output and quality objectives. The timing is determined by the UNFCCC submission timelines and data availability. Steps 1-17 provide an overview of the general inventory cycle. The cycle commences with a review of emission estimation methods, the allocation of tasks, selection of external consultants, and the preparation of the AGEIS for the compilation of the forthcoming inventory. The cycle is completed by external independent review provided by the UNFCCC Expert Review Teams.

Planning and methodology improvement

1. Preparation of *Evaluation of Outcomes* document for the previous year (March – April).
2. Preparation of *QA/QC* and *Inventory Improvement plans*, taking into account DE review of methodologies and activity data; UNFCCC expert review recommendations and the *Evaluation of Outcomes* document (May).
3. Development of investment and maintenance plan for the AGEIS, incorporating the *QA/QC plan* (June).
4. Methodology development, review, and incorporation into AGEIS (June - October).

Data collection and entry

5. Activity data collection, conducted annually by the Department. It is heavily reliant on NGER data, and published data from Australia's economic statistics agencies, and is subject to quality control checks.
6. Activity data entry into the AGEIS input database, by the Department, through predefined data entry templates (August - December).

Implementation of quality control measures

7. Activity data verification and quality control - the Department uses the AGEIS to systematically report a range of diagnostic statistics on the activity data to facilitate identification and correction of anomalous entries to ensure time series consistency and consistency across sectoral emissions estimates.
8. A designated analyst (known as a Supervisory user) investigates anomalies and records an assessment of the quality of the activity data in the system.

9. The data quality is checked and internally audited by a designated analyst, known as the Database Operations Manager (DOM), to provide quality control. Only when the DOM is satisfied is the input data transferred to the core database where emissions estimation are undertaken.

Emission estimation

10. The AGEIS is used to generate emission estimates for all inventory years using time series consistent methodologies.

Emission and report review

11. Emissions estimates verification is undertaken where the Department analysts repeat the range of tests on emissions estimates generated by the AGEIS to ensure time series consistency, consistency across sectoral emissions estimates, and accuracy of recalculations.

12. Completion of quality control measure tests to ensure estimates meet quality criteria.

13. The compiled inventory is circulated to the National Greenhouse Gas Inventory Committee of State and Territory government representatives and the National Inventory Users Reference Group representatives for comment prior to public release (February).

Report publication

14. Automated population of CRF tables (February).

15. The inventory is available for public release.

16. Release of Australia's *National Greenhouse Accounts* and the AGEIS database of emission estimates and background data at http://www.climatechange.gov.au/en/climate-change/emissions (April).

17. UNFCCC Expert Review of the National Inventory Report and CRF Tables (August-November).

1.3.2 Data collection, processing and storage

Data collection

Data collection to support the preparation of the *National Greenhouse Accounts* is managed centrally by the Department utilising a mix of approaches to ensure the reliable flow of data from other agencies to support inventory preparation.

National Greenhouse and Energy Reporting (NGER) System

Input data to support the preparation of the *Accounts* for important elements of the *energy*, *industrial processes* and *waste* sectors are collected using the NGER system.

The legislative framework for this mandatory NGER was established through The *National Greenhouse and Energy Reporting Act 2007* (Cwlth) *(NGER Act)*. An explicit objective of the *NGER Act* is to collect information to support the development of the national inventory.

Under NGER, companies whose energy production, energy use, or greenhouse gas emissions (from the *energy*, *industrial processes* and *waste* sectors) meet certain thresholds must report facility-level data to the Clean Energy Regulator. NGER provides activity data inputs, such as fuel combustion, EFs at facility level and, in some cases, directly measured emissions.

Annual reports have been submitted by companies under NGER for Australian financial years since 2008-09. This data has been used in the preparation of this inventory.

The rules for the estimation of activity data, EFs and emissions by companies are well specified and set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (Cwlth).

The estimation methodologies used for company and facility emissions are estimated within the *National Greenhouse Accounts* framework ensuring consistency among the relevant accounts; national, state and territory, industry, company and facility-level inventories. Integration of the estimation methods and data is critical for ensuring that changes in emissions at facility level are captured efficiently and accurately in the national inventory. The default methods used by companies are derived from the national inventory methods while the default EFs have been derived using the AGEIS.

The Clean Energy Regulator manages the process of input data collection from companies and the dissemination of this data to relevant agencies. The Emissions and Energy Reporting System (EERS) is used for the collection of the input data from companies.

Other data sources

Where possible, NGER data sources are used for the *energy*, *industrial processes* and *waste* sectors, supplemented by the use of other published data sources only where necessary. The collection process for other data is well-integrated with the objectives of other programmes with a strong reliance on data collected and published by Australia's principal economic statistics agencies; the Australian Bureau of Statistics (ABS), the Bureau of Resources and Energy Economics (BREE) – formally a part of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). BREE, and preceding organisations, have collected energy statistics for over 35 years and use this data to meet Australia's reporting commitments to the International Energy Agency. The ABS is the national statistical agency with legislative backing for its collection powers. The ABS, in conjunction with ABARES, is the major source of agricultural activity data.

The Department employs consultants to process the satellite imagery to determine land cover change for the *land use, land use change and forestry* sector. Satellite imagery is sourced from Geosciences Australia (Australia's principal satellite ground station and data processing facility) via a memorandum of understanding. Data to support estimates of HFCs are sourced from compulsory reporting by importers under licensing arrangements under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 2003*. The collection of solid waste data from State and Territory Government agencies is supported by an exchange of letters between Australian and State Government agencies.

Data processing

As described in section 1.2.2, the estimation of emissions is conducted by the Department, utilising the AGEIS and, for the *LULUCF* sector, using FullCAM.

Data Storage

The Australian documentation systems aim to both manage and retain all data used in the estimation of emissions to provide a means for knowledge management, ensuring continuity and security of the National Inventory Systems.

The AGEIS is at the heart of Australia's documentation systems. It allows efficient electronic data management and archiving of the significant quantities of data needed to generate an emissions inventory. AGEIS data management functions include:

- archival and storage within the AGEIS database of the emissions estimates of past submissions;
- archival and storage within the AGEIS of past activity data, EF, and other parameters and models;

- archival and storage of data source descriptions, methodology descriptions, and source reference material; and
- integrated access to the documentation of data sources; methodology description and source reference material.

The aims of these systems include giving inventory staff ready access to all related materials that underpin the emissions estimates and to provide the means for replication of emission estimates from past submissions.

The AGEIS functions are supported by some additional and important elements of the documentation system:

- documentation of the inventory's emission estimation methodologies in the NIR; and
- maintenance of a National Inventory Library of source material documents.

1.4 Brief General Description of Methodologies and Data Sources

1.4.1 Estimation methods

Greenhouse gas emissions are generated from a large number of processes and from a range of often diffuse sources. Emissions are not usually monitored directly but are generally estimated through the application of models and methodologies that link emissions to data on observable activities. The Australian methodology for estimating greenhouse gas emissions and sinks uses a combination of country-specific and IPCC methodologies and EFs. These methods are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997), the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) and *Good Practice Guidance on Land Use, Land Use Change and Forestry* (IPCC 2003) and are comparable with international practice.

In general, *Australia's National Greenhouse Accounts* have been moving towards a mix of tier 2 and tier 3 estimation methods that incorporate:

- facility-specific emission estimation processes;
- characterisations of the capital and technology types at the point of emission;
- dynamic relationships that link current emissions outcomes with the activity levels of previous years; and
- spatial differences in emissions processes across Australia.

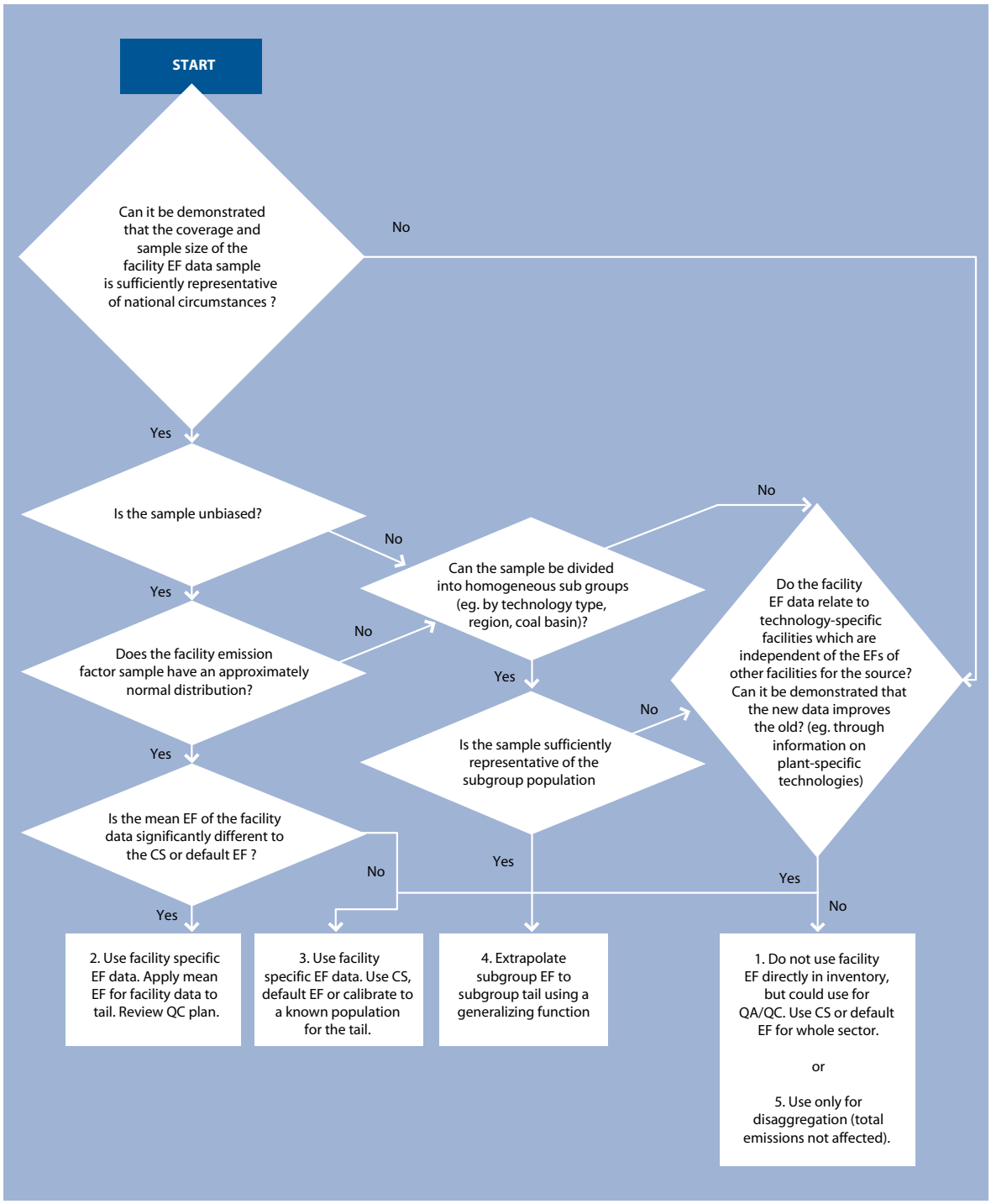
The additional complexity in the methodology allows emissions to be estimated more accurately. Detailed descriptions of methods chosen are set out in the Chapters 3-8 of the NIR.

The commencement of data collection under the *NGER Act 2007* provides the foundation for a progression of national inventory estimation approaches towards tier 3 or facility-specific estimation approaches within the *energy*, *industrial processes* and *waste* sectors.

Tier 3 approaches have been in place for fuel combustion in the electricity industry for a number of years, and from fugitive emissions from underground coal mining sources. These existing tier 3 approaches have been supported by the use of the new NGER data. For a range of additional categories, a mix of tier 2 and tier 3 approaches will continue to be implemented over time as methods for facility-specific measurement of emissions or key data inputs are adopted by reporters and as key pre-conditions for implementation of the new methods are met. These circumstances include that the data must comply with prescribed data standards (in this case, set out in the Determination); that there is a timely and comprehensive data collection system in place; and that the resulting emission estimates for the source pass the inventory quality criteria set out in the QA/QC plan (for example, in relation to completeness and international comparability).

Consistent decision making with respect to the use of facility specific EFs has been ensured through the application of a decision tree, as set out in Figure 1.3.

Figure 1.3: Consistent decision making in method selection



In particular, tier 3 methods incorporating facility–specific EF data obtained from NGER have been utilised where the following conditions have been met:

- the sample size of the available NGER data is sufficiently large;
- there is no evidence of bias in the distribution of the NGER EF data; and
- the distribution of the NGER data is approximately normally distributed.

For the balance of a source where there are facilities for which no facility-specific data are available, a country-specific factor is applied.

Tier 3 methods incorporating NGER facility-specific data are also able to be used in two other cases where large samples displaying characteristics of an approximately normal distribution cannot be obtained.

The first additional case relates to the situation where, within one source, a number of homogenous sub-samples can be discerned. In particular, this is the case for fugitive emissions from coal mining where fugitive emissions depend on a number of variables, including the geological history of a particular coal mining basin. Fugitive emissions from the coal mining source can be broken into sub samples of homogenous groups based on coal mining basins and where data for facilities with unknown characteristics can be determined by the extrapolation of information from the relatively homogenous sub sample or through calibration to a known, unbiased distribution for the population.

The second additional case relates to the situation where facility data are heavily technology dependent, and where the data for each facility are likely to be independent of one another. In particular, this is the case in the industrial wastewater category where knowledge of the technology deployed at one facility does not affect the likelihood of a certain technology being deployed at another facility where no facility data is available. In these cases, it is possible to utilise the facility data, where available, and it may not be appropriate to extrapolate information from the NGER sample to the remainder of a particular source. Consequently, in these cases, the original tier 2 EF has been retained for the tail of the source where NGER data has not yet been collected.

In Table 1.2, the categories where NGER data on EFs have been utilised in this inventory are identified (as 'implemented' in the fourth column of the table). Categories where NGER data will be considered for use in the inventory in future submissions as it becomes available are identified, in the fourth column, as 'potentially'.

Table 1.2: Summary of current uses of NGER data for Australia's national inventory, by IPCC sector

Category		Facility – level activity data	Facility Specific Emission Factors	Verification test for default emission factors	Completeness	Improved uncertainty estimates
1	**Energy**					
1.A.1a	Electricity (coal)	Implemented	Implemented	Yes	Yes	Yes
1.A.1a	Electricity (gas)	Implemented	Implemented	Yes	No	Yes
1.A.1a	Electricity (liquid)	Implemented	Potentially	Potentially	No	Yes
1.A.1b	Petroleum refining	Implemented	Implemented	Potentially	Yes	Planned
1.A.1c	Coke production	Potentially	Potentially	Potentially	No	Planned
1.A.1c	Oil and gas extraction	Potentially	Potentially	Potentially	No	Planned
1.A.2	Manufacturing	Potentially	Potentially	Potentially	No	Planned
1.A.3	Transport	Potentially	No	No	No	No
1.A.4	Other sectors	No	No	Potentially	No	No
1.A.5	Other	No	No	Potentially	No	No
1.B.1	Coal Mining	Implemented	Implemented	Yes	Yes	Planned
1.B.2	Oil & Gas	Partially implemented	Partially	Potentially	No	Planned
2.A.1	Cement	Implemented	Implemented	Potentially	Yes	Planned
2.A.2	Lime	Implemented	Implemented	Potentially	Yes	Planned
2.A.3	Limestone and Dolomite use	Implemented	Implemented	Potentially	No	No
2.A.4	Soda ash production	Implemented	Implemented	NA	Yes	Planned
2.A.4	Soda ash use	Implemented	Potentially	Potentially	No	No
2.B.1	Ammonia	Implemented	Implemented	Potentially	Yes	Planned
2.B.2	Nitric acid	Implemented	Implemented	NA	Yes	Planned
2.B.5	Synthetic rutile and titanium dioxide	Implemented	Potentially	Potentially	Yes	Planned
2.C.1	Iron and steel	Implemented	Potentially	Potentially	Yes	Planned
2.C.2	Ferro-alloy metals	Implemented	Potentially	Potentially	Yes	Planned
2.C.3	Aluminium	Implemented	Implemented	Potentially	Yes	Planned
2.C.4	Other metals	Implemented	Potentially	Potentially	No	Planned
2.E	HFC production	No	No	No	No	No
2.F	HFC consumption	No	No	No	No	No
2.F	SF_6 consumption	Implemented	Implemented	Potentially	No	No
3	**Solvents**	No	No	No	No	No
4	**Agriculture**	No	No	No	No	No
5	***LULUCF***	No	No	No	No	No
6	**Waste**					
6.A	Solid waste	Implemented	Implemented	No	No	No
6.B.1	Domestic and commercial wastewater	Implemented	Implemented	No	No	No
6.B.2	Industrial wastewater	Partially implemented	Implemented	No	No	No
6.C	Waste incineration	Partially implemented	Potentially	Yes	No	No
6.D	Biological treatment of solid waste	No	No	No	No	No

1.4.2 Data sources

The inventory is prepared using a mix of sources for activity data, including published data from national statistical agencies. The principal data sources are set out in Table 1-3.

Table 1.3: Principal data sources for the estimation of Australia's inventory

Category (UNFCCC sector)	Principal data sources	Principal collection mechanism
Energy sector (1A1, 1A2, 1A4, 1A5)	BREE, NGER	Published, Mandatory data reporting system
Energy sector (1A3)	BREE, ABS	Published
Energy sector (1B)	NGER, Coal Services Pty Ltd, QLD DNRM, APPEA	Mandatory data reporting system, published
Industrial processes (2) and solvents (3)	NGER	Mandatory data reporting system
	DE	Mandatory reporting of HFCs under import licensing arrangements
Agriculture (4)	ABS	Published
	ABARES	Published
Land use, land use change and forestry (5)	Geosciences Australia	Memorandum of Understanding
	ABARES	Published
Waste (6)	NGER	Mandatory data reporting system
	State and territory government waste agencies	Exchange of letters between government agencies

National Greenhouse and Energy Reporting (NGER) System

The NGER is an integral element of the national inventory system. The rules for estimation of data and emissions at the facility level by companies are set out in the Determination, which is made under subsection 10 (3) of the *NGER Act*.

The structure of the Determination is designed to facilitate the integration of corporate and facility level data provided under the *NGER Act* with international data standards on greenhouse emissions.

The scope of the Determination is given by the following categories of emission sources:

- **Fuel combustion** emissions from the combustion of fuel for energy (see Chapter 2 of the Determination);
- **Fugitive emissions** from the extraction, production, flaring, processing and distribution of fossil fuels (see Chapter 3 of the Determination);
- **Industrial processes** emissions where a mineral, chemical or metal product is formed using a chemical reaction that generates greenhouse gases as a by-product (see Chapter 4 of the Determination); and
- **Waste** emissions from waste disposal – either in landfill, as management of wastewater or from waste incineration (see Chapter 5 of the Determination).

The scope of the Determination does not include land based emissions covered by the IPCC categories *Agriculture* and *LULUCF*. Emissions from fuel combustion for land based industries are, nonetheless, covered by the Determination.

Four estimation methods are provided for under NGER ranging from low cost simple default methods to higher order methods requiring sampling and analysis of inputs or direct monitoring of emissions.

In general, as with the European Union Emissions Trading Scheme (EU ETS), reporters may choose the estimation method appropriate to their own circumstances. Some important exceptions relate to reporters in the electricity generation, underground coal mining and aluminium industries which are required to use method 2 or higher (see below) for key components of their emission estimations. These restrictions cover around 60% of emissions reported under NGER.

The four NGER estimation methods are:

NGER Method 1: is the *National Greenhouse Accounts* default method. Method 1 specifies the use of designated EFs in the estimation of emissions. These EFs are national average factors determined by the DE using the AGEIS. Although significantly updated, this method is very similar in approach to that used by many corporations for over a decade to voluntarily report emission estimates under the *Greenhouse Challenge Plus* program.

The national inventory only utilises activity data collected from companies that report using this method as no new information is collected in relation to EFs or in relation to other key facility-specific parameters.

NGER Method 2: a facility-specific method using industry sampling and Australian or international standards listed in the Determination or equivalent for analysis of fuels and raw materials to provide more accurate estimates of emissions at facility level. Method 2 enables corporations to undertake additional measurements – for example, the qualities of fuels consumed at a particular facility – in order to gain more accurate estimates for emissions for that particular facility. Method 2 draws on the large body of Australian and international documentary standards prepared by standards organisations in order to provide the benchmarks for procedures for the analysis of, typically, the critical chemical properties of the fuels being combusted. Method 2 was based on existing technical guidelines used by reporters under the *Generator Efficiency Standards* program, which had been in place since 1998.

The national inventory may utilise activity data and EFs or other key facility-specific parameters collected by companies using this method, depending on the analysis of the quality of the data and, in accordance with the decision tree set out in section 1.4.1.

NGER Method 3: a facility-specific method using Australian or international standards listed in the Determination or equivalent standards for both sampling and analysis of fuels and raw materials. Method 3 is very similar to method 2, except that it requires reporters to comply with Australian or equivalent documentary standards for sampling (of fuels or raw materials) as well as documentary standards for the analysis of fuels.

NGER Method 4: direct monitoring of emission systems, either on a continuous or periodic basis. Method 4 provides for a different approach to the estimation of emissions. Rather than providing for the analysis of the chemical properties of inputs (or in some case, products), method 4 aims to directly monitor greenhouse emissions arising from an activity. This approach can provide a higher level of accuracy in certain circumstances, depending on the type of emissions process, however, it is more likely to be more data intensive than other approaches.

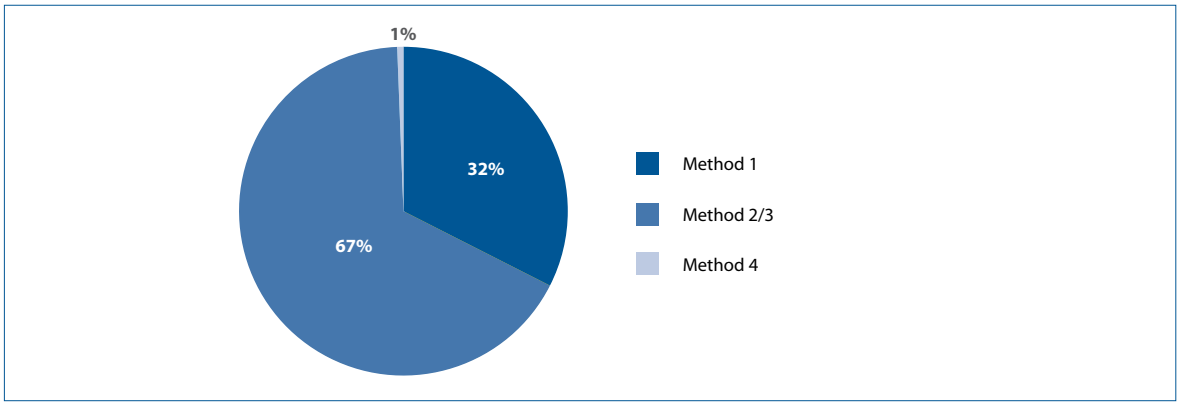
As for methods 2 and 3, there is a substantial body of documented procedures on monitoring practices and state and territory government regulatory experience that provide the principal sources of guidance for the establishment of such systems.

The national inventory may utilise emissions data generated using NGER method 4 depending on the analysis of the quality of the data and in accordance with the decision tree set out in section 1.4.1.

Implementation of the NGER (Measurement) Determination

In the fourth year of implementation of NGER (2011-12), 67% of CO_2 emissions were estimated using method 2 or 3, i.e. using analysis of carbon content of fuels or other inputs. By comparison, 32% of CO_2 emissions were estimated using method 1. Around 1% of CO_2 emissions were estimated using method 4. These outcomes reflect the choices determined by companies within the NGER system, and reflect the significance of the source and the likely variability in the carbon content of the source. For example, over 90% of emissions from the combustion of coal were estimated using a higher order method. However, method 1 continued to be used principally for petroleum products, which tend to be homogenous in character and where payoff from additional measurement effort is often limited. Choices made by companies for gas lay somewhere between coal and petroleum products.

Figure 1.4: CO_2 emissions: method selected by NGER reporters

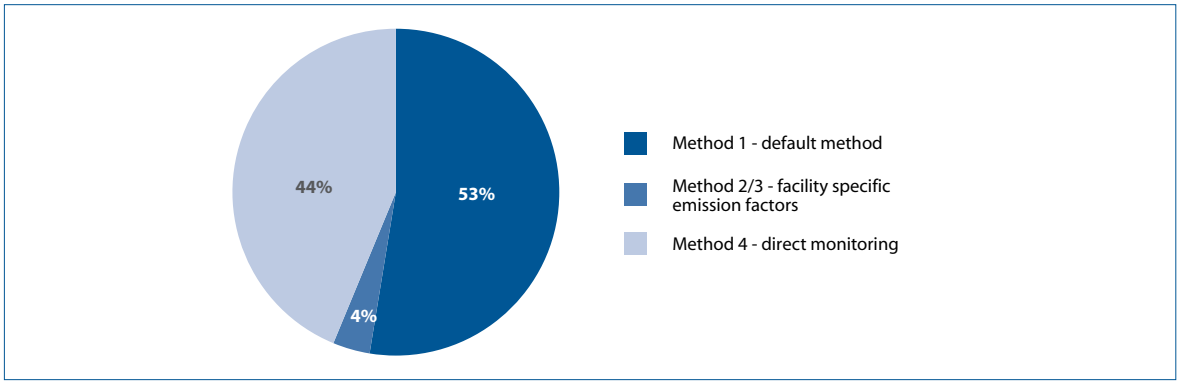


There is a similar story when choices made about estimation methods used for CH_4 are considered. Around 44% of CH_4 emissions were estimated using direct monitoring of emissions while 53% of CH_4 emissions were estimated using method 1.

As for CO_2, the choices of the system, and of companies within the system, have resulted in the use of actual measurements from facilities to determine emissions for major sources of CH_4. This outcome relates principally to the choices made by underground coal mines to use directly monitored estimates.

For minor sources of CH_4 and where measurement is difficult, such as CH_4 from combustion of fuels, method 1 has been used by reporting companies under NGER.

Figure 1.5: CH_4 emissions: method selected by NGER reporters



The particular use of this NGER data within the national inventory for each category is explained within their respective chapters of this document

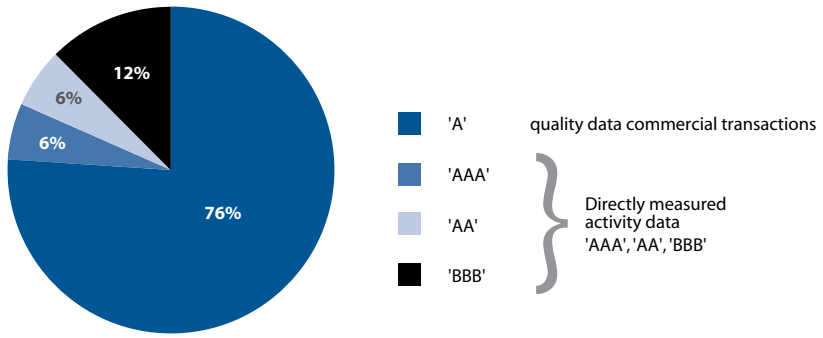
Activity data

NGER generates activity data on fuel consumption and key activity data inputs in the industrial processes and waste sectors for NGER reporters. It also aims to maximise the amount of activity data collected from companies that is used for other regulated purposes, including commercial activity and taxation. This approach both reduces the regulatory burden on companies and ensures consistency across national datasets, also formalising the role of the national measurement systems in the national inventory system.

Activity data is rated 'A' if it is estimated using information used to support commercial transactions such as estimates of the amount of fuel purchased. Activity data is rated 'AA' if companies estimate fuel consumed based on information on the amount of fuel purchased and change in stock at the facility. Activity data is rated 'AAA' if companies directly measure fuel consumed using the same tolerance levels for measurement error that govern commercial transactions. In some cases fuel use is not subject to either commercial or taxation activity (i.e. where a facility both extracts and utilises fuel). In these cases, the quality of the data must be signified by a quality rating (i.e. 'BBB'). All 'quality' data is reported by companies as part of their NGER reporting obligations.

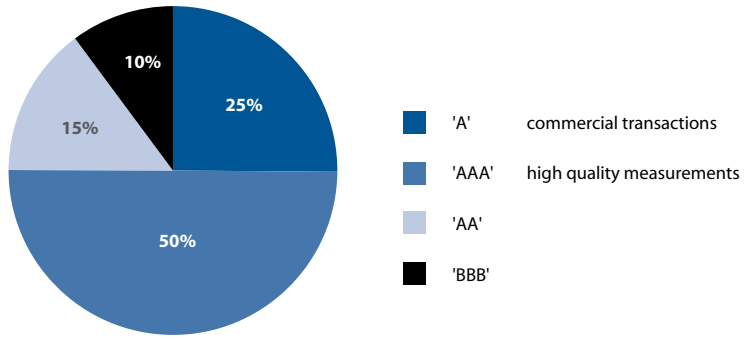
The choices made by companies with respect to the quality of their activity data inputs are presented in Figure 1.6. Over 76% of reported activity data points under NGER is derived from commercial transactions and requires no new measurements to be undertaken by the company in order to meet reporting requirements.

Figure 1.6: Activity data selected by NGER reporters by percentage of data points



However, in terms of CO_2 emissions, companies have tended to choose to use actual measurements of activity to underpin emissions estimates. 50% of emissions were estimated using 'AAA' activity data inputs, i.e. estimates of fuel measured at the point of combustion at an accuracy level consistent with standards required to support commercial activity.

Figure 1.7: Activity data selected by NGER reporters by percentage of emissions



It follows that companies have generally used existing commercial data for relatively minor emission sources. While commercial data accounted for 76% of the data points used in emission estimation processes, these data points only related to 25% of the estimated emissions.

Use of commercial activity data occurs primarily for gas and petroleum products – often minor sources or where uncertainties associated with the use of data on fuels purchased as a proxy for fuels consumed are considered low. It appears that for major emission s sources, Australian companies have chosen to use the most accurate data requiring explicit measurement effort while for minor emission sources they have chosen to use low cost, albeit slightly less accurate data.

NGER data is supplemented where necessary by alternative data sources. Currently national data for the *energy* sector is published by BREE. Agriculture data is obtained by agricultural censuses and surveys conducted by the ABS while waste data is principally obtained under State Government legislation.

1.5 Brief Description of Key Source Categories

The *IPCC Good Practice Guidance* (2000, 2003) introduces the concept of 'key categories' for prioritising the inventory development process.

A key category has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. Australia has identified the key categories for the inventory using the tier 1 level and trend assessments as recommended in the IPCC *Good Practice 2003* report and adopted by COP decision 13/CP9. This approach identifies sources that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms.

When the *LULUCF* sector is included in the analysis, Australia has identified *public electricity (solid fuel), road transportation (liquid fuels)* and *land converted to grassland* the most significant of the key categories (i.e. contributing more than 10% of the level and/or trend) in 2012. When the *LULUCF* sector is excluded from the analysis the most significant key categories in 2012 are *public electricity (solid fuel), road transportation (liquid fuels) and enteric fermentation (sheep).* More details are provided in Annex 1.

The concept of key categories is also used for choosing the good practice estimation methods for emissions and removals due to activities under Articles 3.3 and 3.4 of the Kyoto Protocol. The KP-*LULUCF* key categories have been identified as outlined in the *IPCC Good Practice for LULUCF* (IPCC 2003).

For the Article 3.3 activities, Australia has identified both *deforestation* and *afforestation/reforestation* as key categories.

1.6 Information on the Quality Assurance/Quality Control Plan

This section outlines the major elements of the Quality Assurance/Quality Control plan (QA/QC plan). Australia's QA/QC plan is documented in full in *National Inventory Systems: Quality Assurance/Quality Control plan*.

The IPCC defines QC as being a system of routine technical activities to measure and control the quality of the inventory as it is being developed. A basic QC system should provide routine and consistent checks to ensure data integrity, correctness, and completeness, identify and address errors and omissions, and document and archive inventory material and record all QC activities.

QA comprises a planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process.

The QA/QC processes deployed by the Department aim to conform to IPCC *Good Practice Guidance* (2000, 2003). These processes further aim to contribute to the production of inventories which are accurate, in which uncertainties are reduced to the extent practicable, and in which the inventories are transparent, documented, consistent over time, complete, and comparable. The QA/QC plan identifies key risks to the achievement of these objectives and sets out the mitigation strategies employed to ensure that the quality objectives for emission estimates are attained.

Key risks to the attainment of the defined quality objectives are identified at each level of inventory preparation, including the measurement of data at the facility level, the collation of activity, other input data by DE and other agencies, and the process of emissions estimation.

Principal mitigation strategies are discussed in sections 1.6.1 to 1.6.3. A detailed summary of the quality control measures employed in the preparation of Australia's inventory is presented in Annex 6.

Systems have been established to monitor the outcomes of the mitigation strategies and control measures, principally managed through the AGEIS system (see sections 1.6.1 and 1.6.2). Each year, an evaluation of the data collected under the monitoring systems is undertaken and documented in the *National Inventory Systems: Evaluation of Outcomes* document. Following consideration of the *Evaluation of Outcomes* document, improvements to the inventory are then effected through the *National Inventory Systems: Inventory Improvement Plan*.

1.6.1 Quality Control procedures implemented

The principal data source for this inventory is the NGER. The quality control system for this data is critical for the quality for the inventory as a whole.

Use of Standards

A key mitigation strategy to manage risks associated with measurement error is to ensure that rules for emissions estimation are well specified. Rules for the estimation of emissions by companies have been developed to conform to the *National Greenhouse Accounts* framework and aims to ensure that consistent estimation methods are deployed at the national, state and territory, industry, company and facility level. This consistency is critical to ensure policy efficiency, and to engender confidence in the company estimates by ensuring the methods used are also consistent with *IPCC Guidelines*.

The Determination is supplemented by the referencing of standards for sampling and analysis of key data inputs. For example, for the estimation of facility-specific EFs, NGER methods reference relevant Australian, ISO, and equivalent international standards (EU, US) for sampling and analysis of relevant fuel qualities and characteristics (such as carbon content). These standards provide, *inter alia*, sample handling protocols and tolerance levels for precision (repeatability and reproducibility), as well as for the management of bias.

Where possible, the NGER has been designed to utilise the data systems that operate to support other regulatory functions such as commercial or taxation activities. In particular, measurement of commercial activity data in Australia is regulated by the *National Measurement Act 1960* and *National Measurement Regulations 1999* and, for utilities, by state Government regulations. These legislative instruments underpin the quality of all activity data subject to commercial operation that are used in the *National Greenhouse Accounts*. For example, the *National Measurement Regulations 1999* specify maximum tolerances for measurement error for any amount of solid fuel subject to commercial activity.

Certain data sources are also governed by the regulations of the taxation system. For example, data on liquid fuels are governed by the requirements of the *Excise Tax Act 1901* which places strict tolerance limits on measurement error. To an important extent, the quality of commercial and taxation data in Australia underpins the quality of emissions data reported under NGER.

Compliance

In order to facilitate accurate reporting of information, the Clean Energy Regulator (CER) has resources devoted to 'outreach' whereby the Departmental officials liaise with reporting companies to assist them in the preparation of reports. A validation unit is also deployed by the CER to assist with the initial inspection of reported data, checking for transcription errors and liaising with companies about possible resubmission of estimates.

The NGER Act also provides for a risk-based system for the independent verification of NGER data. Under the Act, the CER has the authority to order a corporation to conduct an external audit on aspects of the corporation's compliance with the Act or with the regulations. Sections 73 and 74 of the Act define the circumstances under which a greenhouse and energy audit may be initiated and allow for the appointment of Registered Greenhouse and Energy Auditors to undertake audit engagements.

The *National Greenhouse and Energy Reporting (Audit) Determination 2009* (Cwlth) sets out the requirements for preparing, conducting and reporting on greenhouse and energy audits. Greenhouse and energy audits may only be conducted by a greenhouse and energy auditor who has been registered under section 75A of the Act. The purpose of greenhouse and energy audits is to determine the extent to which entities that are required to register and report under the Act have, or have not, complied with its requirements.

The Act empowers the CER to initiate a greenhouse and energy audit where:

- there are reasonable grounds to suspect that an entity that is required to register and report under the Act has contravened, is contravening, or is proposing to contravene either the Act or the Regulations; or
- it is determined that, for another reason, an audit of an entity's compliance with one or more aspects of the Act or the Regulations is necessary.

Significant penalties may apply to Chief Executive Officers for contravention of the Act.

An important focus of greenhouse and energy audits in the first years of reporting was to assist corporations to understand their obligations and develop efficient reporting processes that meet the needs of government and business.

Given the risk of a mandatory audit ordered by the CER, and the threat of significant penalty, many companies have voluntarily utilized external auditors to audit their reports prior to submission to the CER in 2009-2013.

The Carbon Pricing Mechanism, which came into effect on 1 July 2012, created new audit responsibilities for liable entities. If an organisation is a liable entity and its emissions exceed 125 Gg CO_2-e these organisations must arrange a pre-submission audit to provide assurance over their reported emissions data. Transparency is a key principle for the operation of the system. Data for individual companies in relation to total emissions are publicly disclosed by the CER through publication four months after submission to ensure additional scrutiny of reported data.

Time series consistency with audited data

For the preparation of the national inventory, data collected under NGER has been checked for time series consistency with facility data available for previous years. In some cases, this data has been collected previously for the inventory, e.g. fuel combustion in the electricity generation sector. However, more generally, NGER data has been compared with data the Department has collected at facility level for 2007 and 2008. This data has become available as the Department has collected data from targeted companies specifying their emission estimates for 2007 and 2008 in order to provide the basis for the provision of compensation arrangements to apply for various climate mitigation related policies.

Rules for these schemes have been issued and include a requirement that these data were audited prior to submission to the Department. Under the Jobs and Competitiveness Program (JCP), NGER methods have been used for the estimation of emissions. This audit and reconciliation processes ensure the quality of the data available for 2007 and 2008 and, through time series consistency checks, the data from NGER used from 2009 onwards.

All JCP emissions data have been made available for use in the preparation of the national inventory. Use of this data is indicated in the respective chapters of the *National Inventory Report*. Where JCP data have been used, facility level data has been implemented for the years 2007 onwards.

Confidential data

Where reporting at a disaggregated level could lead to the disclosure of confidential information emissions data is treated as confidential and aggregated with other sectors before publication. Confidential data utilised in the national inventory is currently collected from companies under NGER. This data is subject to the *compliance* and *use of standards* controls outlined above.

Processes have been put in place to ensure QA/QC is recorded in the National Inventory Report for confidential emission sectors. For sectors where emissions data is confidential the implied emission factors have been published for the relevant sub sectors (see section 4.4.8). As a quality control the implied emission factors for Australia are plotted and compared against a distribution of implied emission factors for all other Annex I parties.

In order to maintain continuity in the compilation of industrial processes emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data including confidential data from before the introduction of NGER. This work is of particular importance in industrial processes where confidentiality of historical activity data poses some challenges for the assessment of time series consistency.

Other datasets

Where the inventory utilises official national statistics, the quality control of this data is managed by the source agencies. The ABS publishes assessments of data quality and quantitative estimates of sampling errors for transport and agricultural activity data. National level energy activity data are produced by the BREE through its annual *Australian Energy Statistics* (AES). The BREE data was reviewed and 'benchmarked' by the ABS in its role of national statistics co-ordinator (ABS 1991b). An additional benchmarking quality control test for natural gas consumption was introduced in this submission. The test compares total natural gas consumption reported in the AES against the sum of natural gas consumed by large users reported under NGER and upstream natural gas data, for small users, available for the first time for the 2012/13 financial year. The test is detailed in section 3.2.6.

With respect to electricity, explicit reconciliations of energy data are undertaken by comparing data collected under NGER and the estimates produced by BREE, the Energy Supply Association of Australia (ESAA) and the Australian Energy Market Operator (AEMO), which are all undertaken for slightly differing reasons and with slight differences in coverage.

Tier 1 quality control checks - emissions estimation

Emissions estimation is conducted through the use of the AGEIS software (apart from the *LULUCF* sector). Management of the AGEIS is conducted in accordance with the Control Objectives for Information and related Technology (COBIT) framework. The AGEIS was subject to a performance audit by the Australian National Audit Office in 2009 (see section 1.6.2).

For this inventory and associated time series, there are over 2.9 million data inputs in the non-*LULUCF* sectors. To facilitate the management of such a large amount of data, AGEIS was specifically developed to play a central role in the quality control of the national inventory. Key tier 1 QC controls have been systematically built into the operation of the AGEIS. Auditable checks are undertaken *inter alia* to reduce the risks of errors associated with the input of activity data, missing data, recalculations and the time series consistency of generated emission estimates.

Input data and implied emission factors (IEFs) are also checked for recalculations and time series consistency prior to submission using AGEIS and the CRF reporter tool. The allocation of roles and responsibilities of staff provide for the separation of data handling and data approval roles within the Department to improve accountability.

Extensive internal verification of emission estimates, as well as external acceptance testing of system integrity and functionality, was undertaken during the development of the AGEIS. Emissions estimated by the AGEIS were compared with those previously reported using traditional spreadsheets to ensure emissions were calculated correctly, that parameter and emission units were correctly recorded, and that data was correctly aggregated from lower to higher reporting levels. Implementation of new estimation methodologies are undertaken using a dual estimation approach, which ensures that AGEIS emission estimates are verified independently.

Australia's QA/QC Plan is designed to align with the requirements of *IPCC Guidelines*. The set of tier 1 QC procedures for the inventory compilation process specified in the *IPCC Good Practice Guidance* (2000, 2003), along with the relevant control measure reference in Australia's QA/QC Plan, are identified in Table 1.4.

Table 1.4: Implementation of tier 1 quality control checks

Tier 1 QC activity: Checks[a]	Control Measure[b]	Implementation / Comment
Assumptions and criteria for the selection of activity data and EFs documented	*3.E.1*	Documented in the *National Inventory Report*.
Transcription errors in data input and reference	2.A.1-3, 2.B.2.	Errors checked for using internal AGEIS data verification checks. AGEIS fully integrated with the UNFCCC CRF Reporter Tool removing risk of errors in CRF tables. Error checks are also implemented during the pre-processing of input data. Bibliographical data references checked for correct citation.
	2.A.4	FullCAM inputs database is checked for transcription errors between source documents and database.
Emissions are calculated correctly	3.A, 3.B, 3.C	Extensive testing during AGEIS development phase and when new methods introduced. Selected dual estimation process using traditional spreadsheets.
Parameter and emission units are correctly recorded and that appropriate conversion factors are used	3.A, 3.B, 3.C	Extensive testing during AGEIS development phase and when new methods introduced. Selected dual estimation process using traditional spreadsheets. Extensive testing during development of FullCAM functionality. Ongoing testing undertaken on an operational basis.
Integrity of database files	3.A1-3	Extensive verification/external acceptance testing during the AGEIS development phase. Automated testing of FullCAM database files. Selected dual estimation process using traditional spreadsheets. Database system and operation documentation updated and archived.
	2.A.5	Integrity of FullCAM inputs database files checked.

Tier 1 QC activity: Checks[a]	Control Measure[b]	Implementation / Comment
Consistency in data between source categories	3.A.1-3	Parameters (activity data, constants, EFs) which are common to multiple sources are entered into global or general data tables so data is only entered once into database.
	2.E.1	FullCAM provides a common platform using a common inputs database for LULUCF estimates. The FullCAM inputs database is reviewed to ensure that parameters that are common between source categories are not differentiated.
Movement of inventory data among processing steps is correct	3.A.1-3	Extensive testing during AGEIS development phase and when new methods introduced. Standard reconciliation reports are run to ensure correct aggregation of emission estimates. Cross checking data between FullCAM, AGEIS and the CRF for consistency.
Uncertainties in emissions and removals are estimated or calculated correctly		Independent review by CSIRO completed.
Time series consistency/ Methodological and data changes resulting in recalculations	3.C, 3.D	Where changes are made to methods or activity data the full time series of emissions is recalculated, the AGEIS and FullCAM ensure consistent use of methods across time series.
Completeness	2.B.1-2, 3.B.1-4	Checked through CRF Reporter Tool. Mass balance checks undertaken for fuel, carbonates, biomass and synthetic gases. FullCAM has a mass balance check incorporated at each stage of the model process.
Trend	3.D.1-2	Activity data, emissions and IEFs are compared with the previous year's estimates, and across entire time series, through the AGEIS and CRF Reporter Tool.
Review of internal documentation	3.E 1-3	All activity data, emission factors and algorithms are archived within AGEIS. Past inventories may be reproduced using AGEIS. Electronic and hard copies of each year's NIR and methodology are kept in a safe. All bibliographical data references are archived within the AGEIS and in a hardcopy library. FullCAM software, simulations and activity data are stored on a secure server and include a documented backup service with offsite storage.

(a) Source: IPCC 2003, Table 5.5.1, page 5.51.

(b) References refer to numbering in Australia's QA/QC Plan (see Annex 6).

Table 1.5: Results of reconciliation quality control objectives

Test	Objective (% difference)	Result
CM 3.B.2 (i) Reconciliation between national inventory and sum of State and Territory inventories	<0.1	Achieved
CM 3.B.2 (ii) Reconciliation between national inventory and national inventory by economic sector	<0.1	Achieved
CM 3.B.2 (iii) Reconciliation between national inventory and output from the AGEIS	<0.1	Achieved
CM 3.B.1 (i) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: fossil fuel consumption	<0.01	Achieved
CM 3.B.1 (ii) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: carbonates consumption	<0.001	Achieved
CM 3.B.1 (iii) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: biomass consumption	<0.001	Achieved
CM 2.B.2 (i) Completeness: Reconciliation of data submitted into AGEIS and reference data: fossil fuels consumption	<0.1	Achieved
CM 2.B.2 (ii) Completeness: Reconciliation of data submitted into AGEIS and reference data: carbonates consumption	<1	Achieved
CM 2.B.2 (iii) Completeness: Reconciliation of data submitted into AGEIS and reference data: biomass consumption	<1	Achieved
CM 2.B.2 (vi) Completeness: Reconciliation of data submitted into AGEIS and reference data: synthetic gas consumption	<0.1	Achieved

Tier 2 quality control checks

Category-specific QC (tier 2) checks are conducted for all sectors to test for completeness, international comparability and verification of country-specific parameters.

Completeness and accuracy are tested through the operation of mass balance checks. The application of mass balance constraints for carbon in fuels, carbonates, biomass wastes, and hydrofluorocarbons and nitrogen balances for domestic and commercial wastewater constitute tier 2 quality control measures. All carbon entering the economy in fuels is accounted for, either as emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses, use of biomass sources of energy, or international bunkers. Carbon balances for biomass, carbonates and synthetic gas consumption have also been implemented. The results of these checks against the principal quality objectives are set out in Table 1.5. Detailed results of the application of these balances are reported in Annex 6.

International comparability of emission estimates is systematically tested through comparisons of the IEFs obtained for significant sources of the Australian inventory with the distribution of IEFs for all other Annex I parties. The results of these analyses are included in the QA/QC discussions of individual sources in this report.

For the energy, industrial processes and waste sectors, systematic verification tests are undertaken for country-specific parameters, such as EFs utilising data collected under NGER. The tests are undertaken in accordance with the decision tree (Figure 1.3). Country-specific parameters are tested against NGER datasets that meet the prescribed conditions. If the mean of the NGER dataset is significantly different to the country-specific parameter, the parameter may be revised to reflect the new information.

The empirical research program set out in the *National Inventory Improvement Plan* is designed to generate information to provide the basis for verification tests for parameters in either tier 2 or tier 3 methods where private measurement activity is not undertaken (see section 10.4 for more details).

In addition, country-specific parameters may also be subjected to verification tests on an ad hoc basis as new information is obtained.

1.6.2 Quality Assurance procedures implemented

Australia's QA systems operate at a number of levels. QA controls that are implemented annually include:

- the preparation of the Inventory is oversighted within DE by the National Inventory and Projections Executive Committee;
- the review of the *National Inventory Report*, prior to submission to the UNFCCC, by the National Greenhouse Gas Inventory Committee, which comprises representatives of state and territory governments, and the CSIRO. This is the principal formal external review mechanism for the report before it is finalised;
- the prioritisation and review of inventory improvements by the National Inventory Users Group;
- reconciliation with DE estimates by external consultants for specified sectors, including *mineral, chemical and metal products* within *industrial processes* and *agricultural soils* within *agriculture*;
- QA of remote sensing imagery and data inputs for the LULUCF (Chapter 7 Appendix A and B);
- the inventory is potentially subject to audit by the Australian National Audit Office (ANAO). The ANAO is an independent office established under *The Auditor-General Act 1997*. It conducts performance audits of government agencies operating under the Standard on Assurance Engagements ASAE 3500 Performance Engagements issued by the Australian Auditing and Assurance Standards Board (AUASB). ANAO reports are tabled in the Australian parliament and subject to review by the Joint Committee of Public Accounts and Audit (JCPAA). The (ANAO) undertook a performance audit of the national inventory in 2009;
- opening the inventory emission estimates and methods for public review through the release of transparent and easily accessible information via the Department and AGEIS webpage. Industry and public feedback is accepted through the inventory e-mail facility nationalgreenhouseaccounts@environment.gov.au;
- feedback from the public on key EFs used has been ascertained through a public consultation process – review of the NGER Measurement Determination: Discussion paper, August 2010; and
- UNFCCC expert review team processes which aim to review and improve the quality of all Annex I inventories in an open and facilitative manner. Australia's inventory has been reviewed by in-country teams in 2002, 2005, 2008 and 2010, with centralised reviews utilised in other years. Annex 6 documents how outstanding recommendations from the 2012 review report have been implemented, or will be addressed in the future. At the time of completing this report, the 2013 review report has not yet been finalised however Australia had received a preliminary list of recommendations from the ERT. Responses to these preliminary recommendations are also addressed in Annex 6.

Specific reviews of sectoral methodologies that have been performed by expert consultants that are not involved in the inventory preparation process are described in Table 1.6.

Table 1.6: Expert reviews of methodologies and activity data

Year of Review	Categories reviewed
2002-2003	4A Enteric Fermentation and 4B Manure Management. (CSIRO, ASIT Consulting, QDNRME, Hassell and Associates Pty. Ltd)
2004	Review of Savanna burning (CSIRO)
2005-06	Emission factors for liquid fuels (GHD Pty Ltd)
2006	Methodologies in the iron and steel and petroleum refining sectors (GHD Pty Ltd) Industrial wastewater and waste incineration methodologies (O'Brien Consulting) Flooded decommissioned coal mines (L. Lunarzewski, Consultant)
2007	Review of Industrial Processes sector (M. Tsaranu, international expert from UNFCCC reviewer roster) Review of Waste sector (Hyder Consulting 2007a,b)
2008	Review of key FullCAM model parameters and assumptions in the *LULUCF* sector (M. Apps, W Kurts, P. Smith and Q. Zhang, international experts from UNFCCC review roster and/or authors of IPCC *Guidelines*)
2009	Review of waste generation and disposal improvements; and Review of DOC_f values (S. Guendehou, international expert from UNFCCC reviewer roster)
2011	4E. Review of Prescribed Burning of Savannas (CSIRO Marine and Atmospheric Research) Review of the characteristics of liquid fuels used in the National inventory (Orbital Australia 2011a)

Additional quality assurance activities that have been undertaken include the review of:

- uncertainty estimates by the CSIRO Atmospheric Research Division in 2005 according to strict review protocols; and
- AGEIS which is managed by DE in accordance with the COBIT framework. The system has been subject to review by Protiviti Consulting in May 2007 and was examined as part of the ANAO performance audit in 2009.

1.6.3 Verification Activities

Australia does not attempt to provide systematic verification through atmospheric concentration estimates given likely scale and related complexities, uncertainties and costs. The CSIRO, however, operates a Baseline Air Pollution Station at Cape Grim in Tasmania. Data on the concentrations of synthetic gases – HFCs and PFCs – have been collected and have been analysed with the aim of providing an independent assessment of emissions of these gases in Australia (see Chapter 4).

The Australian inventory is tested extensively for comparability with the inventories of other Annex I parties. The IEFs and other key parameters for specified variables are reviewed for comparability against the IEFs for all other Annex I parties. Specific t-tests are performed to test whether the IEFs derived from the Australian inventory are significantly different to the mean of all other Annex I parties. The results of these tests are recorded in the *National Inventory Systems: Evaluation of Outcomes* document.

As the Australian inventory has transitioned to tier 3 methods for many sectors, future verification developments will focus on the development of assessments of tier 3 emission outcomes against the results of associated tier 2 models.

1.6.4 Treatment of confidentiality

The national inventory is comprised of emissions estimates which rely upon facility level data reported under the provisions of the *National Greenhouse and Energy Reporting (NGER) Act*. The NGER Act incorporates strict provisions for the handling of confidential data including severe penalties for disclosure of confidential NGER data. Consequently, confidential data handling processes are given careful consideration.

In 2011, the Department has commissioned the CSIRO to undertake a review of confidential data handling practices (CSIRO 2011). As part of this review, the confidential data handling practices of a number of Australian Government departments, as well as a range of international agencies, were appraised. This review has provided information on techniques that can be applied that ensure that confidential data is appropriately presented in the national inventory.

1.7 General Uncertainty Evaluation

Uncertainty is inherent within any kind of estimation, be it an estimate of the national greenhouse gas emissions, or the national gross domestic product. Managing these uncertainties, and reducing them over time, is recognised by the IPCC *Good Practice* reports (IPCC 2000, 2003) as an important element of inventory preparation and development. While it is, in some cases, possible to continuously monitor emissions, it is not usually practical or economic to do so. This leads to estimations based on samples or studies being used which carry a degree of additional uncertainty attached to them. Uncertainty also arises from the limitations of the measuring instruments and the complexity of modelling highly variable sources of emissions over space and time, particularly for some biological sources.

Australia has conducted uncertainty analysis across the sectors of *energy*, *industrial processes*, *agriculture*, *land use, land use change* and *waste* in line with the IPCC *Good Practice* reports (2000, 2003). These estimates have been subjected to an independent review by the CSIRO. Additionally, from the 2013 National Inventory Submission, Australia has incorporated corporation uncertainty data collected under NGER for the first time.

Emission estimate uncertainties typically are low for CO_2 from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates of emissions are higher for *agriculture*, *LULUCF* and *synthetic gases*. A medium band of uncertainty applies to estimates from *fugitive emissions*, most *industrial processes* and non-CO_2 gases in the *energy* sector.

The sectoral estimates presented in Annex 7 show that the uncertainty ranges reported for the various components of the Australian inventory are largely consistent with the typical uncertainty ranges expected for each sector, as identified in the IPCC *Good Practice reports*.

At an aggregate level, using IPCC good practice tier 1 methods, the overall uncertainty surrounding the Australian inventory estimate for 2012 is estimated at ±2.6%. The reported uncertainty for the trend in emissions is estimated to be ±3.0%. When the *LULUCF* sector is excluded from the analysis the uncertainty is estimated at ± 2.2% for the 2012 inventory estimate and ± 1.5% for the trend in emissions. The IPCC approach provides accurate estimates of uncertainty under certain restrictive assumptions that do not always hold for most countries' inventories. Consequently, the Department is planning to undertake more extensive tier 2 analyses of uncertainty using Monte Carlo analyses in its future work programme.

1.8 General Assessment of Completeness

The inventory is considered to be largely complete with only a few minor sources not estimated, due to either a lack of available information or methodology in the *IPCC Good Practice Guidance*. These sources are considered to be insignificant, however, when compared with the inventory as a whole. More information on completeness is available in Annex 5.

The assessment of completeness is used to help identify areas where methodologies can be developed, and where additional sources of data may be sought. With each new inventory, a number of emission sources and removals have been added to the national inventory, resources permitting, as the remaining outstanding sources are generally minor while at the same time resource-intensive to estimate.

In order to provide assurance as to the completeness of the activity data used in the estimation of emissions for the inventory, DE also undertakes tier 2 QA/QC checks of fossil fuels, biomass and carbonate materials. These checks ensure that the estimated supplies of carbon into the economy are reconciled with the estimated uses of carbon, ensuring that any bottom-up data collection processes are reconciled with data available at aggregate levels.

1.9 Geographical Coverage

The Australian inventory covers the six states (New South Wales, Victoria, Queensland, South Australia, Western Australia and Tasmania), the mainland territories (Northern Territory, Australian Capital Territory and Jervis Bay Territory) and the associated coastal islands.

The geographical coverage of the Australian inventory also includes emissions from the following external territories:

- Norfolk Island
- Christmas Island
- Cocos Islands
- Heard and McDonald Islands

Australia's Antarctic Program operations in the Antarctic are also covered.

The following external territories are also covered but are included in the state statistical territories by the ABS:

- Coral Sea Islands (Queensland); and
- Ashmore and Cartier Islands (Northern Territory).

The coverage of emissions/removal categories for the external territories is as follows:

- *fuel combustion*, *waste* and HFC emissions associated with refrigeration are estimated;
- *fugitive emissions* and *industrial processes* emissions are assumed to be not occurring; and
- *agriculture* and *LULUCF* emissions and removals are not estimated but are likely to be negligible.

2. Trends in Emissions

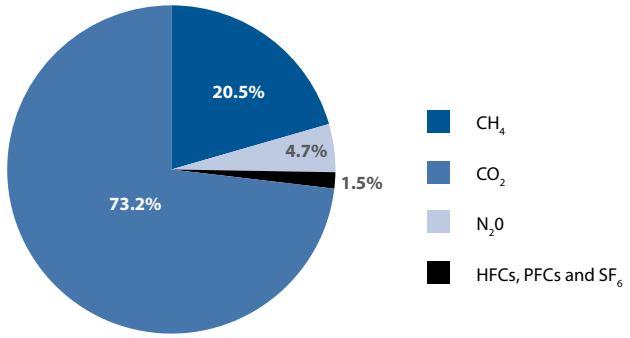
2.1 Emission Trends for Aggregated Greenhouse Gas Emissions

Australia's total greenhouse gas emissions, excluding the *LULUCF* sector, were 543.6 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2012. This represents an increase of 2.1 Mt CO_2-e (0.4%) on net emissions recorded in 2011, and an increase of 31.0% (128.7 Mt CO_2-e) above 1990 levels (Figure 2.1).

When the *Land use, land use change and forestry* sector emissions and removals are included in the total, Australia's net greenhouse gas emissions in 2012 were 558.8 Mt CO_2-e.[3] This represents an increase of 13.3 Mt CO_2-e, or 2.4%, on net emissions recorded in 1990. In 2012, the *LULUCF* sector was a net source of 15.2 Mt.

CO_2 is the most important of the greenhouse gases in Australia's inventory (excluding *LULUCF*) with a share of 73.2% (397.8 Mt CO_2-e) of the total CO_2-e emissions, followed by CH_4, which comprises 20.5% (111.7 Mt CO_2-e) (Figure 2.1). The remaining gases make up 6.3% (34.1 Mt CO_2-e) of Australia's greenhouse gas emissions.

Figure 2.1: Contribution to total net CO_2-e emissions (excluding *LULUCF*) by gas, 2012



The combined *energy* subsectors (including stationary energy, transport and fugitive emissions) were the largest source of greenhouse gas emissions in 2012 comprising 76.0% of emissions excluding LULUCF (Table 2.1) followed by the *agriculture* sector (16.1%).

[3] This total does not reflect Australia's emissions and removal under the Kyoto Protocol accounting framework where the inclusion of LULUCF emissions and removals are restricted to a subset of activities (i.e. Afforestation, Reforestation and Deforestation, which have occurred since 1990).

Table 2.1: Australia's net greenhouse gas emissions by sector under the UNFCCC, 2012

Sector and Subsector	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total	Share of total
	Mt CO_2-e							%
1 All energy (combustion + fugitive)	377.5	33.3	2.6	NA	NA	NA	413.4	76.0%
Stationary energy	*281.0*	*1.3*	*0.9*	*NA*	*NA*	*NA*	283.2	52.1%
Transport	*88.2*	*0.4*	*1.6*	*NA*	*NA*	*NA*	90.2	16.6%
Fugitive emissions from fuel	*8.3*	*31.6*	*0.04*	*NA*	*NA*	*NA*	39.9	7.3%
2 Industrial Processes	20.3	0.1	2.5	7.9	0.3	0.1	31.2	5.7%
3 Solvent and other product use[(a)]	NA	NA	IE	NA	NA	NA	IE	NA
4 Agriculture	NA	67.1	20.2	NA	NA	NA	87.4	16.1%
6 Waste	0.03	11.3	0.4	NA	NA	NA	11.7	2.2%
Total net emissions (excluding *LULUCF*)	**397.8**	**111.7**	**25.8**	**7.9**	**0.3**	**0.1**	**543.6**	**100.0%**
5 *Land use, land use change and forestry*	9.3	4.2	1.7	NA	NA	NA	15.2	2.7%
Total net emissions (including *LULUCF*)	**407.1**	**115.9**	**27.5**	**7.9**	**0.3**	**0.1**	**558.8**	**100.0%**

(a) confidential N_2O emissions from *solvent and other product use* are reported under *industrial processes*

2.2 Emission Trends by Gas

Of the individual greenhouse gases, emissions of CO_2 increased by 44.1% between 1990 and 2012. N_2O emissions increased by 40.4% and HFC emissions increased by 605.4%. PFC emissions fell by 93.6 %, CH_4 emissions fell by 3.0% and SF_6 emissions decreased by 39.4%.

Table 2.2: Change in total net CO_2-e emissions by gas (excluding the *LULUCF* sector), 1990–2012

Greenhouse gases	1990 Mt CO_2-e	2012 Mt CO_2-e	1990% of Total	2012% of Total	Changes Mt	% Change in emissions
CO_2	276.1	397.8	66.5%	73.2%	121.7	44.1%
CH_4	115.2	111.7	27.8%	20.5%	-3.5	-3.0%
N_2O	18.4	25.8	4.4%	4.7%	7.4	40.4%
HFCs	1.1	7.9	0.3%	1.5%	6.8	605.4%
PFCs	4.0	0.3	1.0%	0.05%	-3.7	-93.6%
SF_6	0.2	0.1	0.05%	0.02%	-0.1	-39.4%
Total CO_2-e	**415.0**	**543.6**	**100.0%**	**100.0%**	**128.7**	**31.0%**

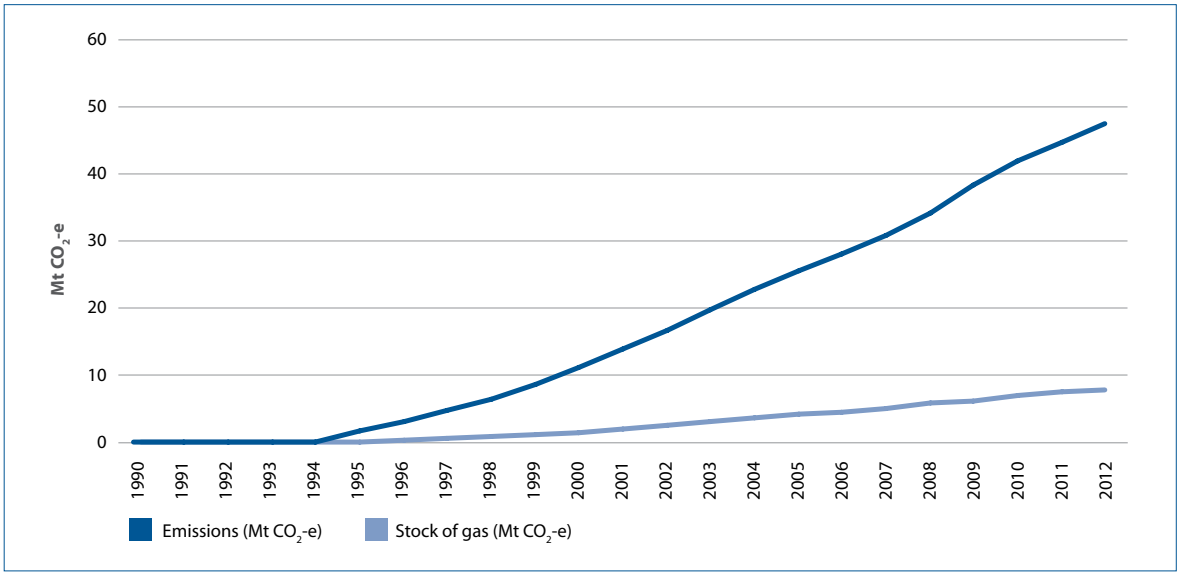
The *energy* sector is the major contributor to CO_2 emissions at 94.9% (377.5 Mt). The increase in CO_2 emissions reflects the increased emissions from the energy sector particularly in electricity generation and road transport.

Agriculture is the main contributor of CH_4 (60.1%, 67.1 Mt CO_2-e) and N_2O (78.5%, 20.2 Mt CO_2-e) emissions. The growth in the N_2O emissions is driven by increases in *industrial processes* emissions and also by increased emissions from the manure of intensively managed livestock and increased use of nitrogenous fertilisers in the *agriculture* sector.

The other greenhouse gases, HFCs, SF_6 and PFCs, which contribute 1.5% of the total emissions (excluding *LULUCF*), have undergone large relative changes between 1990 and 2012. Emissions of PFCs have principally decreased due to improvements in aluminium smelting processes. HFC emissions have increased because of the use of HFCs as a substitute for chlorofluorocarbons (CFCs) phased out under the Montreal Protocol.

The nature of the release of HFC emissions (gradual leakage from an increasing stock) means they will be a growing influence on Australia's National Inventory total for some time. The stock of HFCs has been growing strongly since their introduction in 1994 (Figure 2.2). A small proportion of this stock is emitted each year through leakage however the remaining stock continues to increase and will be mostly emitted in the future (assuming current levels of destruction and recycling remain stable). It is expected that it will take many years for HFC emissions to stabilise as equipment disposals become the dominant mechanism for HFC release.

Figure 2.2: Halocarbons: estimated stock and emissions: all equipment types



Other sources such as CH_4 emissions from solid waste disposal on land and decommissioned coal mines also have extended lifetimes to their emissions profile although the growth rate in emissions from these sources is less than the rate for HFCs.

2.3 Emission Trends by Source

Sectors with increasing emissions over the 1990 to 2012 period included *stationary energy* (45.5%), *transport* (49.7%), *fugitive emissions from fossil fuels* (25.2%), *industrial processes* (26.5%) and agriculture (1.0%). Decreased emissions were recorded for *waste* (31.2%), and *land use, land use change and forestry* (88.4%).

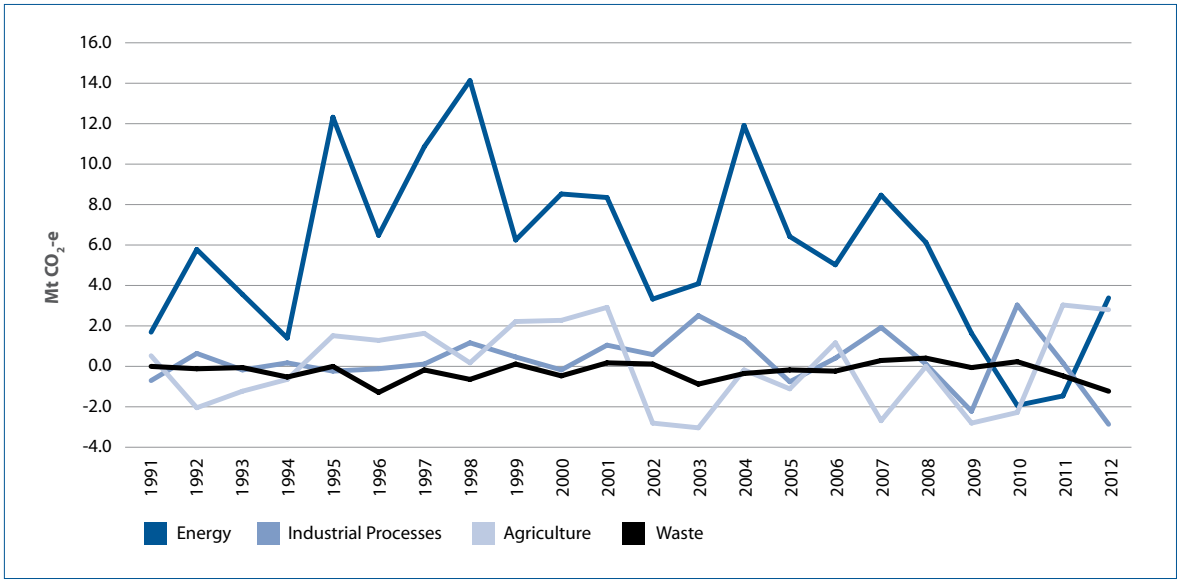
Figures 2.3 shows the absolute annual change for each sector from 1990-2012. The principal drivers of these emission trends are as follows:

- *Energy*: The largest sectoral increase in greenhouse gas emissions over the 1990 to 2012 period, of 45.5 % (88.6 Mt CO_2-e), occurred in the *stationary energy* sector, driven in part by increasing population, household incomes and export increases from the resources sector. The main drivers for the increase in *transport* emissions are continuing growth in the number of passenger vehicles, along with an increase in diesel consumption in heavy vehicles. *Fugitive emissions* have increased largely due to increased production from open cut coal mines;

- *Industrial processes*: The increase in emissions since 1990 is primarily driven by the growth in emissions associated with HFCs and chemical industries;
- *Agriculture*: Between 1990 and 2001 emissions increased due to increased fertiliser use and savanna burning. From 2002 until 2010 emissions declined due to prolonged and widespread drought conditions over southern and eastern Australia which contributed to reductions in animal populations, crop production, fertiliser use, and associated emissions. With the return to wetter conditions emissions have begun to increase again as high levels of crop production have been achieved and livestock populations have increased as farmers rebuild their herd following the drought;
- *Waste*: The net emissions from waste have decreased as increases associated with growing populations and industrial production have been offset by increased CH_4 recovery; and
- *LULUCF*: The decreasing trend in emissions from *LULUCF* since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland* and *grassland*. Changes in *LULUCF* emissions from year to year are affected by other factors, principally natural disturbances such as wildfires.

Trends in emissions from each sector are discussed further in Chapters 3-8.

Figure 2.3: Absolute annual change in CO_2-e emissions by sector, 1990-2012



Emissions from some sectors are heavily reliant on the existing capital stock which influences emissions. An example of this is evident when analysing non-CO_2 emissions from road transport. In recent years updated Australia Design Rules were introduced requiring new vehicles to emit lower levels of pollutants. However, non-CO_2 emissions from this sector have reduced only gradually over the time series because it takes many years to turn over the existing vehicle stock. Figures 2.4 and 2.5 show the emissions of CH_4 and N_2O from road transportation in Australia. The gradual decrease in emissions in recent years is a result of the gradual replacement of the vehicle fleet to vehicles manufactured under more recent Australia Design Rules.

Figure 2.4: CH_4 emissions from road transportation in Australia, 1990-2012

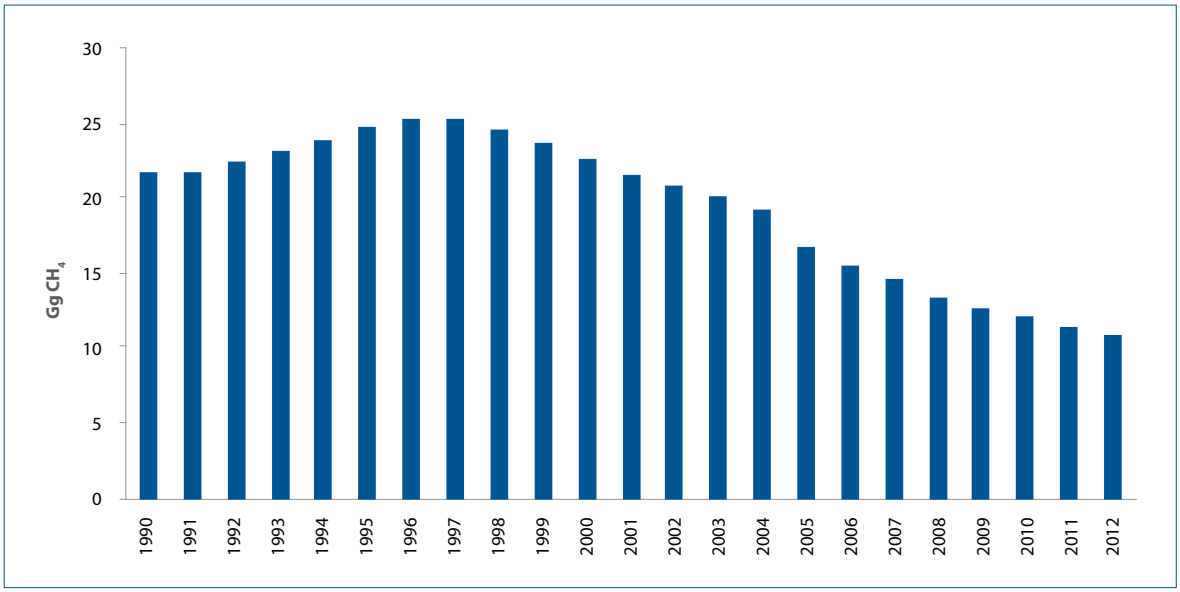
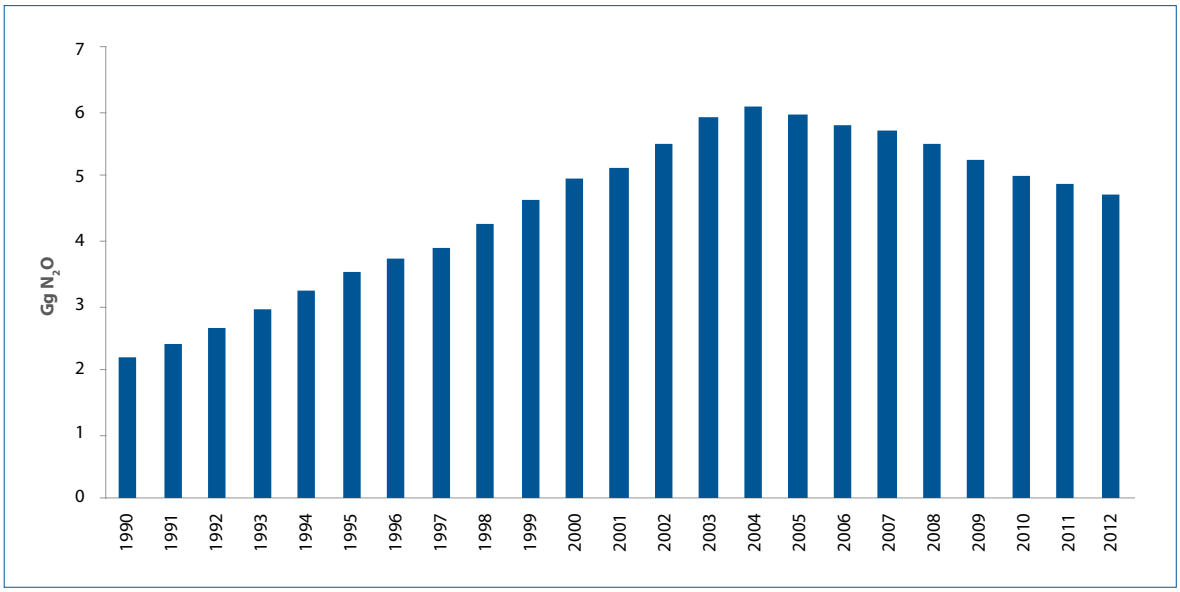


Figure 2.5: N_2O emissions from road transportation in Australia, 1990-2012



2.4 Emission Trends for Indirect Greenhouse Gases and SO_2

The indirect greenhouse gases NO_x, CO, NMVOC and SO_2 are also reported but as they have not been allocated global warming potentials they are not included within Australia's total aggregated emissions. Since 1990 there have been increases in the emissions of CO, NO_x, SO_2 and NMVOCs (Table 2.3).

The main source of NO_x is the *energy* sector, with the largest single source public electricity and heat production. The *agriculture* and *LULUCF* sectors are the largest producers of CO and NMVOCs. These gases, along with NO_x, are emitted during biomass burning. Emissions of SO_2 occur in the *industrial processes* and *energy* sectors, the principal sources being other metal production (2.C.5) and electricity and heat production (1.A.1.a).

Table 2.3: Emissions of indirect greenhouse gases and SO_2 in 1990 and 2012[1]

Greenhouse gas	1990 (Mt)	2012 (Mt)	Change from 1990 (Mt)	Change from 1990 (%)
NO_x	1.8	2.5	0.8	44.6
CO	20.7	28.0	7.3	35.1
NMVOC	2.6	2.9	0.3	12.5
SO_2	1.6	2.3	0.8	50.1

1. Including emissions from the *LULUCF* sector

2.5 Emission Trends for Kyoto Protocol

Australia's initial assigned amount[4] is equivalent to an average of 591.5 Mt CO_2-e for each year of the commitment period (2008-2012). The initial assigned amount is based on the revised 2005 inventory submitted in 2008 and reported in Australia's *Initial Report under the Kyoto Protocol, revised submission* (DCC, 2008). The initial assigned amount is fixed and is the value that Australia's Kyoto Protocol emissions account will be compared with for the first commitment period.

Under the KP accounting rules, Parties must report emissions from the Article 3.1 (Annex A) sectors, namely the *energy*, *industrial processes*, *solvents*, *agriculture* and *waste* sectors. However, only a subset of the *LULUCF* sector emissions and removals are included in the account. These include deforestation, afforestation and reforestation activities that have occurred since 1990 (Article 3.3 activities which are mandatory) and forest, cropland or grazing land management and revegetation (Article 3.4 activities which can be elected by the Party). Australia has not elected to account for any Article 3.4 activities for the first commitment period.

In 2012, *afforestation/reforestation* activities on unharvested land units contributed a net sink of 22.2 Mt CO_2-e, while harvested land contributed 10.7 Mt CO_2-e (Table 2.4). *Deforestation* activities were a net source of 32.8 Mt CO_2-e in 2012.

Table 2.4: Net emissions and removals from Article 3.3 *LULUCF* activities by gas in 2012

KP-*LULUCF* Activities	CO_2	CH_4	N_2O	Total
	Mt CO_2-e			
Afforestation/Reforestation				
Units of land not harvested during the commitment period	-22.2	0.0	0.0	-22.2
Land units harvested during the commitment period[(a)]	10.7	0.0	0.0	10.7
Deforestation	31.6	0.7	0.5	32.8

(a) These are the estimated emissions and removals not the accounting quantities

Australia has elected to account for the Article 3.3 activities on an annual basis. In accordance with the harvested forest sub-rule (paragraph 4 of the annex to decision 16/CMP.1) in calculating the *afforestation/reforestation* accounting quantity for 2012, the emissions on harvested land units that are a net source of emissions over the period 2008-2012 have been set to zero (Table 2.5). The total net emissions associated with Kyoto Protocol Article 3.1 sectors and Article 3.3 *LULUCF* activities in 2012 were 554.6 Mt CO_2-e.

4 The initial assigned amount (2,957,579.143 Gg CO_2-e) is calculated as five times 108% of base year emissions. The base year emissions (547.7 Mt CO_2-e) are the 1990 emissions from the annex A sectors and land use change as reported in the revised 2005 inventory.

Table 2.5: Emissions and removals associated with Articles 3.1 and 3.3 of the Kyoto Protocol, 2012

Sector and Subsector	Emissions Mt CO_2-e
Article 3.1 – Annex A sectors	
1 Energy	413.4
2 Industrial Processes	31.2
3 Solvent and other product use[(a)]	IE
4 Agriculture	87.4
6 Waste	11.7
Inventory Total	**543.6**
Article 3.3 – KP *LULUCF* activities[(b)]	
Afforestation/Reforestation[(c)]	-21.9
Deforestation	32.8
Kyoto Protocol Total	**554.6**

(a) Included elsewhere - emissions are included in *industrial processes* for confidentiality reasons.

(b) Australia has elected to account for Article 3.3 activities on an annual basis.

(c) Accounting quantity in accordance with paragraph 4 of the annex to decision 16/CMP.1.

2.5.1 Latest Quarterly Trends

The department publishes preliminary estimates of emissions for each quarter. Up to date estimates of Australian emissions trends are produced by supplementing the estimation methodologies documented in the *National Inventory Report* with preliminary activity and economic data from government and industry sources.

Preliminary emissions estimates for the year to December 2013 showed Australia's emissions, excluding *Land Use, Land Use Change and Forestry* (LULUCF) activities under Article 3.3 of the Kyoto Protocol, were 538.4 Mt CO_2-e (Table 2.6); a decrease of 0.8% on the previous year. The primary contributor to the decrease in emissions was a decline in emissions from the *electricity* sector due to reductions in electricity demand and changes in the generation fuel mix.

Table 2.6: Preliminary National Inventory for the year to December 2013[a]

Sector	Annual Emissions through to the December Quarter 2013 (Mt CO_2-e)[b]	Change on the year to December Quarter 2012 (%)
National Inventory – Annex A sectors		
Energy – Electricity	176.6	-5.0%
Energy – Stationary energy excluding electricity	92.2	0.9%
Energy – Transport	92.5	0.6%
Energy – Fugitive emissions	45.6	6.7%
Industrial Processes	30.2	-0.9%
Agriculture	11.7	-0.3%
Waste	89.6	1.1%
National Inventory (excluding LULUCF)	**538.4**	**-0.8%**
LULUCF - Deforestation[b]	33.7	2.7%[c]
LULUCF – Afforestation and reforestation[b]	-19.2	-12.2%[c]
National Inventory (including LULUCF)	**552.9**	**NA[d]**

(a) Emissions estimates are preliminary. As more data becomes available from the Department's reference sources these preliminary activity data will be replaced and the estimates of emissions revised before submission to the UNFCCC.

(b) The estimates for *deforestation and afforestation and reforestation* are subject to a greater level of uncertainty than the other sectors.

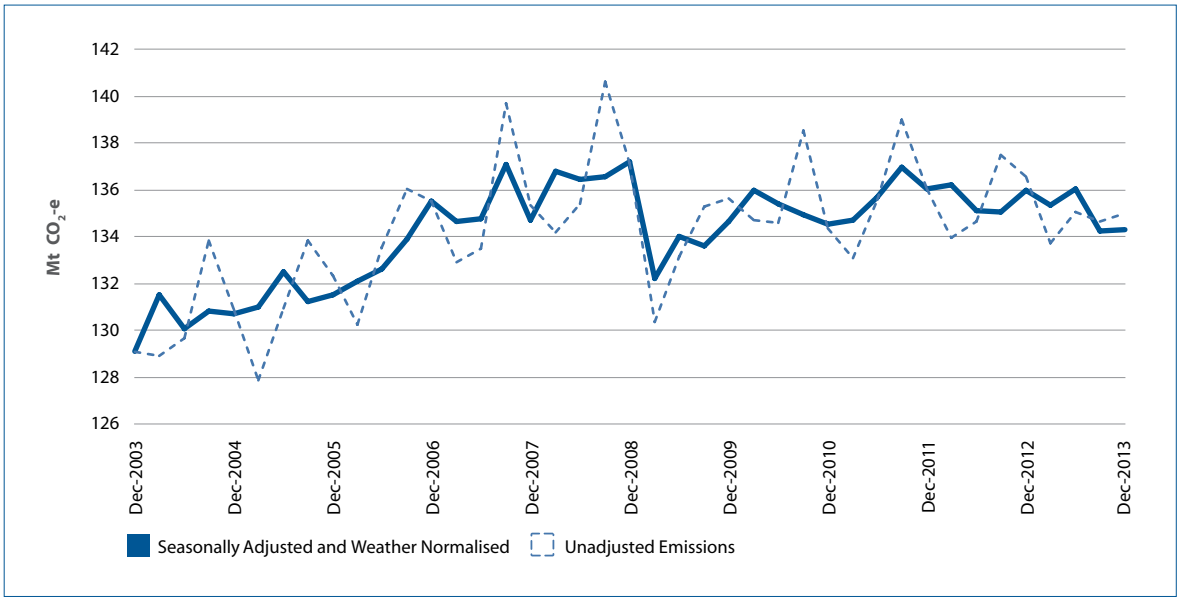
(c) LULUCF estimates were developed on the basis of accounting rules applicable to the first commitment period of the Kyoto Protocol (ended 31 December 2012) and the second commitment period (commenced 1 January 2013). As the accounting rules that apply to these two periods are slightly different, a consistent year-on-year comparison of emissions is subject to limitations during this transition period (2012-13).

(d) Quarterly estimates are not yet available for Article 3.4 LULUCF activities which are applicable for reporting in the second commitment period. Future quarterly inventories will progressively incorporate estimates for Article 3.4 LULUCF activities; *forest management, cropland management and grazing land management*.

Australia's emissions (excluding LULUCF) for the December 2013 quarter are unchanged on a seasonally adjusted and weather normalised basis relative to the September 2013 quarter, and down by 0.4 per cent on a trend basis.

Quarterly estimates are estimated on a seasonally adjusted and weather normalised basis. Seasonally adjustment removes the seasonal component of the emission estimate which has a systematic effect on emissions over a year. Weather normalisation involves further adjusting to correct for the effects of variations around average seasonal temperatures. This process is designed to provide a clearer indication of the underlying trends in the emissions data. Figure 2.6 presents unadjusted and seasonally adjusted and weather normalised emissions by quarter from December 2003 to 2013.

Figure 2.6: National Inventory, unadjusted and seasonally adjusted and weather normalised emission estimates – December quarter 2003 to December quarter 2013[a]



(a) In Figure 2.6 the unadjusted and seasonally adjusted and weather normalised emission estimates for each quarter are shown. Unadjusted emissions will fluctuate during the year as a result of seasonal weather patterns and variations in economic activity.

Future *Quarterly Updates* will implement additional changes to reflect updated activities, global warming potentials and accounting rules applicable to the second commitment period of the Kyoto Protocol.

3. Energy

3.1 Overview

Total emissions from the *energy* sector for 2012 were estimated to be 413.4 Mt CO_2-e (Table 3.1). *Energy industries* were the main contributor, accounting for 53.6% of emissions from the *energy* sector. Other significant contributors to total *energy* emissions were *transport* (21.8%), and *manufacturing industries and construction* (9.7%).

Energy sector emissions increased by 44.2% between 1990 and 2012. Annual emissions from 2011 to 2012 from the sector increased by 3.4 Mt (0.8%).

Table 3.1: Energy sector CO_2-e emissions, 2012

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
1 ENERGY	**377,513**	**33,257**	**2,589**	**413,359**
A. Fuel combustion activities	**369,247**	**1,631**	**2,552**	**373,430**
1 Energy industries	**220,495**	**337**	**730**	**221,562**
a Electricity and heat production	192,042	283	683	193,008
b Petroleum refining	5,092	2	13	5,107
c Manufacture of solid fuels	23,362	52	33	23,447
2 Manufacturing industries and construction	**39,774**	**33**	**141**	**39,948**
3 Transport	**88,234**	**362**	**1,610**	**90,206**
a Civil aviation	7,368	1	71	7,440
b Road transportation	74,982	233	1,495	76,710
c Railways	2,776	3	25	2,804
d Navigation (domestic)	3,064	125	19	3,208
e Other transportation	44	0	0	45
4 Other sectors	**19,400**	**899**	**64**	**20,364**
5 Other	**1,343**	**1**	**8**	**1,351**
a Lubricants	480			480
b Mobile (military)	863	1	8	871
B. Fugitive emissions from fuels	**8,266**	**31,625**	**37**	**39,929**
1 Solid fuels	**1,568**	**25,446**	**0**	**27,015**
2 Oil and natural gas	**6,698**	**6,179**	**37**	**12,914**

3.1.1 Stationary Energy

Stationary energy principally comprises fossil fuel combustion in *electricity and heat production* and *manufacturing and construction industries.* Total estimated emissions from *stationary energy* combustion were 283.2 Mt CO_2-e in 2012, equal to 52.1% of net national emissions (excluding *LULUCF*).

The *energy industries* subsector includes fuel combustion in electricity generation, petroleum refining, gas production and solid fuel manufacture. *Electricity and heat production* (1.A.1.a) contributed 193.0 Mt CO_2-e or 68.1% of *stationary energy* emissions in 2012. This category includes emissions only from electricity generation because heat production as defined by the IPCC does not occur in Australia. Estimated emissions from the remaining *energy industries* subsectors were 28.6 Mt CO_2-e in 2012.

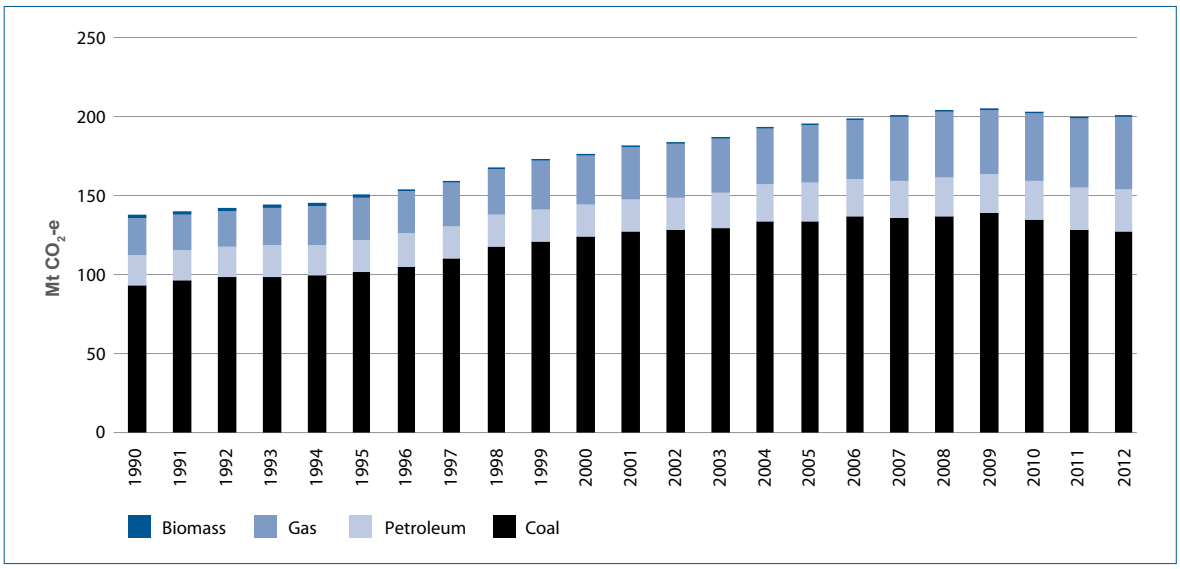
The *manufacturing industries and construction* subsector (1.A.2) emissions were 39.9 Mt CO_2-e in 2012. This subsector includes direct emissions from fuel combustion in manufacturing industries, ferrous and non-ferrous metals production, plastics production, construction and non-energy mining. These calculations do not fully reflect the greenhouse impact of these industries, as the emissions generated from the production of electricity used in these industries are included under *electricity and heat production* (1.A.1.a).

Estimated emissions from *other sectors* (1.A.4) were 20.4 Mt CO_2-e in 2012. This subsector comprises direct fuel combustion in the residential, commercial and institutional sectors, including energy used in mobile equipment in *agriculture*, *forestry* and *fishing* industries. However, as with *manufacturing*, much of the greenhouse impact of these sectors arises from their large consumption of electricity, which is not reflected in this figure alone (reported under 1.A.1.a). *Other* (1.A.5) includes emissions from *lubricants* (0.5 Mt CO_2-e) and *military transport* (0.9 Mt CO_2-e). Emissions from *lubricants* arise from the combustion of engine oil in vehicles.

Trends

Emissions from *stationary energy* increased by 45.5% (88.6 Mt CO_2-e) between 1990 and 2012, including an increase in emissions from the combustion of solid fossil fuels of 36.4% (48.0 Mt CO_2-e) in the same period (Figure 3.1). Although the combustion of solid fossil fuels accounted for the highest absolute increase in emissions over this period, emissions related to gaseous fossil fuels have shown the largest relative growth, increasing by 94.9% (31.3 Mt CO_2-e) between 1990 and 2012. Emissions from liquid fossil fuels increased by 37.9% (10.5 Mt CO_2-e) in the same period. Biomass emissions decreased by 50.6% (1.1 Mt CO_2-e) between 1990 and 2012. Between 2011 and 2012, emissions from *stationary energy* increased by 0.2% (0.7 Mt CO_2-e).

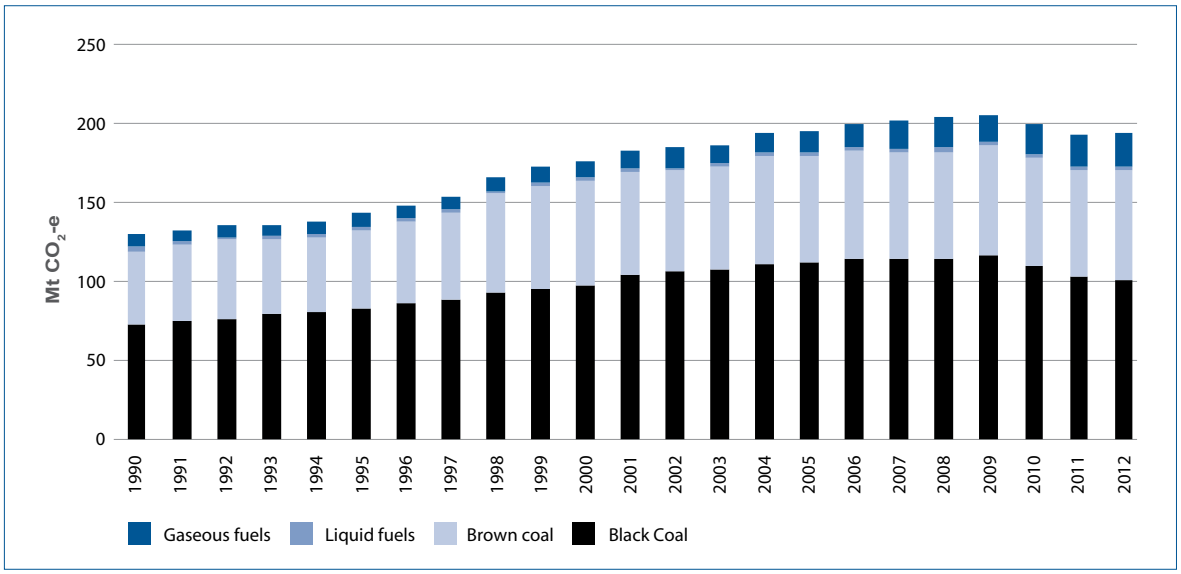
Figure 3.1: Total CO_2-e emissions from stationary energy combustion by fuel, 1990–2012



Electricity generation emissions increased by 0.4 Mt (0.2%) from 2011 to 2012, and increased by 63.5 Mt (49.0%) from 1990 to 2012 (Figure 3.2). The 2011 to 2012 electricity generation emissions increase (0.2%) was in contrast to a decrease in electricity generation (1.2%). This was primarily due to a decrease in the electricity generated from black coal which was replaced by increases in brown coal and gaseous fuels.

Emissions from *stationary energy* subsectors, other than *electricity generation*, increased by 0.3 Mt CO_2-e (0.3%) between 2011 and 2012, and increased overall by 25.1 Mt (38.6%) from 1990 to 2012. Emissions from the *manufacturing industries and construction* subsector increased 1.9% (0.8 Mt CO_2-e) between 2011 and 2012 and increased by 12.4% (4.4 Mt CO_2-e) from 1990 to 2012.

Figure 3.2: CO_2-e emissions from electricity generation by fossil fuels, 1990–2012



3.1.2 Transport

In 2012, *transport* contributed 90.2 Mt CO_2-e or 16.3% of Australia's net emissions (excluding *LULUCF*).

The major source of *transport* emissions in Australia is road transportation, which accounts for 85.0% (76.7 Mt CO_2-e) of *transport* emissions. This outcome is principally driven by the importance of motor vehicles as modes of transportation of passengers and freight in Australia. Passenger cars account for 43.8 Mt CO_2-e and trucks (light and heavy) and buses 19.5 Mt CO_2-e. Other sources are far smaller: domestic aviation contributed 8.2% (7.4 Mt CO_2-e), domestic navigation 3.6% (3.2 Mt CO_2-e), and railways 3.1% (2.8 Mt CO_2-e).

Fuel used in *international transport (international aviation* and *marine 'bunkers')* is by international agreement reported separately from the national total net emissions. In 2012, international bunker fuels generated 12.3 Mt CO_2-e of emissions.

Trends

Transport emissions are one of the strongest sources of emissions growth in Australia. Emissions from this sector were 49.7% higher in 2012 than in 1990, and on average have increased by around 1.8% annually (Figure 3.3). Emissions from road transportation increased by 44.7% (23.7 Mt CO_2-e) between 1990 and 2012 (Figure 3.4). Emissions from passenger cars increased by 28.1% (9.6 Mt CO_2-e). Emissions from light commercial vehicles (LCVs) and heavy duty trucks and buses have also grown strongly (79.7% and 72.7% respectively).

Figure 3.3: Total transport emissions, 1990–2012

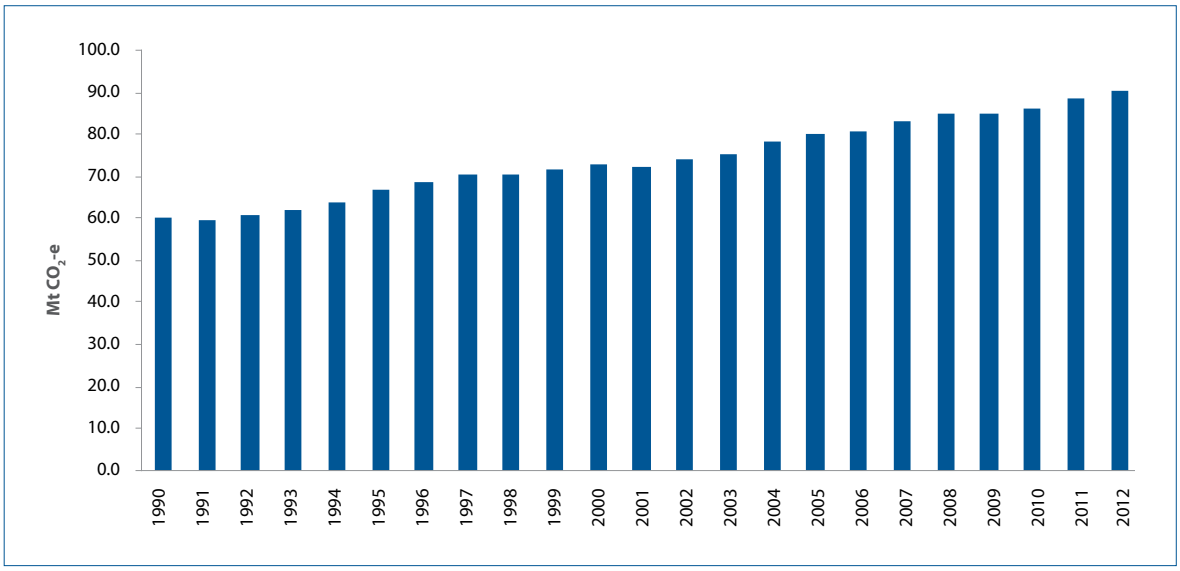
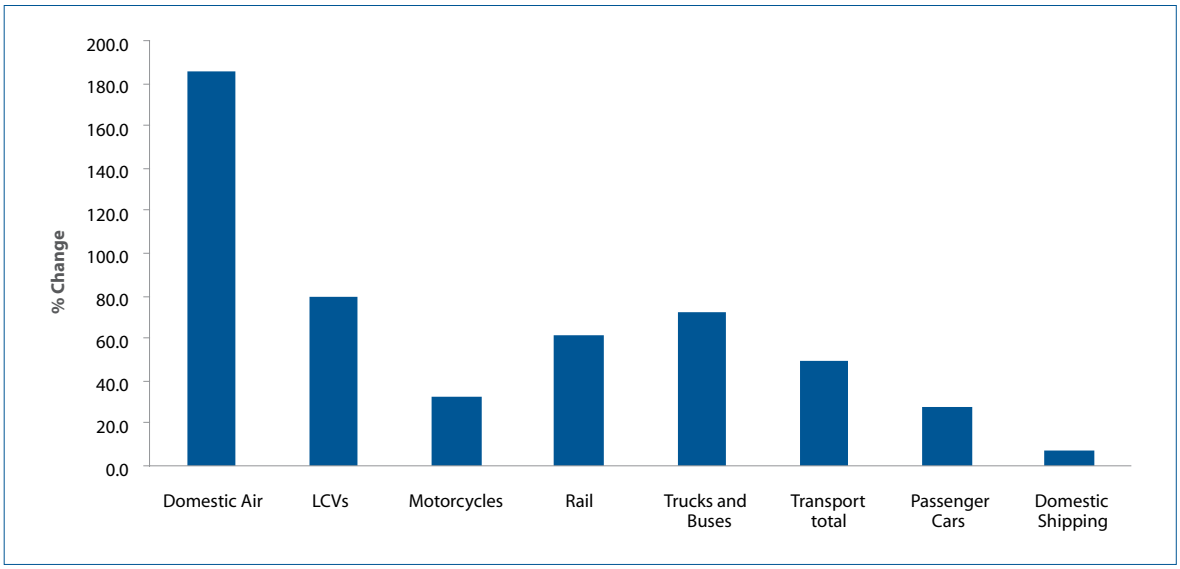


Figure 3.4: Comparison of growth in transport emissions by subcategory, 1990–2012



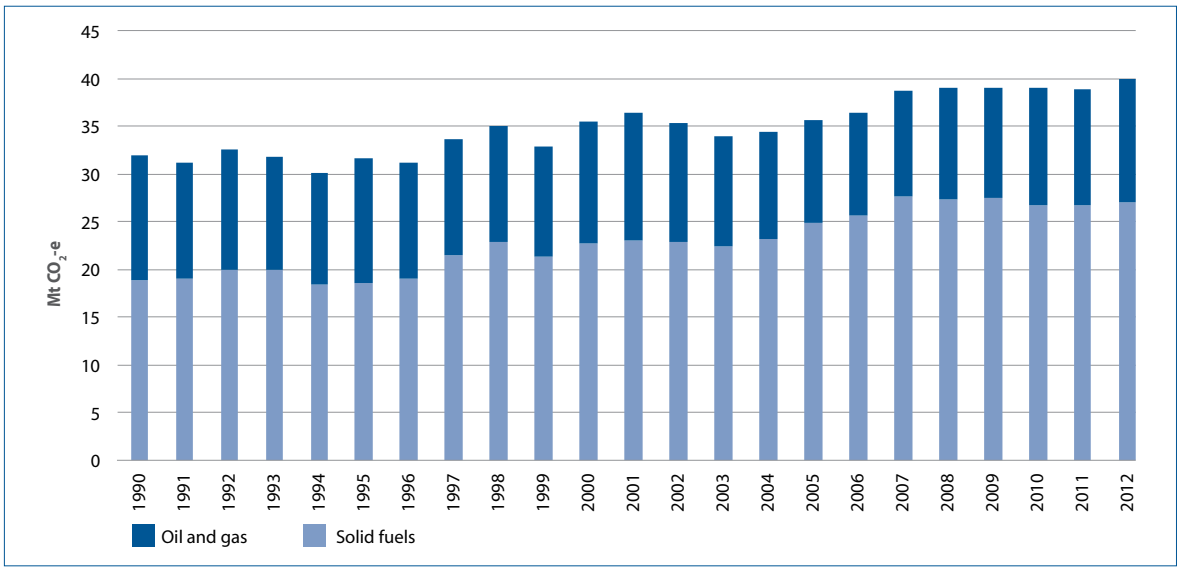
3.1.3 Fugitive Emissions

Total estimated *fugitive emissions* for 2012 were 39.9 Mt CO_2-e, representing 7.3% of net national emissions (excluding *LULUCF*). Net *solid fuel* emissions contributed 67.7% (27.0 Mt CO_2-e) of *fugitive emissions. Oil and natural gas production, processing and distribution* account for the remaining 32.3% (12.9 Mt CO_2-e) of *fugitive* emissions.

Trends

Overall *fugitive emissions* increased 25.2% (8.0 Mt CO_2-e) between 1990 and 2012, and increased by 2.7% (1.1 Mt CO_2-e) from 2011 to 2012 (Figure 3.5). From 1990 to 2012, fugitive emissions from *solid fuels* increased by 43.6% (8.2 Mt CO_2-e) and *oil and natural gas* emissions decreased by 1.6% (0.2 Mt CO_2-e).

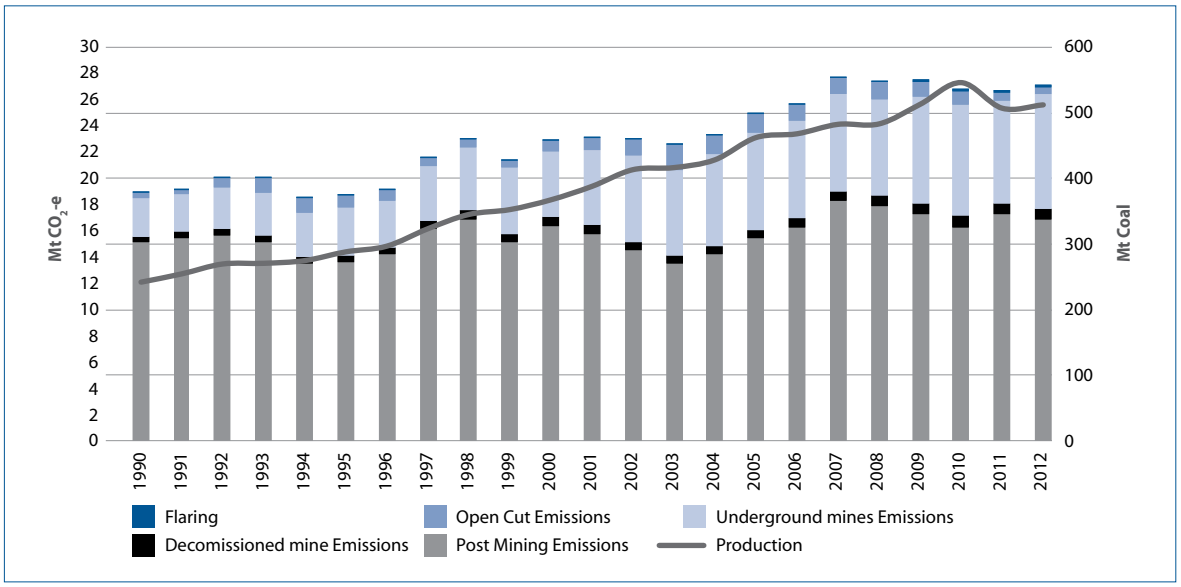
Figure 3.5: CO_2-e fugitive emissions by category, 1990–2012



Solid fuel emissions increased by 1.3% (0.4 Mt CO_2-e) between 2011 and 2012. Underground mine emissions increased by 6.9% (1.2 Mt CO_2-e). Emissions from surface mines decreased by 2.2% (0.4 Mt CO_2-e) between 2011 and 2012. Emissions from decommissioned mines have decreased 15.3% (0.1 Mt CO_2-e) between 2011 and 2012, and emissions from flaring increased by 13.0% (0.02 Mt CO_2-e).

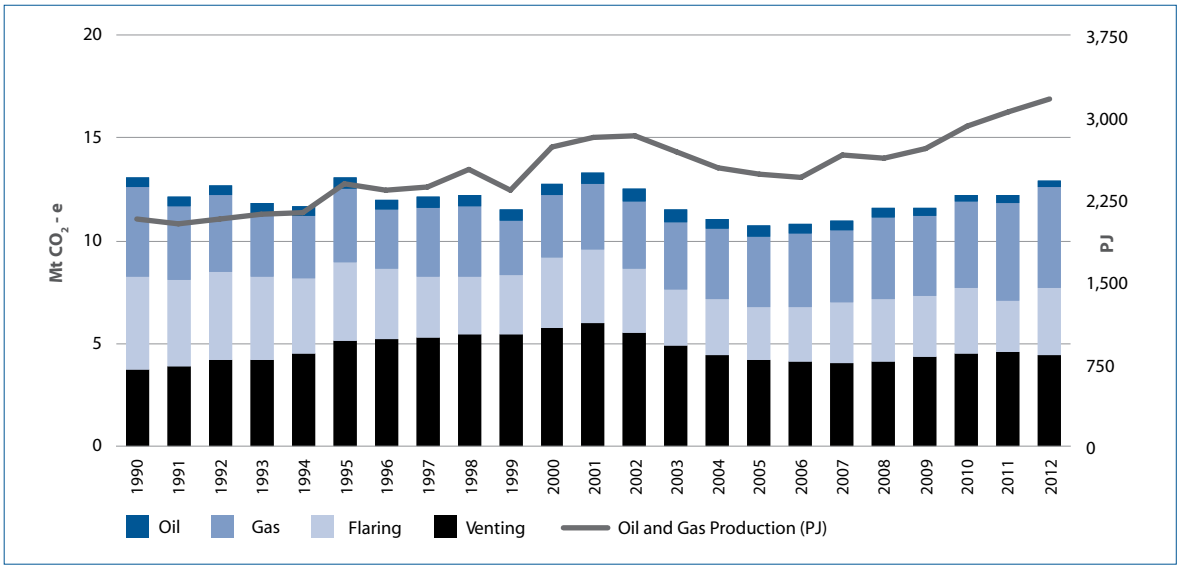
Emissions tend to fluctuate from year to year depending on the volume of coal mined and the share of production from underground mines of varying gas contents. Mine production of coal has increased from 241.0 Mt in 1990 to 510.1 Mt in 2012, an increase of 112.5%. CH_4 emissions have not grown as fast as activity principally because, since 1998, there has been an increasing trend in activity from surface mines compared to that of underground mines (Figure 3.6) and, within underground mines, a decreasing share of production from the gassiest southern New South Wales coalfield (Figure 3.15). In addition, technologies to recover and utilise coal mine waste gas for electricity generation have been increasingly adopted in underground mining, particularly in recent years.

Figure 3.6: Fugitive CO_2-e emissions from coal mining activities, 1990–2012



Oil and natural gas fugitive emissions decreased by 1.3% (0.2 Mt CO_2-e) between 1990 and 2012 (Figure 3.7). This compares with a 52.5% increase in production activity. The decrease in emissions relative to the increase in activity is the result in particular of improvements in gas distribution and a reduction in the emissions from flaring. Between 1990 and 2012, emissions from oil-related activities decreased by 28.9% (-0.1 Mt CO_2-e) and emissions from gas-related activities increased by 12.6% (0.5 Mt CO_2-e). Emissions from venting decreased by 3.3% (0.1 Mt CO_2-e) from 2011 to 2012 and, compared with 1990, emissions were higher by 18% (0.7 Mt CO_2-e). Flaring-related emissions increased by 28.9% (0.7 Mt CO_2-e) from 2011 to 2012, and emissions in 2012 were lower than 1990 levels by 28.1% (-1.3 Mt CO_2-e).

Figure 3.7: Fugitive CO_2-e emissions from oil and gas production, 1990–2012



3.2 Overview of Source Category Description and Methodology - Energy

The *energy* sector includes emissions from the combustion of fossil fuels (1.A.1 *energy industries*; 1.A.2 *manufacturing industries and construction*; 1.A.3 *transport;* 1.A.4 *other sectors*; and 1.A.5 *'other'*) as well as *fugitive emissions from the extraction of fossil fuels* (1.B).

The use of solid, liquid and gaseous fuels for energy use has been identified as key sources in Australia's inventory.

The methodology for estimating emissions from fossil fuel combustion in the *stationary energy* sectors is consistent with the IPCC tier 2 approach. Tier 2 methods may be regarded as those dividing fuel consumption on the basis of sample or engineering knowledge between technology types which are sufficiently homogenous to permit the use of representative EFs. Emissions for the *transport* sector have been estimated with a mix of tier 1, tier 2, and tier 3 approaches.

The Bureau of Resources and Energy Economics (BREE) compile the *Australian Energy Statistics* (AES; BREE 2013) which estimates Australian energy consumption by fuel and economic sector for the purpose of meeting Australia's reporting commitments to the International Energy Agency. National Greenhouse and Energy Reporting System (NGER) data have been adopted as the main energy consumption data source for the AES. Previously, the construction of BREE historical energy statistics were based on the voluntary Fuel and Electricity Survey (FES), conducted in the second half of each year. With the introduction of NGER, survey year 2008–09 became the final year that the FES was conducted. For survey year 2009–10 and onwards, NGER data has been used as the primary source of energy consumption data.

The AES provides a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. To ensure internal consistency and completeness, the data are reconciled with 'top-down' statistics on the supply and use of all major fuels in Australia collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries.

3.2.1 CO_2 Emissions and Emission factors

In general, the estimate of emissions of CO_2 used for each fuel, *k*, in each economic sector, *h*, is estimated by:

$$E_{hk} = (F_{hk} \cdot EF_{hk} \cdot P_{hk} / 100) - S_{hk} \cdot 44/12 \quad (3.1)$$

where: E_{hk} is the amount of CO_2 emitted from fuel k in economic sector h (in Gg);

F_{hk} = the amount of fuel k combusted in sector h (in PJ);

EF_{hk} = the CO_2 EF (in Gg CO_2/PJ) for fuel k;

P_k = the oxidation factor (in per cent) of fuel k; and

S_{hk} = the amount of carbon sourced from fuel k which is stored in sector h (in Gg).

EFs for CO_2 depend only on the chemical composition of the fossil fuel concerned under IPCC methods. For fuels having well defined and/or stable chemical composition, CO_2 EFs can be specified with considerable accuracy. This is particularly the case for natural gas and for petroleum products, with the exception of fuel oil, which may vary considerably in composition, and to a lesser degree for coals, which can vary in their composition of both combustible components (carbon, volatiles) and non-combustible components (ash, moisture).

Solid fuels

Coal

Approximately 90% of all coal consumed in Australia is used by the electricity generation industry. Under NGER all electricity generators who consume coal as their primary fuel must sample and analyse their coal and report their facility specific CO_2 EF. The reported EFs are illustrated in Figure 3.8. After the electricity industry, the largest user of coal in Australia is the steel industry. The steel industry has provided a representative CO_2 EF of 91.8 Gg/PJ for black coal used in iron/steel/coke production (L. Leung, BHP 2001, pers. comm.). This figure has been further verified by industry data obtained from NGER as being representative. For other uses of coal, CO_2 EFs are reported in Table 3.2.

Coke

The CO_2 EF for coke is derived from a carbon balance conducted on the coke oven subsector. Carbon input into coke ovens is estimated and balanced against carbon contained in the fuel and product outputs from coke ovens. The carbon content of coke is determined as the carbon content required to achieve a carbon balance for the overall coke oven process. The resulting coke EF varies slightly from year to year depending on the balance of inputs and outputs, in a range between 105.9 and 108.9 Gg/PJ which is comparable to the IPCC default factor (Table 3.A.22). The underlying data used to estimate the coke EF is confidential due to the sector being characterised by a limited number of producers.

Coal By-Products

Coal by-product fuels are defined as coke oven gas, coal tar and liquefied aromatic hydrocarbons. They are produced largely as a by-product of coke oven processes, however liquefied aromatic hydrocarbons can also be produced from petroleum refining. An EF of 37 Gg/PJ has been assigned to coke oven gas following advice from the steel industry (Deslandes and Kingston 1997). The steel industry has also advised a representative EF for coal tar of 81.8 Gg/

PJ. Liquefied aromatic hydrocarbons consist of compounds such as benzenes, toluene and xylene. Because of their similarities with naphtha and solvents, the same EF of 69.7 Gg/PJ was assigned to these products.

Liquid fuels

Refined Petroleum Products

Australian oil tends to be of the light crude variety and the petroleum products generated by Australian refineries reflect the characteristics of these supplies. The country-specific EFs for marketable petroleum products for this inventory are taken from GHD Australia (GHD 2006a), which reports the results of a review of Australian petroleum products. EFs are listed in Table 3.2. A representative value to be used for fuel oil, derived from IPCC 1997, was confirmed by discussion with Nabalco (J. Bawdin, pers. comm. 1996), one of the largest industrial users of fuel oil in Australia, and Shell (J. Le Cornu, pers. comm. 1996).

Other Petroleum Products

In the AES sectors, Basic Chemicals (ANZSIC Group 253), Oil and Gas Mining (ANZSIC Subdivision 12) and Basic Non-Ferrous Metals (ANZSIC Group 272) (after excluding petroleum coke from the latter sector), petroleum products not elsewhere classified (nec) consists largely of naphtha. The EF for naphtha of 69.7 Gg CO_2/PJ, (IPCC 1997), was therefore used in these sectors. For all other AES sectors in which petroleum products nec appears as a fuel type, an EF of 69.7 Gg CO_2/PJ is used based on IPCC 1997 default for refinery feedstocks and other oil.

Petroleum refining consumes refinery gas/liquids and refinery coke in the process of converting raw crude oil to refined products. EFs of 54.7 Gg CO_2/PJ (refinery gas and liquids) and 92.7 Gg CO_2/PJ (refinery coke) have been adopted from the 2006 *Guidelines* (IPCC 2006), as no appropriate factors are provided for these fuel types in the IPCC *Guidelines* (1997).

Recycled tyres are combusted for energy within Cement, Lime, Plaster and Concrete (ANZSIC Group 263). An EF of 81.6 Gg CO_2/PJ was sourced from the US Energy Information Administration (GHD 2006b). The EF is conservative as it makes no allowance for any biomass component of tyres. The report on the validity of the inventory liquid fuel characteristics also assessed the natural carbon versus fossil carbon content of tyres. Scrap tyres are used in certain manufacturing industries such as cement production to produce heat. The assumption is currently that all the carbon within tyres is of fossil origin, however it is well known that tyres contain a significant portion of natural rubber, which if considered as a biomass fuel, would lower the current CO_2 EF. The report estimated that the ratio of natural to synthetic rubber in tyres at 56:44. However about 30% of the tyres mass is carbon black which is of fossil origin, while another significant proportion such as the steel components is incombustible. Given the apparent complexity in establishing an appropriate EF for tyres, the Department intends to further consider the results of the report before making any changes.

Solvents, Lubricants, Greases and Bitumen

Australian information on CO_2 EFs for these products is not available. The factor for solvents (69.7 Gg/PJ) is based on IPCC *Guidelines* (1997). For the remaining fuels, EFs from the 2006 *Guidelines* (IPCC 2006) are used where updated factors have been provided or where there are no fuel specific factors in the previous IPCC *Guidelines* (1997) - 80.7 Gg/PJ for bitumen, and 69.6 Gg/PJ for lubricants and greases.

Gaseous fuels

Natural Gas

A national EF has been estimated for natural gas using data on the composition of natural gas in each pipeline system, as published by the Australian Gas Association (various years), weighted by the volumes of gas consumed from each pipeline system (see Table 3.2).

The CO_2 EF for natural gas varies slightly between States, depending on the composition of the gas supplied to energy users in the State, which in turn depends on the characteristics of natural gas in the fields from which supply is sourced. In these circumstances, use of a single national weighted average EF for all natural gas will not introduce errors at the level of aggregate national *energy* sector emissions. All emission estimates for natural gas are therefore based on national consumption data and national EFs, except for gas used for electricity generation. Under NGER all electricity generators, that use gaseous fuels as their primary fuel, are required to sample and analyse their natural gas or coal seam methane and report their facility specific EF. The reported EFs are illustrated in Figure 3.8. For small electricity generators who do not meet the reporting thresholds of NGER the national CO_2 EF for natural gas is used.

An additional adjustment is made for natural gas activity data reported in the AES as used by the chemical industry because this includes both natural gas and the separate ethane supply that is used as feedstock. The CO_2 EF used for the inventory was derived based on data within the *ASHRAE Handbook Fundamentals* (2001) and is 56.5 Gg CO_2/PJ. Ethane is the main source of feedstock and fuel supply for the petrochemical industry in Victoria, which is the location for a large proportion for the total Australian petrochemical industry.

Town Gas

Town gas is a minor source of emissions and is given the same EF as LPG. It is assumed that in the manufacture of town gas, both carbon content and energy content is reduced in the same proportion, meaning that the carbon EF is unchanged.

Biomass Fuels

Emissions of CO_2 from biomass fuels are not included in the national inventory but are required to be reported as a Memo item. The CO_2 EFs for bagasse and wood/woodwaste combusted in commercial and residential sectors are listed in Table 3.2. A detailed explanation of residential wood heater EFs is provided in section 3.6. Factors for bagasse (95.0 Gg/PJ) and ethanol (67.3 Gg/PJ) are based on IPCC 2006 as fuel specific factors were not available in IPCC 1997.

Table 3.2: Emission factors for CO_2 2012

Fuel Type	Fuel	CO_2 emission factor (Gg CO_2/PJ)
Coal derived fuels	Coal used in public electricity generation [a]	84.5 – 95.8
	Coal used in steel industry [m]	91.8
	Black coal used by other industry [a]	90.0
	Brown coal used by industry [a]	94.6
	Coke [n]	107.7
	Coal by-products (coke oven gas) [b]	37.0
	Coal by-products (coal tar) [b]	81.8
	Coal by-products (liquefied aromatic hydrocarbons [l]	69.7
	Brown coal briquettes [a]	95.0
Petroleum fuels	LPG [c]	60.2
	Naphtha [l]	69.7
	Automotive gasoline [c]	67.4
	Aviation gasoline [c]	67.0
	Lighting Kerosene [c]	68.9
	Aviation turbine fuel [c]	69.6
	Power Kerosene [c]	68.9
	Heating oil [c]	69.5
	ADO [c]	69.9
	IDF [c]	69.9
	Petroleum products nec [l]	69.7
	Refinery gas and liquids [e]	54.7
	Refinery coke [e]	92.7
	Fuel oil [l]	73.6
	Tyres [k]	81.6
	Solvents [l]	69.7
	Lubricants and greases [e]	69.6
	Bitumen [e]	80.7
Gases	Natural gas (including coal seam gas) [f]	51.4
	Natural gas (Basic chemicals sector) [f]	51.4
	Ethane [g]	56.5
	Town gas [c]	60.2
Biomass fuels	Wood and wood waste [h]	94.0
	Wood (For Residential subsector) [i]	77.5
	Ethanol [e]	67.3
	Bagasse [e]	95.0

Sources: (a) NGER 2009.
(b) Deslandes and Kingston 1997.
(c) GHD 2006a.
(e) IPCC 2006.
(f) AGA 2001.
(g) ASHRAE 2001.

(h) Todd 1993.
(i) Todd 2011.
(k) GHD 2006b.
(l) IPCC 1997.
(m) L.Leung BHP 2001.
(n) Derived from carbon balance within coke oven/iron and steel subsectors.
Note: All EFs expressed in terms of energy measured as gross calorific equivalents (GCV).

Oxidation Factors for CO_2

The oxidation factor is defined as the proportion of carbon contained in a fuel which is oxidised to CO_2. Oxidation factors are either IPCC default values (IPCC 1997) or explained below and are reported in Table 3.3. One minus this factor is the proportion of carbon (on a mass basis) that is stored in solid products such as ash and soot.

Table 3.3: Oxidation factors for CO_2 (non-electricity)

Fuel	Sector	Oxidation Factor
Black Coal	All Categories	98.0%[(a)]
Brown Coal	All Categories	98.0%[(a)]
Coal By-products	Other than Basic Chemicals and Petroleum and Coal Products nec	99.5%
	Basic Chemicals and Petroleum and Coal Products nec	99.0%
Coke	All Categories	98.0%[(a)]
Petroleum	All Categories	99.0%[(a)]
Gas	All Categories	99.5%[(a)]
Biomass	Residential	100%
	All Other Categories	98.0%

Source: (a) IPCC (1997, Volume 3)

The oxidation factor for combustion of biomass for Residential is combined with the associated CO_2 EF, and is therefore reported as 100%. The oxidation applied to the combustion of biomass has been set at 98.0% for all sub-categories other than the Residential and Accommodation, Cultural and Personal (Division H, P and Q) categories. Less efficient combustion in these sectors has been assumed and hence a lower oxidation factor applied.

Not all carbon consumed is combusted. Some fossil fuels are used as feedstocks for the production of goods that act as a temporary store of carbon. Storage of carbon in Australia occurs principally in outputs produced in the chemical industry but also occurs in other products such as bitumen and steel.

Facility specific CO_2 EFs reported under the NGER incorporate the rate of oxidation based on analysis of ash contents. In such cases the application of the default oxidation factors would double count the effect of incomplete combustion, so an oxidation factor of 100% is applied.

3.2.2 Non-CO_2 Emissions

In addition to emissions of CO_2, the combustion of fuel in stationary sources results in the emission of CH_4, N_2O, NO_x, CO, and NMVOCs. Of these, CH_4 and N_2O account for around 1% of emissions, on a CO_2-e basis, in this sector. The magnitude of these emissions is dependent on a large number of factors, including fuel type, equipment design, and emission control technology. It is, therefore, inherently more complex and more uncertain than estimates of CO_2 emissions.

For non-CO_2 gases, emissions are estimated by:

$$E_{hkl} = F_{hk} \cdot E_{fhkl} \quad (3.2)$$

where: E_{hkl} = amount greenhouse gas l emitted from combustion of fuel type k, in economic sector h (in Gg);

F_{hk} = amount of fuel type k combusted in sector h (in PJ);

E_{fhkl} = technology weighted EF (in Gg/PJ) for greenhouse gas l, from fuel type k in sector h.

The characteristics of the capital stock are an important determinant of the non-CO_2 emissions generated by the combustion of fossil fuels. Consequently, EFs for non-CO_2 are capital–and technology-specific and require capital specific information to be collected, including equipment type, technology, and, in some cases, the age of capital.

The non-CO_2 factors are derived from IPCC 1997 and USEPA 1995b default values for uncontrolled emissions from various source categories, corrected for control technologies in use in Australia. In Australia, emissions from stationary fuel combustion sources are controlled to varying degrees

The EFs for non-CO_2 greenhouse gases for various equipment types are summarised in Table 3.A.4. In the absence of evidence to differentiate N_2O variations in measured N_2O concentrations between boilers (i.e. differences cannot be attributed either to differences in boiler type - e.g. tangentially-fired, boiler size, boiler load, or combustion modifications - e.g. low NO_X burners, it is assumed that the N_2O EFs are dependent on fuel type only.

Data on the quantities of energy used by each type of equipment, disaggregated by ANZSIC Group and by major fuel type (coal, oil, gas and biomass) for the manufacturing industries, are provided by ABARES. These data are used to compile a set of weighted EFs for each type of fuel combusted in each economic sector, reflecting the mix of equipment types in use in those sectors.

For the other economic sectors not covered by the above analysis fuel use by equipment type and EFs for equipment types were estimated as follows. For ANZSIC class:

- Division A (Agriculture, Forestry, Fishing), it was assumed that all diesel is used in mobile equipment. It is assumed that the small quantities of other fossil fuels consumed in Division A are used in the agricultural industry, in miscellaneous small combustion equipment;
- Division E (Construction), mobile equipment EFs are used; and
- Divisions F, H, I, J, K and L, it was assumed that all fuel combustion occurs in miscellaneous small combustion equipment.

For:

- Other Transport Services and Storage, 50-53, it was assumed that consumption of gaseous fuels occurs in gas turbines (used to power compressors in gas transmission and distribution systems) and all consumption of liquid fuels occurs in mobile equipment; and
- the Residential sector, it was assumed that all combustion of solid, liquid fuels and gas occurs in miscellaneous residential combustion equipment.

In ANZSIC subdivision 26, Electricity generation, data is available on the relevant equipment data for each power station.

3.2.3 SO_2 Emissions

Data on EFs was obtained from the following sources:

- Petroleum products: Australian Institute of Petroleum and the National Pollutant Inventory (DE);
- Natural gas and LPG: Australian Gas Association;
- Coal (default values): the former Australian Government Department of Primary Industries and Energy; and
- Electricity industry: specific SO_2 emission data have previously been obtained from power station operators. If historical data is not available defaults are used as listed in Table 3.4. For other sectors, the EFs are derived from data from the Australian Institute for Petroleum, the Australian Gas Association and the former Australian Government Department of Primary Industries and Energy.

Table 3.4: SO_2 emission factors

Fuel	SO_2 emission factors (Gg SO_2/PJ)
Black coal	0.37
Brown coal	0.15
LPG	0.002
Aviation gasoline	0.008
Kerosene	0.057
Heating oil	0.057
ADO	0.057
IDF	0.057
Fuel oil	1.282
Natural gas	0.002

Source: Australian Institute for Petroleum (pers. comm. 1996), National Pollutant Inventory (petroleum refining, DE 1998–2012), Department of Primary Industries and Energy (pers. comm. 1998) (for default coal values) and Annual Gas Industry Statistics (AGA 1988–94).

For both CO_2 and non-CO_2 gases, total national emissions are calculated by summing the estimated emissions from each fuel in each sector across all fuels and across all sectors.

3.2.4 Activity Data

The Bureau of Resources and Energy Economics (BREE), and predecessor organisations, have compiled the Australian Energy Statistics (AES) of energy use by economic sector and fuel since the 1970s. The statistics provide a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. They are reconciled with 'top-down' statistics of all major fuels in Australia, collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries. These statistics have been compiled from an annual fuel and electricity survey conducted by the Bureau supplemented by a variety of other sources of information.

In the latest update BREE has utilised data collected under NGER as the primary source of energy consumption data. NGER reporting is compulsory for facilities over specified energy and emissions thresholds and provides greater coverage than was previously available from the previous voluntary FES. Revisions were made to the 2003–11 AES statistics to incorporate NGER data into the time series where appropriate which has resulted in some changes in fuel use in certain subsectors. Further work is being considered in future releases of the AES to extend the revision associated with NGER data back further through the time series. Those recalculated time series will be incorporated in the inventory when available.

In undertaking the AES, NGER data were supplemented with information from other Australian Government agencies, state-based agencies and industry associations. As in the past, in sectors with low or no NGER coverage (commercial and services, agriculture and residential), energy consumption was estimated using the energy balance process and other estimation techniques. The AES provides a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. To ensure internal consistency and completeness, the data are reconciled with 'top-down' statistics on the supply and use of all major fuels in Australia collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries.

The data is presented in common energy units (PJ) on an individual State basis. BREE also collects statistics of energy use by equipment (technology) type. These have been used to compile the technology weighted sectoral EFs for non-CO_2 greenhouse gases.

Several re-allocations to the BREE statistics are required in order to:

- break down energy consumption into sub-sectors where this is required to match EF data, but is not done by BREE;
- identify and allow for stored carbon;
- separate coke production from other parts of the iron and steel industry, also as specified in the IPCC *Guidelines* (1997);
- eliminate double counting of gas leakage from the gas distribution system; and
- allocate fuel use to the industrial process sector for the estimation of emissions from the use of fuels as reductants.

BREE undertakes reconciliation at the level of the supply and use of energy in the economy at the level of energy units. The BREE analysis ensures that all energy entering the economy is accounted for by end-uses.

Activity data for the time series 1990 to 2012, reported by category level and fuel type, are available on the AGEIS website: http://ageis.climatechange.gov.au/QueryAppendixTable.aspx

3.2.5 Feedstock and Non-Energy Fuel Use

Activity data and emissions associated with the non-energy use of fuels are not reported within the *fuel combustion* subsector. In accordance with the IPCC *Guidelines*, they are reported under the *industrial processes sector* and *fugitive emissions from fuels* sub-sector as follows.

- Reported in *industrial processes*
  - Coke and natural gas where used as a reductant in the integrated coke/iron and steel production – reported in 2.C.1 Iron and Steel Production;
  - Pulverised black coal where used as a reductant in the integrated coke/iron and steel production – reported in 2.C.1 Iron and Steel Production;
  - Black coal where used as a reductant in synthetic rutile production – reported in 2.B.5 Chemical Industry– Other;
  - Black coal, coke, petroleum coke and fuel oil where used as a reductant in base metal production – reported in 2.C.2 and 2.C.5 Ferroalloys and Other;
  - Petroleum coke where used as a reductant in titanium dioxide production – reported in 2.B.5 Chemical Industry - Other;
  - Petroleum coke, coal tar and coke used for anodes in aluminium production – reported in 2.C.3 Aluminium Production;
  - Natural gas used in Ammonia production – reported in 2.B.5 Other; and

- Coke where used as a reductant in soda ash production – reported with other emissions from soda ash production in 2.A.3 Limestone and Dolomite Use.
- Reported in *fugitive emissions from fuels*
  - Oil refinery flaring – reported in 1.B.2.a. Oil Refining/Storage; and
  - Natural gas leakage – reported in 1.B.2.b Natural Gas Distribution.

There were 13.5 Mt CO_2 emissions from non-energy fuel use reported in the *industrial processes* sector of the inventory. Coke and pulverised coal used as a reductant within iron and steel production were the most significant non-energy use of fuel, resulting in the reporting of 6.6 Mt CO_2 within the *industrial processes* sector. The production of aluminium and other metals accounted for another 3.8 Mt CO_2 emissions from non-energy fuel use of reported in the *industrial processes* sector.

The use of ethane and petroleum products used as feedstocks within chemicals production resulted in the equivalent of 2.0 Mt CO_2 being stored in products such as plastics, and therefore were not included in the estimate of emissions from the *energy* sector. A further 4.9 Mt CO_2 was associated with nonenergy fuel use stored in other products. This includes lubricants, bitumen, solvents and coal oils and tars from coking ovens.

3.2.6 QA/QC

The Carbon Balance

A carbon balance for all years was undertaken in terms of the supply and use of carbon from fuels in the economy. All carbon entering the economy is accounted for—either as emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses, use of biomass sources of energy and international bunkers. While the predominant outcome of carbon entering the economy is emissions, a small portion of the total is stored in carbon-containing products or non-oxidised as ash.

Tables detailing the results of the carbon balance can be found in Annex 6.

Comparison with international data

IEFs for all major fuels are tested for differences against the mean of the population of all other Annex I data. For each major fuel, the t-tests conducted show that the implied CO_2 EFs for Australian fuels are not significantly different to the mean of the implied EFs for the Annex I population with one exception. For non-CO_2 fuels IEFs are not significantly different to the mean of the Annex I population with the exception of diesel oil for transport purposes which is discussed in more detail in section 3.5.4 and 3.5.6.

The Bureau of Resources and Energy Economics (BREE) is the common source of energy data both for the preparation of the national inventory through its publication, AES, and for Australia's report to the International Energy Agency (IEA). Some differences occur from year to year between the activity data in the inventory CRF tables, and those data published by the IEA. A project has been undertaken to reconcile the data provided by BREE to the IEA with the published BREE data used in the inventory.

The Department has found that the data reported to the IEA by the Bureau of Resources and Energy Economics (BREE, the Australian Government department responsible for publishing the *Australian Energy Statistics*) is consistent with the data published in the *Australian Energy Statistics* (in petajoules units).

The investigation found the following reasons for differences between data reported by Australia in the CRF tables and data published by the IEA:

The energy conversion used by the IEA is a significant cause of the differences, and that data provided to the IEA has been processed by methods outside of the control of Australia.

Coal production data reported in the CRF table are significantly higher (around 13-25%) than those reported to the IEA. The reason for this difference is that the coal production reported to the IEA only comprises black coal production and does not include brown (lignite) coal production. The IEA data does correspond with coal production reported in Australia's CRF table when brown coal production is included.

Total Natural Gas Consumption

Australia has introduced a new quality control procedure to verify estimates of natural gas consumption. This procedure utilises new data reported for the first time by natural gas suppliers in October 2013. The availability of this new data coincides with a recalculation of natural gas consumption reported in the *Australian Energy Statistics (AES)* and incorporated into Australia's inventory submission.

Recalculation

The 2013 edition of the AES included a recalculation in the amount of natural gas consumed from 2003-04 to 2010-11. The recalculations were primarily a result of increased adoption of NGER data to estimate natural gas consumption for more sectors in the AES from 2008-09 to 2011-12. These updated estimates were also used to inform recalculations of the time series. The magnitude of the recalculations is outlined in Table 3.5.

Table 3.5: Change in national natural gas consumption (PJ), reported in the AES

	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Recalculation in Natural Gas Consumption	- 44.0	- 53.8	- 56.9	- 59.8	- 56.2	- 91.2	- 81.1	- 172.3

Source: Table F of the Australian Energy Statistics, BREE

The natural gas consumption data in the AES is applied to the national inventory in accordance with the methods outlined in this National Inventory Report. These recalculations predominantly flow through to emissions in sector *1.A.1.a Public Electricity and Heat Production* and *1.A. 1.c Manufacture of Solid Fuels and Other Energy Industries*. Emission recalculations by sector are listed in Table 3-6.

Table 3.6: Recalculations in emissions from the consumption of gaseous fossil fuels

Sector	2002-03 (Gg CO_2-e)	2003-04 (Gg CO_2-e)	2004-05 (Gg CO_2-e)	2005-06 (Gg CO_2-e)	2006-07 (Gg CO_2-e)	2007-08 (Gg CO_2-e)	2008-09 (Gg CO_2-e)	2009-10 (Gg CO_2-e)	2010-11 (Gg CO_2-e)
1.A.1.a Public Electricity and Heat Production	-21.2	-60.9	-545.6	-129.3	-166.2	-184.3	-4,709.1	-4,257.2	-5,815.8
1.A.1.c Manufacture of Solid Fuels and Other Energy Industries	-1,694.3	-2,217.0	-2,732.2	-2,888.6	-2,902.0	-2,928.8	-2,873.7	-2,611.8	-2,985.2
Other Fuel Combustion (1.A) Sectors	-446.9	-468.4	-221.3	-182.6	-147.5	-331.0	488.6	-267.5	-886.8

The new quality control procedure has been used to test the updated estimate of natural gas consumption.

NGER and Upstream Natural Gas Data

Under the NGER system, companies who produce or consume energy or emit greenhouse gases over certain thresholds must report facility-level data to the Clean Energy Regulator annually. These large companies have reported natural gas consumption since 2008-09. Data has not previously been collected for small consumers that do not meet the NGER reporting thresholds. Small consumers of natural gas includes the residential sector, most commercial users, small manufacturing facilities and small off-grid electricity generators.

On 31 October 2013 companies that supply natural gas to end users were required to undertake additional reporting. This reporting was designed to ensure that all natural gas combusted is either reported by large consumers or reported 'upstream' by natural gas suppliers. Complete coverage is ensured by the design of the reporting system that requires reporting by:

- Suppliers - If natural gas is supplied to an end user, the supplier must report the potential greenhouse gas emissions embodied in the natural gas, except where liability is transferred from the supplier to the end user through a mechanism called an obligation transfer number (OTN); and
- Users - Entities responsible for 'large gas consuming facilities' that have applied for and received an OTN are liable as direct emitters for the natural gas supplied to them. It is mandatory for these companies to quote an OTN and mandatory for suppliers to accept the quotation.

Upstream natural gas data was reported in October 2013 and applies to the 2012-13 financial year. When added to natural gas combustion from large consuming facilities (already reported through NGER) an estimate for total natural gas combustion in Australia basaed on bottom-up NGER data can be estimated for quality control purposes.

Accuracy, comparability and consistency of reported data are ensured through the use of consistent methodologies by companies estimating the quantity of natural gas supplied and potential emissions. The methods are published in a legislative instrument, the NGER (Measurement) Determination.

Australia's carbon pricing mechanism creates audit responsibilities for liable entities including for natural gas supply. If an organisation is a liable entity and their emissions number exceeds 125 000 Gg CO_2-e they are required to arrange a pre-submission audit report to provide assurance over their covered emissions report. Audit reports must be submitted to the Clean Energy Regulator by the reporting due date of 31 October.

The audit must be a reasonable assurance engagement, it must be conducted in accordance with the National Greenhouse and Energy (Audit) Determination 2009, and it must be undertaken by a Category 2 or 3 registered greenhouse and energy auditor. More information on the audit requirements is available at the Clean Energy Regulator website at www.cleanenergyregulator.gov.au/.

Quality Control – 'Bottom Up' Verification

An estimate of total natural gas consumption can be derived for 2011-12 by adding 2011-12 NGER natural gas consumption from large consumers with an estimate of upstream natural gas consumption. The same process has been adopted for all years back to 2008-09, the year NGER data first became available. A comparison of this derived amount with the natural gas combustion reported in the fuel combustion and industrial processes sectors of the national greenhouse gas inventory is reported in Table 3.7.

Upstream natural gas data has only been collected for 2012-13. For the purpose of this analysis 2012-13 upstream natural gas consumption has been applied to earlier years assuming a growth rate of 3 per cent per year (broadly in line with the growth in natural gas consumption by large users). This assumption introduces uncertainty into the verification because upstream natural gas consumption will vary from year to year.

Table 3.7: Natural Gas Reconciliation

Natural Gas	2008-09	2009-10	2010-11	2011-12
NGER - Large Emitters Natural Gas Combustion (PJ) (1)	946.2	985.6	1,068.5	1,060.8
NGER - Upstream Natural Gas Not Reported by Large Emitters [(a)] (PJ) (2)	208.3	214.5	220.9	227.6
NGER total derived natural gas combustion (PJ) (3) = (1) + (2)	1,154.4	1,200.1	1,289.5	1,288.4
2013 National Inventory Natural Gas Combustion and Industrial Processes [(b)] (PJ) (4)	1,166.3	1,236.1	1,287.9	1,315.2
% Difference between total derived natural gas consumption and 2013 National Inventory Natural Gas Consumption (5) = (4)/(3) -1	1.0%	3.0%	-0.1%	2.1%

(a) Upstream natural gas are estimates only and are calculated using the reported value for 2012-13 and assuming a 3 per cent annual growth rate.

(b) For the purpose of this analysis natural gas includes natural gas distributed in a pipeline, coal mine waste gas, coal seam methane, compressed natural l gas, liquefied natural gas, ethane and biogas.

Table 3.7 shows that for all years except 2010/11 the amount of natural gas reported as combusted in the inventory is greater than the amount derived using NGER data by between 1.0 per cent and 3.0 per cent. In 2010/11 national inventory gas consumption is 0.1 per cent (1.6 PJ) less than the derived amount. This difference is within the expected uncertainty levels given the assumptions applied to the upstream natural gas data.

The outcome of this verification activity using 'bottom-up' data shows that natural gas consumption has not been underestimated in the national inventory for the period 2008-09 to 2011-12. This quality control test will be repeated when the *Australian Energy Statistics* are updated for 2012-13 data in July 2014.

3.3 Source Category 1.A.1 – Energy Industries

3.3.1 Source Category Description

This category includes emissions from fuel combustion within electricity generation, petroleum refining and other energy manufacturing industries such as coke ovens, briquette production, coal mining, oil and gas extraction, and natural gas production, transmission and distribution. BREE report energy consumption for economic sectors defined using the Australia New Zealand Standard Industrial Classification (ANZSIC) developed by Australia's national statistical agency, the Australian Bureau of Statistics. The mapping of data to IPCC classifications from the ANZSIC codes is complete and reported in Table 38.

Table 3.8: Relationship between IPCC source categories and ANZSIC sectors: Energy Industries

IPCC Source Category	ANZSIC Subdivision		
	Division	Sub-division	Description
1.A.1 Energy Industries			
a Electricity and heat production[(a)]	D Electricity, Gas and Waste Services	26	Electricity supply
b Petroleum refining	C Manufacturing	17	Petroleum refining
c Solid fuel transformation and other energy industries	B Mining and C Manufacturing		Coal mining (incl. briquette production)
	B Mining		Oil and gas extraction (incl. gas processing and LNG production)
	C Manufacturing	21	Coke ovens associated with Basic iron and steel manufacturing
	D Electricity, Gas and Waste Services	27	Gas supply
	I Transport and Storage	50-53	Pipeline transport of gas

Note: (a) This comprises only electricity generated at single purpose power stations and at co-generation plants that are predominantly orientated to producing and exporting electricity. Accounting for all fossil fuel combustion associated with other cogeneration occurs in the industry sector within which co-generation occurs. There is no public generation of distributed heat in Australia.

Energy

3.3.2 Methodology

In summary, emissions for the *energy industries* category are estimated using tier 2 approaches and country specific factors (Table 39).

Table 3.9: Summary of methods and emission factors: Energy Industries

Categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A1a Public electricity	T2	PS, CS	T2	CS	T2	CS
1A1b Petroleum refining	T2	CS, PS	T2	CS	T2	CS
1A1c Manufacture of Solid Fuels	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1. T2 = tier 2. T3 = tier 3. CS= Country-specific. D= IPCC default, PS = Plant Specific.

Electricity Generation (ANZSIC Subdivision 26) (1.A.1.a)

Electricity generation includes power for supply to the grid (whether the power stations are owned by public or private corporations). Where it is not possible to separately identify the quantity of fuel consumed for electricity generation - for example, in electricity generation at industrial sites, the fuel consumed and the associated emissions are allocated to the industry involved and hence not included in the emissions for this sub-category. Public heat production does not occur in Australia.

Choice of emission factors

A tier 2 approach is used for the key category of electricity generation in which EFs for fuels such as coal vary from source to source and over time. The fundamental reporting unit in this sector is the individual power

station. Data is collected from power stations through NGER. Under NGER, facilities over certain thresholds are required to submit annual data on fuel consumption, fuel energy content, fuel EFs (incorporating oxidation factors), emission estimates and the amount of electricity generated and sent out to the Greenhouse and Energy Data Officer. Power stations must sample and analyse their primary solid and gaseous fuels in accordance with the requirements and standards listed in the *National Greenhouse and Energy Reporting (Measurement) Determination 1998* (Cwlth). The adoption of these methods and standards ensures accuracy and comparability in the facility specific information reported. This data provides facility specific energy content and EFs for the solid and gaseous fuels consumed in each power station.

When the NGER was established the methods to be used by power stations were aligned with those that applied under the Generator Efficiency Standards program – as detailed in the *Generator Efficiency Standards Technical Guidelines* (AGO 2006a). The Generator Efficiency Standards program had been in place in Australia since 2000 and data collected under this program has been utilised in the national inventory throughout the time series. The adoption of consistent methods in the NGER and the Generator Efficiency Standards program ensured time series consistency in the emission estimates in the national inventory.

Country-specific EFs are utilised for minor (mainly liquid) fuels.

Activity data

NGER data is received from all large and medium sized power stations in Australia. There are around 100 such fossil fuel based power stations in Australia at present (the number depends on how generating units at the same site are treated). NGER data has resulted in a significant increase in the number of power stations where facility level data is available (increasing from 50-60 to around 100). The energy use of the small power stations, that do not meet the NGER reporting thresholds, are estimated as the difference between the total of reported values under NGER and Bureau of Resources and Energy Economics (BREE) energy statistics for ANZSIC subdivision 26. This approach has been adopted throughout the time series. Therefore the improved coverage of power stations under NGER does not alter the method for estimating total fuel consumption in this sector. The coverage of individual coal power station NGER data is comprehensive and has displaced the necessity to use coal data to inform the BREE energy statistics for ANZSIC subdivision 26 in calculations.

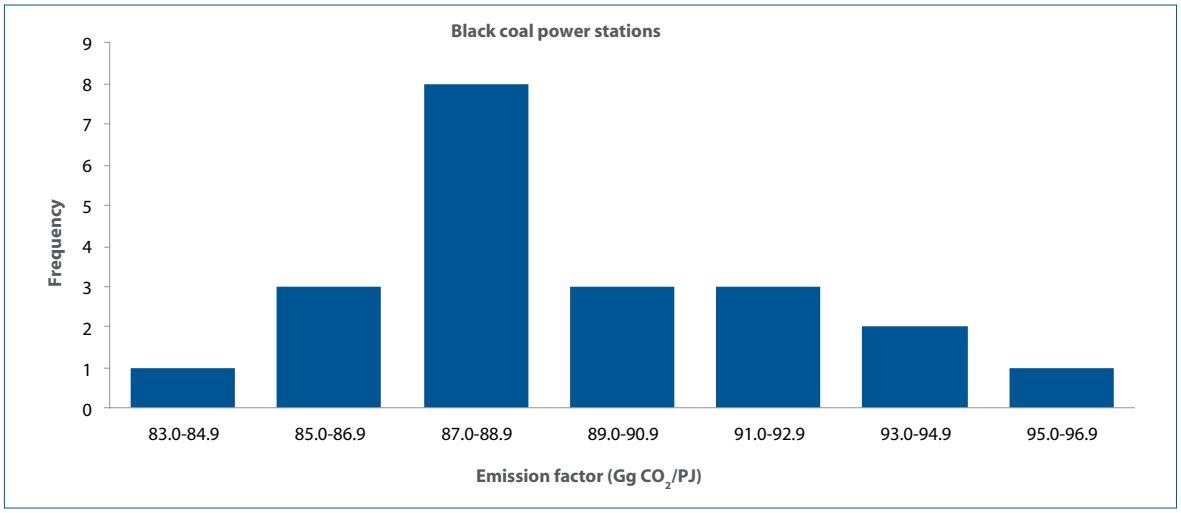
New research conducted by BREE on regional and remote electricity generation in Australia (BREE 2013b) has been incorporated for the first time. This research surveyed off-grid electricity generated and consumed outside of the major electricity grids of Australia, including the smaller grid systems of the Pilbara, Darwin to Katherine and the Mt Isa areas. The fuels covered in the survey are natural gas, diesel oil and fuel oil. This new survey data has been used to validate or update the fuel consumption totals estimated by BREE in the *Australian Energy Statistics*.

Under the NGER, oxidation factors and the emissions factors are linked in that power station operators report CO_2 EFs including the effects of oxidation based on analysis of ash contents and in accordance with *NGER Measurement Determination 2008* (Cwlth). In such cases applying the default oxidation factor would double-count the effect of incomplete combustion, so an oxidation factor of 100% is used. Throughout the time series CO_2 factors for many facilities do not include the effects of incomplete oxidation. For these facilities oxidation factors are applied as reported by the power station. If the power station has not reported a facility specific oxidation factor then the national default factor is applied. Figure 3.8 shows the distribution of emission factors reported by electricity generators for major fuel types.

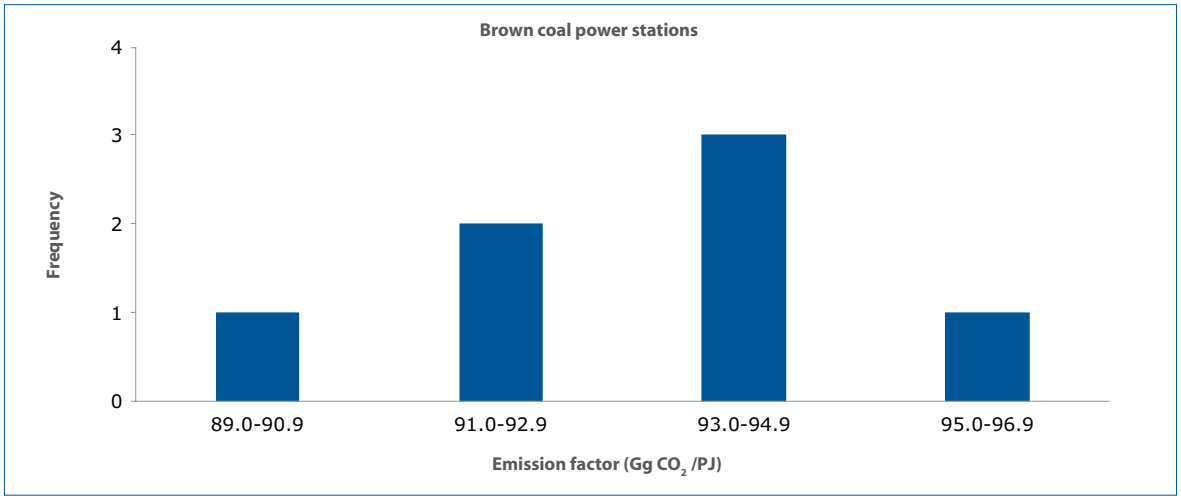
CH_4 and N_2O emissions from landfill gas captured for combustion for electricity generation are reported in this subsector and CO_2 emissions are reported as a memo item.

Figure 3.8: Emission factors for CO_2 in electricity generation, 2012

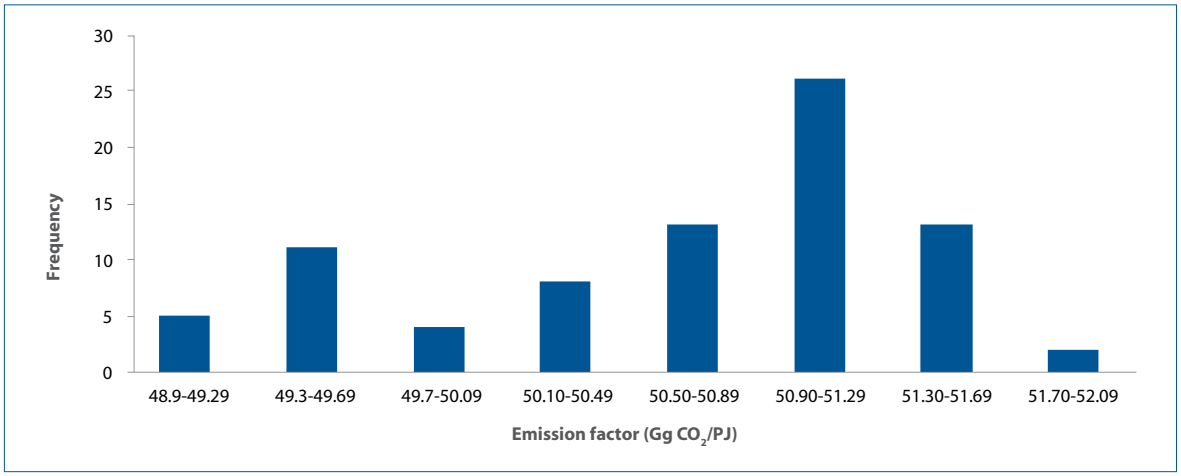
(a) Black Coal Power Stations



(b) Brown Coal Power Stations



(c) Natural gas and waste gas power stations



Source: NGER
Notes: Values incorporate the effect of partial oxidation of fuels.

Petroleum Refining (ANZSIC Class 1701) (1.A.1.b)

The main fuels used by petroleum refineries are refinery gas/liquids and natural gas along with some minor use of other liquids fuels. The BREE *Australian Energy Statistics* reports refinery feedstock, i.e. essentially crude oil, as the major input, together with other, undefined, petroleum products. The various market petroleum products are shown as energy outputs. The total energy content of the products produced by the sector is less than the energy content of the petroleum input, with the difference being energy consumed by the refining processes (distillation, cracking etc.). The fuel from which this energy is derived is obtained from the crude oil input and is referred to as refinery fuel.

Choice of emission factor

NGER data made available facility-specific EFs for the fuels; refinery gas and liquids, refinery coke and natural gas from several of the petroleum refineries. A decision to utilise these factors for the relevant refineries while maintaining the default factors for the remainder, was made in consultation with the decision tree in section 1.4.1. In doing so, it was recognised that refinery EFs for these fuel types are strongly linked with the specific technology types and process configurations inherent in individual refineries.

Activity data

The refinery fuel balance contained in the BREE *Australian Energy Statistics* is analysed using a model that examines the expected refinery plant efficiency in the conversion of crude oil to final products, taking into account factors such as the change to low sulphur diesel. For years where BREE AES has difficulty providing a reasonable balance (2000-2008) the modelled data has been used for refinery fuel consumption.

Detailed fuel consumption data was made available via NGER for all Australian oil refineries from 2009 to 2012. In particular, NGER data provides details on the refinery fuel use, enabling a split between the combustion of refinery gas/liquids and the burning of refinery coke to restore the activity of the catalyst during the refining process. Given that this component of petroleum refining emissions has previously been included within total refinery fuel combustion, it was decided to continue with this practice for this submission in order to maintain time series consistency. This remains consistent with practice followed by most other countries and the IPCC *Guidelines* are unclear as to where emissions from this source should be reported. However, for transparency purposes, these emissions from refinery coke have also been noted in the Fugitives – petroleum refining section of this report. Refinery flaring is accounted for in the Fugitive Fuel Emissions sector.

Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c)

The manufacturing of solid fuels and other energy industries sector, 1.A.1c, comprises six ANZSIC sectors:

- Coke Oven Operation (ANZSIC Subdivision 21);
- Briquetting (ANZSIC Subdivision 17);
- Coal Mining (ANZSIC Division B);
- Oil and Gas Extraction (ANZSIC Division B);
- Other Transport Services and Storage, assumed to be gas pipeline transport (ANZSIC Subdivision 50-53); and
- Gas Supply (ANZSIC Subdivision 27).

Estimated emissions are derived from equations 3.1 and 3.2 and the EFs reported in Tables 3.2 and 3.3 and Table 3.A.1.

The *Coke Oven Operation (ANZSIC* Subdivision 21*)* sub-sector is effectively a subsidiary activity of the iron and steel industry but is classified by the IPCC as an energy transformation industry and hence is reported separately. This sub-sector is both a consumer of black coal and coal by-products and a producer of coke and coal by-products. Consequently, fuel combustion is calculated by deducting derived fuels produced by the sector from energy inputs.

The consumption of natural gas in the *Other Transport Services and Storage (Natural Gas Transmission) (ANZSIC Subdivision 50-53)* is assumed to be used in gas turbines to drive pipeline compressors, and is thus considered an energy transformation activity. Emissions from the small amount of other energy used in these Subdivisions are accounted under Commercial/Institutional.

The *Gas Production and Distribution (ANZSIC Subdivision 27)* sector is also one of the energy transformation industries, manufacturing town gas from both natural gas and LPG. Fuel consumption, as indicated by the *Australian Energy Statistics* (BREE 2012) consists of:

- natural gas and LPG used to make town gas;
- other gas (including both natural gas and town gas) used by the industry for its own purposes; and
- gas leakage.

The quantity of town gas produced is shown as an energy output of the sector in the *Australian Energy Statistics*. It was assumed that all LPG is converted to town gas, and none is combusted in the conversion process. LPG consumption was therefore offset in full against an equal quantity (in terms of energy content) of town gas produced. The remaining town gas production was subtracted from total natural gas consumption. Gas leakage, reported under 1.B *fugitive fuel emissions*, was also subtracted from the remaining net natural gas consumption. The figure remaining was assumed to be the quantity of natural gas combusted in the sector.

3.3.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Figure 3.8 provides an illustration of the level of variability in reported CO_2 EFs for coal and natural gas burned in electricity generation.

A revision of was undertaken of AES by BREE in response to improved activity data available under the NGER. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2011. The revisions have improved time series consistency from 2003 onwards, however, a step changes exists after 2002 in the time series for a small number of fuel types within source categories. See the Recalculations section below in 3.3.5 for a description of these changes and how they affect time series consistency in particular source categories. See under Planned Improvements for discussion regarding plans to revise the pre-2003 parts of time series affected by the step change.

Time series variability of GHG IEFs are also likely to be influenced by changes in fuel mix within categories, and changes of actual fuel EFs. Notable examples of where such variations occur in 1.A.1 *energy industries* are set out below:

- 1.A.1.c *manufacture of solid fuels and other energy industries* – CO_2 from solid fuels: The IEF declines by 10% between 1990 and 2001. This can be explained by the relative rise of coal by-products—coke oven gas as a fuel (with a relatively low EF of 37 Gg/PJ) at the expense of black coal; and
- 1.A.1.a *public electricity* – CO_2 from biomass: Biomass combustion for electricity consists of a growing proportion of biogas from landfill. Biogas has a relatively low CO_2 emission factor compared to other biomass fuel, hence Australia's CO_2 biomass IEF is relatively low.
- 1.A.1.a *public electricity* – CO_2 from liquid fuels: Variations occur in the IEF over the time series due to changes in the proportions of Fuel Oil and Diesel Oil in the liquid fuel mix. These fuels have consumption variability year on year as they are generally used for unscheduled and off-grid electricity generation.

- 1.A.1.b *petroleum refining* – CO_2 from liquid fuels: Variations in the IEF of around 2% are evident since 2008. The estimation of CO_2 for the petroleum refining sector utilises facility-specific emission factors obtained from the NGER Scheme. The CO_2 IEF will tend to vary depending on the liquid fuel mix used and the refinery processes undertaken in the year. Australia has a limited number of refineries (7 in 2011/12). Therefore changes in fuel mix and qualities in those refineries will tend to result in minor variations in the overall liquid IEF.

3.3.4 Source Specific QA/QC

This source category is covered by the general QA/QC measures of the greenhouse gas inventory discussed in section 1.6. Results for the reference approach for the *energy* sector, reported in Annex 4, and the carbon reconciliation reported in Annex 6, provide quality control checks for this sector.

Fuel and generation data for 1.A.1.a *public electricity* are compiled by the Department from NGER data and from BREE energy data. Inputs are reconciled and emission data is fully reconciled against the outputs from the AGEIS to ensure the accurate reporting in this sector.

Fuel and generation data are also checked and reconciled against the alternative data sources of the Energy Supply Association of Australia (ESAA) and the Australian Energy Market Operator (AEMO). These comparisons confirm the consistency of the estimates to a high level of accuracy and show that all energy/carbon has been accounted for.

A top-down/bottom-up reconciliation and verification using supplementary data was undertaken for natural gas consumption in the inventory, as a means of verifying recaclulations for natural gas with 1.A.1. - see Section 3.2.6 QA/QC.

3.3.5 Recalculations Since the 2011 Inventory

Recalculations to 1.A.1 *energy industries* are detailed at the sub-category level in Table 3.11.

Key reasons for recalculations in *energy industries* include:

- *Revisions to the AES by BREE:*

  A key reason for recalculations arises from revisions by BREE to the AES. The revisions to the AES are due to the incorporation of improved activity data available under the NGER and subsequent improvements in time series consistency. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2011. The revisions have improved time series consistency from 2003 onwards; however, a step change exists after 2002 in the time series for a small number of fuel types within source categories. See under Planned Improvements for discussion regarding plans to revise the pre-2003 parts of time series affected by the step change.

- 1.A.1.a *public electricity and heat production.*

  Recalculations arise from recalculations in the electricity supply sector data of the latest release of the BREE AES. The natural gas time series from 2003-2011 was the largest source of recalculation in the 2013 AES (see section 3.2.6). Other fuels which were recalculated are bagasse, diesel and fuel oil.

  Implemented this year in fuel estimation calculations are the results of the survey conducted by BREE and published in *Beyond the NEM and the SWIS: 2011-12 regional and remote electricity in Australia* (BREE 2013b) which has provided new information on off-grid generation. The survey results have been incorporated into the fuel estimations for natural gas and diesel oil. This has resulted in minor recalculations in emissions for 2009-2011.

The combined effect on the emissions time series of these two BREE data sources are recalculations in emissions in the time period 2003-2011.

There has also been a reallocation of bagasse betwen *1.A.2.d* and *1.A.1.a* throughout the time series as a result of discrepancies between the amounts reported in the AES and in NGERs.

- 1.A.1.b *petroleum refining*

  Solid fuels:

  The consumption of coal by-products has been reallocated from 1.A.1.b petroleum refining, where it was previously reported for only years 2007 and 2008, to 1.A.2.c chemicals. This has been implemented to improve the time series consistency of the petroleum refining sub sector in response to questions during the previous ERT review.

- *1.A.1.c Manufacture of Solid Fuels and Other Energy Industries - Other Energy Industries - Oil and Gas Extraction*

  Natural gas:

  Natural gas consumption for Oil and Gas Extraction has been revised downward by BREE in the AES for the period 2004 to 2011. This is part of a broader revision of natural gas consumption in the AES for which a top-down, bottom up reconciliation and verification with supplementary data sources has been conducted and detailed in Section 3.2.6 QA/QC. With respect to the Oil and Gas Extraction category, the revision is largely associated with the improved estimation of raw natural gas consumption in the production of LNG, through the use of fuel combustion data obtained from NGER facility reporting.

  An investigation was undertaken to determine the basis underpinning the AES revision. It found that previously, the natural gas consumption for LNG production within the AES was estimated by BREE using a throughput efficiency approach, where a percentage of natural gas throughput was assumed to be combusted. A throughput approach is a generalised method that applies an efficiency assumption across total national LNG production to estimate an energy consumption figure that integrates all losses. In contrast, the new method used in this submission now incorporates data, as reported by individual LNG facilities under the NGER scheme, for directly measured consumption of natural gas used for fuel combustion purposes.

  In summary, the revised estimates for natural gas consumption for Oil and Gas Extraction in this NIR submission are a substantial improvement on the previous estimate because they are based on direct measurement at a facility level under NGER rather than using a generalised efficiency assumption at a national level.

Table 3.10: 1.A.1 Energy Industries: recalculation of total CO_2-e emissions, 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.1.a Electricity and heat production				
1990	129,551	129,551	0	0.0
2000	175,427	175,427	0	0.0
2001	182,608	182,608	0	0.0
2002	183,831	183,831	0	0.0
2003	185,647	185,625	-21	0.0
2004	193,647	193,586	-61	0.0
2005	194,938	194,393	-546	-0.3
2006	199,119	198,990	-129	-0.1
2007	200,971	200,805	-166	-0.1
2008	204,329	203,607	-722	-0.4
2009	209,914	204,857	-5057	-2.4
2010	203,350	198,918	-4431	-2.2
2011	198,750	192,611	-6139	-3.1
1.A.1.b Petroleum refining				
1990	5,524	5,524	0	0.0
2000	6,165	6,165	0	0.0
2001	6,275	6,275	0	0.0
2002	6,201	6,201	0	0.0
2003	6,056	6,056	0	0.0
2004	5,529	5,529	0	0.0
2005	5,472	5,472	0	0.0
2006	4,914	4,914	0	0.0
2007	5,369	5,328	-42	-0.8
2008	5,160	5,118	-42	-0.8
2009	5,170	5,170	0	0.0
2010	5,262	5,262	0	0.0
2011	5,642	5,642	0	0.0
1.A.1.c Manufacturing of solid fuels and other energy industries				
1990	7,931	7,931	-	0.0
2000	10,881	10,881	-	0.0
2001	10,859	10,859	-	0.0
2002	11,125	11,885	760	6.8
2003	16,272	14,591	-1681	-10.3
2004	17,201	14,957	-2244	-13.0
2005	19,432	16,682	-2750	-14.2
2006	20,486	17,602	-2884	-14.1
2007	20,914	18,042	-2871	-13.7
2008	20,511	17,575	-2936	-14.3
2009	21,927	19,096	-2831	-12.9
2010	24,381	21,186	-3195	-13.1
2011	25,791	23,267	-2524	-9.8

3.3.6 Planned Improvements

In the 2013 AES, BREE has further incorporated improved activity data available under the NGER into the time series. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period 2003 to 2011. An undesirable outcome of this improved data is that a step change exists in some time series for individual fuel types within certain source categories. BREE are exploring the possibility of extending the revision through to the earlier part of the time series in future AES releases and these revisions will be incorporated into future recalculations of the national inventory when available.

Uncertainty data reported by corporations under the NGER system has been incorporated into the national inventory for the electricity sector. A review of NGER uncertainty data in other fuel combustion sectors will be undertaken with the intention of incorporating these estimates in the uncertainty analysis.

In response to a recommendation from a previous review report, a study was commissioned by the Department to investigate the appropriateness of the fuel characteristics, including the CO_2 EF, for liquid fuels types used in the NGGI. The CO_2 EF used by the inventory for ethanol was found to be around 7% higher than that published in another Australian report (Orbital 2011a), however there are a very limited number of data points available for comparison. Therefore, further analysis of Australian ethanol characteristics will be undertaken before any changes are made to the EF used to compile the inventory.

3.4 Source Category 1.A.2 – Manufacturing Industries and Construction

3.4.1 Source Category Description

This source category includes emissions from fuel combustion in manufacturing, construction and non-energy mining. This includes both stationary and mobile equipment such as earth moving and mining equipment.

BREE report energy consumption for economic sectors defined using the Australia New Zealand Standard Industrial Classification (ANZSIC). The mapping of ANZSIC codes against IPCC classifications is complete and given in Table 311.

Table 3.11: Relationship between IPCC source categories and ANZSIC sectors: Manufacturing and Construction

IPCC Source Category	ANZSIC Subdivision/Group/Class			
	Division	Sub-division	Group/ Class	Description
2. Manufacturing Industries and Construction				
A Iron and Steel	C Manufacturing	21	211-212	Iron and steel manufacturing (excl. Coke ovens)
B Non-Ferrous Metals	C Manufacturing	21	213-214	Basic non-ferrous metal manufacturing
C Chemicals	C Manufacturing	17	1709	Other petroleum and coal product manufacturing
		18-19		Basic chemical and chemical, polymer and rubber
D Pulp, Paper and Print	C Manufacturing	14		Wood and paper products
		15-16		Wood and wood products
E Food Processing, Beverages and Tobacco	C Manufacturing	11-12		Food, beverages, tobacco
F Other (part)	B Mining	8-10		Other mining,
F Other (part) (all other manuf.)	C Manufacturing	13		Textiles, clothing , footwear and leather
F Other (part) (non-metallic mineral products)	C Manufacturing	20	201	Glass and glass products
F Other (part)	C Manufacturing	20	202	Ceramics
	C Manufacturing	20	203	Cement, lime, plaster and concrete
	C Manufacturing	20	209	Other non-metallic mineral products
F Other (part) (all other manuf.)	C Manufacturing	22		Fabricated metal products
F Other (part)	C Manufacturing	24		Machinery and equipment
		25		Furniture and other manufacturing
F Construction	E Construction			Construction

3.4.2 Methodology

The emissions for *manufacturing industries and construction* are estimated using tier 2 approaches. Emissions estimated from activity data are based on the national survey of energy consumption by industry sector and fuel type compiled by the BREE. CO_2 EFs are country-specific and direct industry advice on the use of CO_2 emissions factors has been adopted for the use of coal by-products within 1.A.2.c *chemicals*, black coal within 1.A.2.a *iron and steel*, and natural gas in general. Non-CO_2 EFs have been calculated using a sectoral equipment-weighted average approach and are reported in Table 3.A.2. More detail is provided for the metal and chemicals industries.

Table 3.12: Summary of methods and emission factors: Manufacturing and Construction

Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A2a Iron and Steel	T2	CS	T2	CS	T2	CS
1A2b Non-Ferrous Metals	T2	CS	T2	CS	T2	CS
1A2c Chemicals	T2	CS	T2	CS	T2	CS
1A2d Pulp, Paper and Print	T2	CS	T2	CS	T2	CS
1A2e Food Processing, Beverages and Tobacco	T2	CS	T2	CS	T2	CS
1A2f Other	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific, D= IPCC default.

Iron and Steel (ANZSIC Subdivision 21) (1.A.2.a)

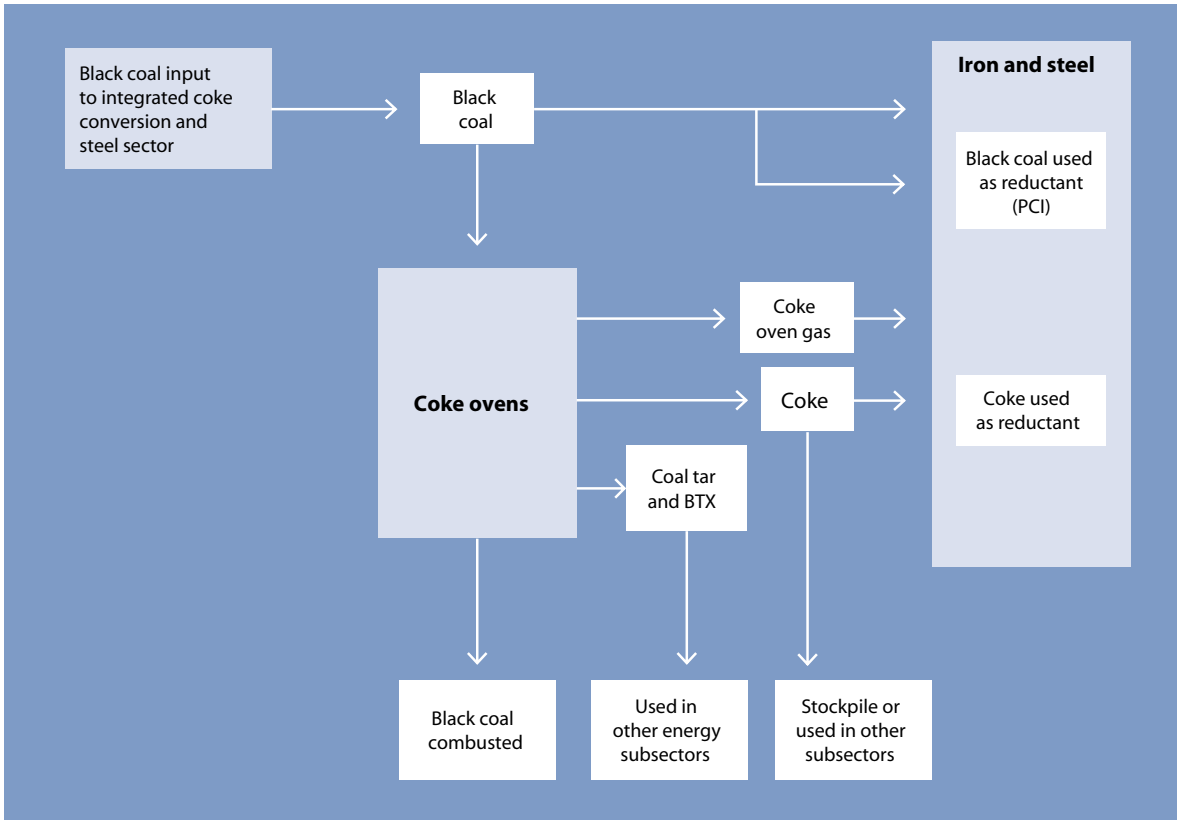
The methodology in the *iron and steel* sub-sector is somewhat more complex than many other sections of the inventory. This complexity arises from a number of factors:

- The operation of Coke Ovens is considered to be an energy transformation industry, and hence must be reported separately to the rest of the iron and steel emissions;
- The production of coke yields a variety of by-products, including coke oven gas, coal tar;
- liquefied aromatic hydrocarbons and naphthalene, each having quite different calorific values and EFs. Coke oven gas is used as fuel in coke ovens and adjacent steelworks, while the other products are in general not combusted, but are used as feedstock in the chemical industry;
- Overall, the Coke Ovens sector is a producer of coke, most of which is consumed in the Iron and Steel sector and some of which is exported to other sectors (and other countries);
- The operation of blast furnaces to produce pig iron also produces yet another coal by-product, blast furnace gas, which is a low calorific value fuel consisting mainly of CO (and atmospheric nitrogen), used elsewhere in the steelworks. For the purpose of calculating CO_2 emissions, the production and subsequent combustion of blast furnace gas is ignored, and it is assumed that all coal and coke used in the iron and steel industry undergoes complete oxidation to CO_2, apart from the small adjustments resulting from application of oxidation factors and a further allowance for carbon sequestered in steel;
- The use of coke, as well as natural gas in hot briquetted iron production is regarded primarily as a chemical process rather than fuel combustion under IPCC reporting *Guidelines*. Consumption and emissions are therefore reported under the *industrial processes* sector 2.C.3 rather than the *energy* sector;
- Pulverised black coal has been used as a reductant in the production of iron since 2003. Therefore the consumption and emissions are now reported under the *industrial processes* sector in 2.C.1 *metal production* rather than the *energy* sector;
- Although Coke Ovens are in operation in the iron and steel industry, they are considered an energy transformation industry under the IPCC methodology. Therefore, Coke Ovens must be separated from the other parts of the iron and steel industry, so that it can be reported under IPCC category 1.A.1.c;
- The statistics show that production of both coke and coal by-products exceed consumption within the sectors, i.e. the iron and steel industry as a whole is a net producer of coke and coal by-products. Only the estimate of consumption is used to estimate emissions from the Iron and Steel sector. Some of the remaining production may appear elsewhere in the national inventory if it is consumed as fuel by other industries in Australia, in which case the emissions are allocated to the consuming industry; and

- Production consumed elsewhere includes some coke (though in most years the majority of surplus coke produced by the industry is exported from Australia), and surplus coal by-products, most of which are consumed by the Coal and Petroleum Products sector.

A schematic chart showing energy flows within the integrated coke oven/Iron and Steel subsectors is shown in Figure 3.9. All coke used for reduction is reported in the *industrial processes* sector. Some electricity is produced as a by-product of the iron and steel production process. Given the primary role of the fossil fuel inputs in the iron and steel production process, those emissions are not re-allocated to electricity production.

Figure 3.9: Coke Oven and Iron and Steel energy flow chart



Non-Ferrous Metals (ANZSIC Group 213-214) (1.A.2.b)

The consumption of petroleum products nec (meaning other, unspecified petroleum products 'not elsewhere classified') in this sector includes petroleum coke and coal tar used to make carbon anodes for aluminium production. CO_2 emitted from oxidation of carbon anodes in aluminium smelters is accounted in UNFCCC category 2.C.3. The quantity of petroleum coke and coal tar consumed in this sector, as advised by industry each year, is therefore subtracted from energy consumption of petroleum products nec and coal by-products, in order to eliminate double counting. It is assumed that the remaining energy consumption of Petroleum Products nec consists of naphtha. Some use of black coal in the production of synthetic rutile as well as black coal, coke, petroleum coke and fuel oil for base metal smelting occurs for reductant purposes. Therefore, these fuel quantities are also deducted from the *energy* sector fuel consumption and reported under the *industrial processes* sector.

Chemicals (1.A.2.c)

This sub-sector spans the following ANZSIC classes:

- Other petroleum and coal product manufacturing (ANZSIC Class 1709); and
- Basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19).

The Chemicals sector is a major energy user. Most of the energy is used by the Petroleum Refining and Basic Chemical Manufacturing sub-categories. Energy use in these two sub-categories is separately reported at the national level.

Non-energy use of natural gas in the production of ammonia is regarded as an industrial process and is therefore reported under the *industrial processes* sector rather than the *energy* sector, in order to prevent double counting. Likewise, the non-energy use of petroleum coke for titanium dioxide production and coke oven coke used in soda ash production are also reported within the *industrial processes* sector.

The calculation of emissions in the Chemicals sector must identify and allow for carbon stored in products. Sequestration takes place in the Other petroleum and coal product manufacturing (ANZSIC Class 1709) and Basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19) sub-categories, where fossil fuels are used as feedstock. Data is also obtained directly from chemical companies in order to estimate the quantity of carbon sequestered in products from feedstocks, with emissions estimates adjusted accordingly.

Coal by-products constitute the largest fuel input into the Other petroleum and coal product manufacturing (ANZSIC Class 1709) sector. It is assumed that these consist of coal tar and liquefied aromatic hydrocarbons and that, in the absence of specific information about this industry sector in Australia, 75% of this fuel is sequestered in long lived coal products, following the default assumption of the IPCC methodology.

The basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19) sub-category includes the major bulk chemical manufacturing enterprises producing fertilisers, other nitrogenous chemicals, polymer resins (plastics) and carbon black. The fossil fuel feedstocks used include natural gas (CH_4), ethane, propane, butane, propylene and naphtha. Ethane, propane and butane may be either 'naturally occurring', i.e. sourced directly from oil and gas fields, or derived from crude oil as by-products of refining. In Australia, all ethane is derived from naturally occurring sources, while both naturally occurring and ex-refinery propane and butane are used. Propylene and naphtha are refinery products. BREE statistics include ethane within the reported total natural gas consumption, after appropriately adjusting for the different energy content of ethane. BREE also group propane and butane together as LPG and group propylene and naphtha as petroleum products nec.

The important outputs of this sector can be classified into two components:

- synthetic resins (polymers); and
- nitrogenous fertilisers and other nitrogenous products.

A third component, carbon black manufacture, uses significant quantities of fossil fuel feedstock as a source of carbon, however relatively little is combusted. A fourth, methanol, has been manufactured in Australia since 1994.

Synthetic Resins

The balance between combustion and storage in products varies greatly between chemical plants, depending on the production processes involved and the configuration of the particular plant. Therefore the quantity of feedstock supplied to chemical plants is not a useful indication of the quantity of stored carbon. The only reliable guidance comes from the quantities of chemical products produced. The major products in which fossil carbon is sequestered include polyethylene, polypropylene, synthetic rubber and styrene. Other bulk plastics are made in Australia from imported monomers, e.g. PVC made from imported vinyl chloride monomer. These imported monomers contain large quantities of fossil carbon, but since this has not been derived from primary fossil fuels (crude oil, petroleum products and natural gas) produced in or imported to Australia, this carbon is not estimated.

The IPCC Methodology assumes that default fractions of specified fossil fuel products, e.g. ethane, naphtha, are sequestered. The national inventory utilises the actual production figures provided by the companies making the products concerned. The analysis is nevertheless relatively complex, because most products are derived from several different feedstocks. The carbon contents of the various feedstocks and basic chemical products used in estimating the carbon sequestration are reported in Table 313 and Table 314.

The quantities of feedstocks used in the Chemical sub-sector, and the associated amounts of carbon stored in products, are detailed in CRF Table 1.A(d) – Feedstocks and non-energy use of Fuels. For 2011, 26.9 PJs of ethane and 8.3 PJs of petroleum (naphtha) feedstocks resulted in the storage of 376 kt and 166 kt of carbon in long life products respectively. The majority of emissions of ethane and naphtha combusted as fuels are reported in the national inventory under 1.A.2c Chemicals. In 2011, net emissions from the combustion of ethane were 0.2 Mt CO_2-e, while 2.5 Mt CO_2-e of naphtha emissions were reported.

Carbon Black

Carbon black is produced in Australia by partial oxidation of petroleum feedstocks and used in a variety of long lived products, including tyres.

Table 3.13: Feedstock assumptions in basic chemicals

Feedstock	Carbon Faction	Calorific Value (GCV)
Ethane	0.80	(a)
Propylene	0.86	52.2
Naphtha (Benzene)	0.84	48.1
Gas Oil (ADO)	0.85	45.6
Carbon Black Feedstock	(a)	(a)

Sources: Energy Strategies 2007 Analysis. (a) Data is provided on in a confidential manner annually from the relevant companies and hence is not reported here.

Table 3.14: Product assumptions in basic chemicals

Product	Carbon Faction
Polyethylene	0.86
Polypropylene	0.86
Butadiene Rubber / Styrene-Butadiene Rubber	0.86
Styrene	0.92
Carbon black	1.00

3.4.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Revisions to the AES have taken place due to the incorporation of improved activity data available under the NGER. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2011. The revisions have improved time series consistency from 2003 onwards, however a step change exists after 2002 in the time series for a small number of fuel types within source categories.

This submission has made progress in improving time series consistency by reallocating fuel use between subsectors for instances noted in previous ERT reviews, such as *iron and steel*, *non-ferrous metals* and *chemicals* (see section 3.4.5 for discussion of recalculations). See under Planned Improvements for discussion regarding plans to revise the pre-2003 parts of time series affected by the step change.

Time series variability of GHG IEFs are likely to be influenced by changes in fuel mix within categories, and changes of actual fuel EFs. Notable examples of where such variations occur in Manufacturing Industries and Construction 1.A.2 are set out below:

- 1.A.2.a *iron and steel:-CO_2*

  Solid fuels

  The use of coke in *iron and steel* is reported in *industrial processes* sector in accordance with the IPCC *Guidelines*. Of the two remaining solid fuels: coal and coke oven gas, the coke oven gas has a relatively low CO_2 EF of 37 Gg/PJ compared to 91.8 Gg/PJ for coal. This tends to lower the overall CO_2 IEF for solid fuels.

  Liquid fuels

- The liquid fuel CO_2 IEF is relatively low, driven by the dominant use of LPG (CO_2 EF of 60.2 Gg/PJ) compared to other liquid fuels with higher EFs. However, a sharp increase in the IEF in 2001 was the result of an increase in the use of diesel and fuel oil relative to the consumption of LPG. As LPG has a relatively lower CO_2 EF, the change in fuel mix resulted in an increase in the overall liquid CO_2 IEF.

- *1.A.2.b Non Ferrous Metals*

  The ERT noted during the 2013 review of Australia's submission that non-ferrous metals emissions peaked in 2008 and then decreased markedly through to 2011.In response to review questions, Australia noted that the trend was largely an allocation issue due to the nature of non-ferrous metals production companies often span over several industry categories, for example, where a mining operation occurs as part of a metal production or smelting plant. This leads to potential difficulties in the allocation of facilities across mining and non-ferrous metals categories in *stationary energy*.

  Revisions of the AES undertaken by BREE involving the reallocation of fuels between stationary energy categories have now significantly improved the time series consistency of Non Ferrous metals in this submission.

- 1.A.2.c *chemicals*: Emissions and IEFs for *chemicals* are influenced by the mix of end products which sequester carbon. The production mix of the Australian chemicals industry changes over time, resulting in a variable trend.

3.4.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6.

3.4.5 Recalculations Since the 2010 Inventory

Recalculations to 1.A.2 *manufacturing and construction* are detailed at the sub-category level in Table 3.16.

Revisions to the AES by BREE:

A key reason for recalculations arises from revisions by BREE to the AES. The revisions to the AES are due to the incorporation of improved activity data available under the NGER and subsequent improvements in time series consistency. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2011. The revisions have improved time series consistency from 2003 onwards; however, a step change exists after 2002 in the time series for a small number of fuel types within source categories. See under Planned Improvements for discussion regarding plans to revise the pre-2003 parts of time series affected by the step change.

1.A.2.a Iron and Steel

Solid fuels- allocation of pulverised coal injection to Industrial Processes:

Previous ERT reports have noted that Australia reports pulverised coal injection (PCI) consumed as a reductant in the energy sector (1.A.2.a Iron and Steel) and recommended that it be reported in the Industrial Processes sector. Australia has implemented the ERT recommendation in this submission. This has resulted in a reallocation of black coal from 1.A.2.a *iron and steel* to 2.C.1 *metal production* from 2003 onwards, when PCI was first used in Australia.

The allocation of PCI coal to the industrial processes sector also improves the time series consistency of the solid fuel CO_2 IEF.

1.A.2.b Non Ferrous Metals

BREE revisions to AES included significant increases in the consumption of Natural gas (23.8 PJ) and black coal (6.3 PJ) for 2011.

Improved time series consistency in the solid CO_2 IEF was achieved in both the non-ferrous metals and chemical subsectors through the reallocation of black coal from the chemicals subsector for the period 2003 to 2011.

An analysis of NGER data revealed that a minor quantity of coke used as a reductant, currently allocated from 1.A.2.a Iron and Steel to the industrial process sector was also being deducted from 1.A.2.b non-ferrous metals. A recalculation in this submission has removed this duplicate allocation and resulted in an increase of solid fuel non-ferrous emissions for the entire time series

1.A.2.c Chemicals

The chemicals subsector has been subject to a number of recalculations in response to revisions by BREE to the AES. These included significant decreases in the consumption of Natural gas (21.7 PJ) and diesel (4.3 PJ) for 2011.

In addition, a reallocation has been undertaken of particular fuels between subsectors (as detailed below), in response to ERT issues in an effort to improve the time series consistency of various CO_2 IEFs.

Solid fuels:

A reallocation of black coal from chemicals to non-ferrous metals has been implemented, as detailed above under 1.A.2.b Non Ferrous Metals. This has improved the time series consistency of the CO_2 IEF for solid fuels in both subsectors

In addition, a reallocation of coal by-products fuels previously reported under 1.A.1.b petroleum refining (years 2007 onwards) to chemicals has been implemented to improve the time series consistency of the petroleum refining sub sector.

Liquid and gaseous fuels:

BREE undertook a revision to the AES involving the reallocation of around 20 PJs natural gas from chemical to non-ferrous metals for 2011 only. This resulted in a recalculation which improved the time series consistency of both sectors.

The acquisition of further facility data reported under NGER allowed for improved understanding of the representation of feedstocks and fuel transformation in the chemicals subsector. Subsequently, revisions were made to the treatment of derived fuels resulting in an increase in emissions from 2003 onwards. In addition, liquid fuels in 2009 also increased due to the rectification of a data input error and revised ADO consumption in the AES.

1.A.2.d, and f

The recalculations were made in response to revisions by BREE to fuel consumption in the AES. There has also been a reallocation of bagasse betwen *1.A.2.d* and *1.A.1.a* throughout the time series as a result of discrepancies between the amounts reported in the AES and in NGERs.

Table 3.15: 1.A.2 Manufacturing and Construction: recalculation of total CO_2-e emissions, 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.2.a Iron and steel				
1990	2,641	2,641	0	0.0
2000	2,423	2,423	0	0.0
2001	2,445	2,445	0	0.0
2002	2,659	2,659	0	0.0
2003	3,687	2,360	-1327	-36.0
2004	4,171	2,579	-1592	-38.2
2005	4,399	2,807	-1592	-36.2
2006	4,082	2,558	-1524	-37.3
2007	4,248	2,390	-1858	-43.7
2008	4,316	2,724	-1592	-36.9
2009	3,435	2,299	-1136	-33.1
2010	3,908	2,436	-1473	-37.7
2011	4,075	2,472	-1603	-39.3
1.A.2.b Non-ferrous metals				
1990	10,836	11,040	205	1.9
2000	12,945	13,150	205	1.6
2001	12,182	12,387	205	1.7
2002	12,382	12,588	206	1.7
2003	11,818	12,324	506	4.3
2004	12,080	12,631	550	4.6
2005	13,050	13,610	560	4.3
2006	13,151	13,756	606	4.6
2007	13,449	14,029	580	4.3
2008	14,027	14,374	347	2.5
2009	12,804	13,331	528	4.1
2010	12,946	13,757	810	6.3
2011	11,417	13,747	2329	20.4
1.A.2.c Chemicals				
1990	5,802	5,583	-219	-3.8
2000	6,398	5,997	-400	-6.3
2001	6,883	6,605	-279	-4.0
2002	6,415	6,096	-319	-5.0
2003	5,917	6,199	282	4.8
2004	6,572	6,903	331	5.0

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
2005	6,122	6,486	365	6.0
2006	5,779	6,131	352	6.1
2007	5,175	5,795	620	12.0
2008	6,169	6,527	358	5.8
2009	5,232	6,849	1618	30.9
2010	6,164	6,769	604	9.8
2011	6,793	5,472	-1321	-19.5
1.A.2.d Pulp paper and print				
1990	1,301	1,301	0	0.0
2000	1,783	1,465	-319	-17.9
2001	1,839	1,477	-363	-19.7
2002	1,831	1,477	-354	-19.3
2003	1,520	1,234	-285	-18.8
2004	1,635	1,246	-389	-23.8
2005	1,783	1,339	-443	-24.9
2006	1,788	1,323	-465	-26.0
2007	1,729	1,370	-359	-20.8
2008	1,674	1,326	-348	-20.8
2009	1,678	1,481	-197	-11.7
2010	1,711	1,496	-215	-12.6
2011	1,474	1,352	-121	-8.2
1.A.2.e Food, beverages and tobacco				
1990	2,949	2,909	-39	-1.3
2000	3,161	3,108	-53	-1.7
2001	2,563	2,514	-49	-1.9
2002	2,567	2,520	-46	-1.8
2003	3,244	3,244	0	0.0
2004	2,959	2,964	5	0.2
2005	3,145	3,155	10	0.3
2006	3,070	3,075	5	0.2
2007	3,007	3,017	10	0.3
2008	3,058	3,073	15	0.5
2009	3,086	3,109	24	0.8
2010	3,005	3,051	47	1.5
2011	3,146	2,878	-268	-8.5
1.A.2.f Other				
1990	12,080	12,080	0	0.0
2000	12,094	12,094	0	0.0
2001	12,330	12,330	0	0.0
2002	13,838	13,080	-758	-5.5
2003	12,544	11,951	-593	-4.7
2004	12,406	11,793	-613	-4.9

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
2005	12,329	11,795	-534	-4.3
2006	11,933	11,371	-562	-4.7
2007	12,788	12,022	-766	-6.0
2008	13,189	12,399	-790	-6.0
2009	13,085	12,430	-655	-5.0
2010	13,179	12,136	-1044	-7.9
2011	14,015	13,275	-740	-5.3

3.4.6 Planned Improvements

In the 2012 and 2013 updates of the AES, BREE has further incorporated improved activity data available under the NGER, as well as undertaken fuel reallocations between subsectors to improve time series. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period 2003 to 2011. An outcome of this improved data is that a step change exists for 2002-2003 in some time series for individual fuel types within certain source categories. BREE are exploring the possibility of extending the revision through to the earlier part of the time series in future AES releases and these revisions will be incorporated into future recalculations of the national inventory when available.

Uncertainty data reported by corporations under the National Greenhouse and Energy Reporting system has been incorporated into the national inventory for the electricity sector. A review of NGER uncertainty data in other fuel combustion sectors will be undertaken with the intention of incorporating these estimates in the uncertainty analysis.

In response to a recommendation from a previous review report, a study was commissioned by the Department to investigate the appropriateness of the fuel characteristics, including the CO_2 EF, for liquid fuels types used in the NGGI. The CO_2 EF used by the inventory for ethanol was found to be around 7% higher than that published in another Australian report, however there are a very limited number of data points available for comparison. Therefore, further analysis of Australian ethanol characteristics will be undertaken before any changes are made to the EF used to compile the inventory.

The report on fuel characteristics also assessed the natural carbon versus fossil carbon content of tyres. Scrap tyres are used in certain manufacturing industries such as cement production to produce heat. The assumption is currently that all the carbon within tyres is of fossil origin, however it is well known that tyres contain a significant portion of natural rubber, which if considered as a biomass fuel, would lower the current CO_2 EF. The report estimated that the ratio of natural to synthetic rubber in tyres at 56:44. However, about 30% of the tyres mass is carbon black which is of fossil origin, while another significant proportion, such as the steel components, is incombustible. Given the apparent complexity in establishing an appropriate EF for tyres, the Department intends to further consider the results of the report before making any changes.

3.5 Source Category 1.A.3 – Transport

3.5.1 Source Category Description

This source category includes emissions from the *transport* sector, comprising the civil aviation, road transportation, marine navigation, railways and 'other' categories.

Activity data on fuel consumption is based on BREE *Australian Energy Statistics*. A number of mobile source categories have been allocated to the stationary source inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. In particular, emissions from miscellaneous off-road vehicles used in specific ANZSIC classifications (such as tractors and other farm vehicles, forestry vehicles, quarry trucks and front-end loaders, construction equipment, and forklifts) are allocated to the corresponding ANZSIC group and accounted for in sectors 1.A.2 and 1.A.4. It is estimated that these emissions account for approximately 20,180 Gg in 2012. More information on the assumed mobile components of stationary sources is at section 3.2.2. Emissions from mobile utility engines (such as lawn-mowers, chain-saws, portable generators and mobile compressors) and military transport are reported in sectors 1.A.4 and 1.A.5 using the methodologies detailed in this sector. Emissions from other off-road mobile sources, however, such as unregistered trail bikes, recreation vehicles and competition vehicles are reported under 1.A.3.

3.5.2 Methodology

Like other energy sub-sectors, the methodology for 1.A.3 is based on the application of 'bottom up' approaches to the estimation of emissions. Tier 2 approaches are employed for the estimation of nonCO_2 emissions from civil aviation, which takes account of fuel consumed, landing and take-off cycles and Australian fleet characteristics. The estimation of non-CO_2 emissions from passenger and light commercial vehicles utilises a tier 3 approach that depends on data on vehicle kilometres travelled, vehicle fleet characteristics and vehicle operating modes.

Table 3.16: Summary of methods and emission factors: Transport

Source Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A3a Civil Aviation	T1	CS	T1/T2	CS/D	T1/T2	CS/D
1A3b Road Transportation – passenger, light commercial and heavy vehicles	T2	CS	T3	CS/D	T3	CS/D
1A3b Road Transportation - other	T2	CS	T1	CS/D	T1	CS/D
1A3c Railways	T2	CS	T1	D	T1	D
1A3d Navigation (Domestic)	T2	CS/D	T2	D	T2	D
1A3e Other Transport	T2	CS	T1	D	T1	D

Notes: T1 = tier 1. T2 = tier 2. T3 = tier 3. CS= Country-specific. D= IPCC default.

General Methodology

The emission estimate of a greenhouse gas from fuel combustion in the engines of a mobile source, using a specified fuel type, is calculated by:

$$E(l)_{ijk} = Au_{ijk} \times F(l)u_{ijk} \quad (3.3)$$

where: $E(l)_{ijk}$ is the emission of greenhouse gas l in gigagrams (Gg) from a mobile vehicle and age class i and technology j using fuel type k;

Au_{ijk} is the activity level, where u refers to either energy consumption in petajoules (PJ) or to distance travelled in kilometres (km); and

$F(l)u_{ijk}$ is the EF, in units of grams of gas l emitted per megajoule of energy use (g/MJ) for CO_2 and SO_2, and grams of gas l emitted per kilometre travelled (g/km) for other non-CO_2 gases.

Fuel consumption data for the *transport* sector are taken from BREE *Australian Energy Statistics*. The main adjustments applied to BREE energy consumption data allocate some fuels to off-road, residential and military fuel uses (reported in Table 3.A.13).

The allocations of fuel to military transport in 2008, 2009 and 2010 are informed by direct reporting of fuel consumption by the Australian Department of Defence (2010–2012). Allocations for 1995-2007 are linearly extrapolated between the reported data points in 1994 and 2008.

Allocations for 2011 and 2012 are based on energy use data published by the the Australian Government in accordance with its *Energy Efficiency in Government Operations (EEGO) Policy (AGO 2007)*. This requires the preparation of an annual whole-of-government report on the total energy use and estimated greenhouse gas emissions of Australian Government departments and agencies, and presented in the report *Energy use in the Australian Government's operations* using information reported to the Department of Resources, Energy and Tourism from all government departments and agencies - including the Department of Defence.

Civil Aviation (1.A.3a)

The estimation of CO_2 emissions from civil aviation is undertaken using a tier 1 methodology and EFs given in Tables 3.2 and 3.3.

Non–CO_2 emissions from domestic civil aviation from fuel use are estimated using both a tier 1 and a tier 2 methodology. For larger aircraft operating on aviation turbine fuel, emissions are calculated as a function of both the landing/takeoff cycles (LTOs) and of cruise emissions for both domestic and international aircraft. Small aircraft operating on aviation gasoline make up a small portion of aviation emissions, and are estimated using a tier 1 approach and IPCC default EFs.

The tier 2 estimation of emissions from landing and takeoff cycles of larger aircraft operating on aviation turbine fuel requires data on the number of LTO cycles at Australian airports; data on the profile of the Australian aviation capital stock or fleet; and EFs by type of aircraft. The data required for the total yearly LTO for the domestic and international aircraft are available from the Bureau of Infrastructure, Transport and Regional Economics (BITRE 2013) within the Department of Infrastructure and Regional Development (DIRD). The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority (Table 3.17). EFs for each aircraft type are taken from IPCC 2006 and are used to estimate weighted average LTO cycle EFs for the domestic/interstate and international aviation fleets (Table 3.18). These EFs most accurately reflect the technology and aircraft types currently in the Australian aircraft fleet. In a couple of instances EFs are not available for a certain aircraft type. These aircraft are allocated to the aircraft type, for which an EF exists, that most closely reflects the aircraft's engine characteristics.

The estimation of cruise emissions is a function of fuel use, after deduction of fuel consumption required for the LTO cycles, and cruise EFs. Data on the yearly fuel consumption for domestic and international activity are available from BREE 2013a. Cruise EFs are taken from IPCC (1997) (Table 3.19).

The methodology is applied to each of the eight Australian states and territories (with the exception of the Australian Capital Territory which due to the unavailability of disaggregated fuel consumption data is included in estimates for the state of New South Wales). Differences in emission estimates across the States principally reflect differences in fuel consumption and both the number of LTO cycles and the relative importance of major interstate movements relative to regional LTO cycles, which impacts on the aircraft type that use State airports. National emissions are estimated as the sum of the State and Territory emissions.

For small piston engine aircraft operating on aviation gasoline fuel, non-CO_2 emissions are estimated using a tier 1 approach. This method applies default EFs (provided in IPCC (1996) and IPCC (2006) for all fuels and aircraft types) to all aviation gasoline fuel consumed by state (Table 3.20).

Emissions from international aviation are also estimated, but are reported as a Memo item only, by international agreement.

Activity data for international bunkers is estimated by BREE as part of the AES. BREE also utilise data from their *Australian Petroleum Statistics* (APS 1996–2012) which publishes monthly national and state petroleum statistical information while sales of aviation turbine fuel, diesel and fuel oil for domestic and international uses are published on a quarterly basis. The APS explanatory note, which informs company reporting, states that the dissection of international and domestic fuel consumption is made according to the predominant mode of usage by the consumer.

Independent of the national inventory the DIRD has developed a software tool to compute and track the carbon footprint associated with aircraft fuel uplifted in Australia. The DIRD completed an assessment of the robustness of their results by comparing their calculated values with the APS. Their results showed that for domestic aviation, computed CO_2 estimates using the software tool and inventory estimates differed by 0.9% in 2010 and 1.1% in 2011 (DIRD data for comparison not available for 2012 at time of publication). This is considered to be a good independent verification of the estimates.

Table 3.17: The Australian aircraft fleet, 2012, and emission factors by type of aircraft

Type of aircraft	Number	Emission Factors				
		CH_4	N_2O	NO_x	CO	NMVOC
		kg/LTO	kg/LTO	kg/LTO	kg/LTO	kg/LTO
Domestic/ Inter-state						
DHC-8-100	31	0.00	0.02	1.51	2.24	0.00
DHC-8-200	13	0.00	0.02	1.51	2.24	0.00
A320	68	0.06	0.10	9.01	6.19	0.51
A330–200/300	34	0.13	0.20	35.57	16.20	1.15
BAE 146	33	0.14	0.00	4.07	11.18	1.27
B717	13	0.01	0.10	10.96	6.78	0.05
B727-200	1	0.81	0.10	11.97	27.16	7.32
B737–300/400/500	20	0.08	0.10	7.19	13.03	0.75
B737–700	7	0.09	0.10	9.12	8.00	0.78
B737–800	114	0.07	0.10	12.30	7.07	0.65
B767–200		0.33	0.10	23.76	14.80	2.99
B767–300	24	0.10	0.20	28.19	14.47	1.07
SAAB 340	52	0.00	0.02	1.51	2.24	0.00
SA227	44	0.00	0.02	1.51	2.24	0.00
SA226	12	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	47	0.14	0.10	5.63	8.88	1.23
EMB 110	6	0.06	0.01	0.30	2.97	0.58
EMB 120	20	0.00	0.02	1.51	2.24	0.00
Cessna 525	15	0.33	0.03	0.74	34.07	3.01
Beech 200	99	0.06	0.01	0.30	2.97	0.58
F27	134	0.03	0.02	1.82	2.33	0.26
International						
747–300	0	0.27	0.40	65.00	17.84	2.46
747–400	26	0.22	0.30	42.88	26.72	2.02
777	5	0.07	0.30	52.81	12.76	0.59
A380	12	0.40	0.30	69.31	28.40	2.02

Source: CASA Civil Aircraft Register (2013), International Civil Aviation Organisation, Aircraft Engine Emissions Databank (EASA 2012)

Table 3.18: Weighted average emissions factors per Landing and Take Off cycle, 2012

Fleet	CH_4 (kg)	N_2O (kg)	NO_x (kg)	CO (kg)	NMVOC (kg)
Domestic Fleet	0.07	0.06	6.62	6.18	0.56
International Fleet	0.25	0.30	51.41	25.56	1.85

Source: DE estimates

Table 3.19: Aviation cruise emission factors (grams per tonne of fuel consumed)

Fleet	CH_4 (g/t)	N_2O (g/t)	NO_x(g/t)	CO (g/t)	NMVOC (g/t)
Domestic Fleet	0	0.1	11	7	0.7
International Fleet	0	0.1	17	5	2.7

Source: IPCC (1997).

Table 3.20: Aviation Tier 1 Non-CO_2 Emission Factors

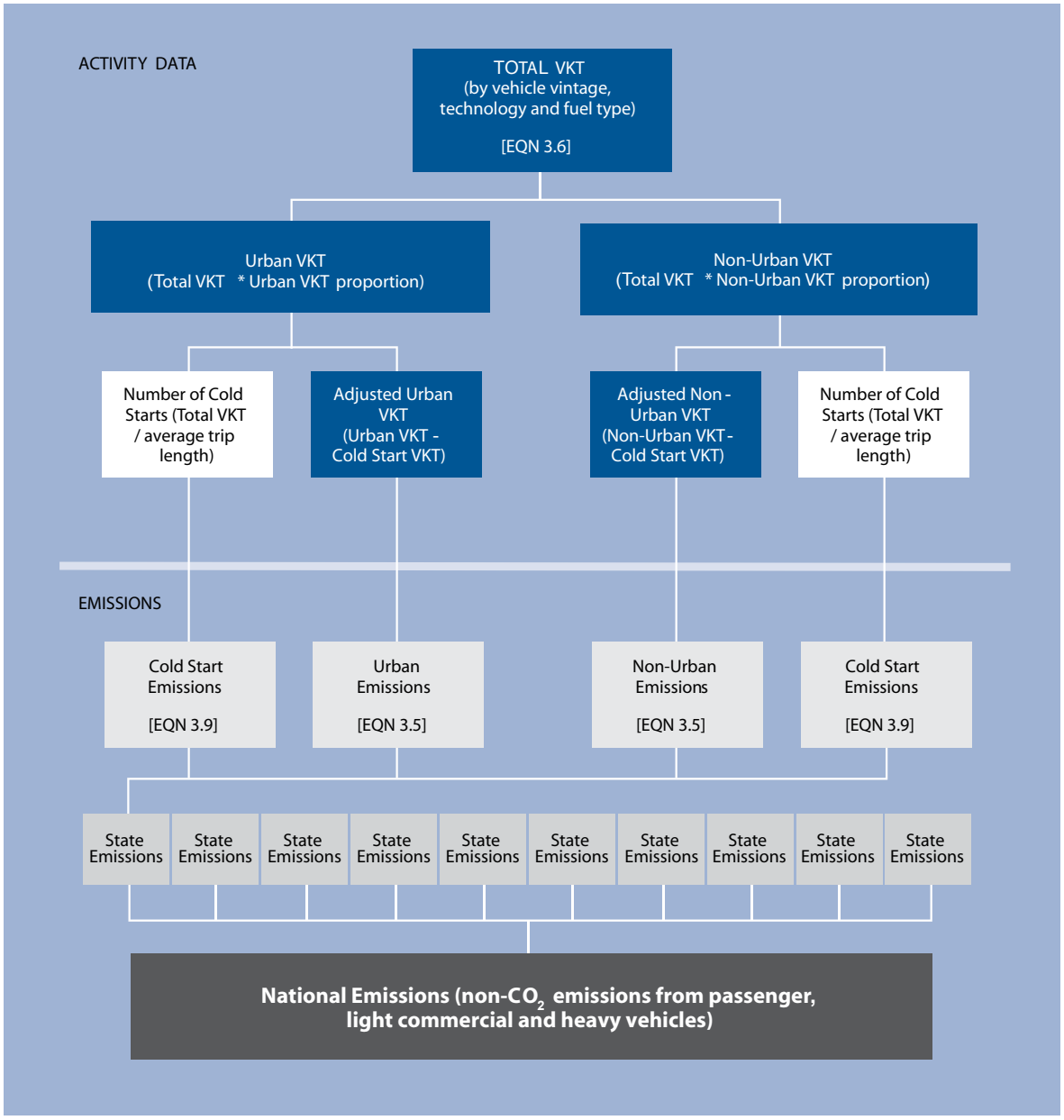
Tier 1 Non-CO_2	CH_4 (kg/TJ)	N_2O (kg/TJ)	NO_x(kg/TJ)	CO (kg/TJ)	NMVOC (kg/TJ
All Fuels	0.5	2	250	0.024	0.00054

Source: IPCC (1997), IPCC (2006).

Road Transportation (1.A.3.b)

Like the aviation sector, the estimation of CO_2 emissions from the road transport sector is based on a tier 2 method with EFs given in Table 3.2. The estimation of non–CO_2 emissions is based on a tier 3 method, with the emission estimates dependent on the type of vehicle, the age of the vehicle capital stock, technology, operating mode (cold versus hot) and road type (urban versus non-urban). Activity data is expressed in terms of vehicle kilometres travelled and EFs are expressed in g/km. The methodology is applied to each of the eight Australian states and territories. Differences in emission estimates across the states and territories principally reflect differences in fuel consumption and the impacts on non-CO_2 emission estimates of differentials in the age distribution of each state and territory's vehicle fleet. National emissions are estimated as the sum of the State and Territory emissions (see Figure 3.10).

Figure 3.10: Methodology for the estimation of non-CO_2 emissions from passenger and light commercial vehicles



Passenger and Light Commercial Vehicles, Heavy Vehicles and Buses (1.A.3.bi-v)

CO_2 emissions from all vehicle fuel sources have been estimated based on the quantity of fuel consumed by the CO_2 EF specific to that fuel and the proportion of that fuel which is completely oxidised.

$$E_{ijk} = A^{u=1}_{ijk} \times (F(I)_k \times P_k) \quad (3.4)$$

where: $F(I)_k$ is the CO_2 EF applicable to complete oxidation of fuel carbon content for fuel type k (where k=petrol, diesel and LPG);

P_k is the proportion of fuel that is completely oxidised upon combustion; and

A^u_{ijk} is the activity data for vehicle type i with emission control technology j and fuel type k (and where u=1 for fuel consumption in each Australian State)

The CO_2 EFs and oxidation factors for each fuel are summarised in Tables 3.2 and 3.3.

For all vehicles besides motorcycles consuming automotive gasoline, ethanol, diesel and LPG nonCO_2 emissions for each age class are estimated based on vehicle kilometres travelled (VKT) in each State or Territory; the profile and age of the vehicle capital stock in each State; the penetration of catalytic control technology; mode of operation and road type; and vehicle and fuel specific EFs.

It is assumed that all light duty vehicles go through a cold start phase for each trip which is associated with higher emissions due to engine and catalyst temperatures that are below optimum. The number of cold starts is derived from total VKT and an average trip length sourced from Pekol Traffic and Transport 2013. Average trip length by State and Territory and by vehicle type is estimated for each year throughout the time series. This data source replaced a static average trip length of 10km that was previously applied across States and Territories and vehicle types. Average trip length data is listed at appendix Table 3.A.20. A cold-start duration of 3km (as cited in IPCC 2006) is used to determine the total cold start VKT. This is subtracted from total VKT to derive an adjusted total VKT value.

EFs vary by road type (urban versus non-urban) to reflect the different driving conditions and engine operating profiles. Distance travelled is disaggregated into urban and non-urban VKT in each State and Territory and by vehicle type (Pekol Traffic and Transport 2013). The urban VKT proportion data is listed at appendix Table 3.A.21.

Vehicles using automotive gasoline, ethanol, diesel and LPG are further classified by age of vehicle using data contained in ABS 2012a. The divisions in the vehicle fleet enable differences in emissions control technology and differences in fuel efficiency across age classes to be factored into the emissions estimation. Passenger vehicles and light commercial vehicles manufactured and sold in Australia before 1976 are assumed to have no emissions control equipment. The 1976-1985 group uses a variety of non-catalytic control (such as exhaust gas recirculation) and the 1985-1997, 1998-2003, 2004-2005 and the post-2005 groups use catalytic control.

In general, non- CO_2 exhaust emissions from vehicles have been calculated by the following form of equations:

$$E(l)_{ijk} = A^{u=2}_{ijk} \times EF(l)_{ijk} \quad (3.5)$$

where: l = non-CO_2 gases; $A^{u=2}$ for vehicle kilometres travelled and k= automotive gasoline, diesel, and LPG; $EF(l)_{ijk}$ is the exhaust EF for gas l from vehicle type i and age class j using fuel type k for urban and rural operation in each state or territory and where vehicle distances travelled during the hot-engine phase of operation are related to energy consumption levels using:

$$A^{u=2}_{ijk} = A^{u=1}_{ijk} / R_{ik} \times D_k \quad (3.6)$$

where: $A^{u=2}_{ijk}$ is the distance travelled for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG; and

R_{ijk} is the average rate of fuel consumption (in l/km, given in Tables 3.A.15-3.A.17) for vehicle type i and age class j, using fuel type k; and

D_k is the energy density of fuel type k (in MJ/L)

and where

$$EF(l)_{ijk} = (ZKL_{ijk} + DR_{ijk} \times CumVKT_{ijk}) \quad (3.7)$$

where: $EF(l)_{ijk}$ is the EF for gas l from each vehicle type i and age class j , using fuel type k=automotive gasoline, diesel, and LPG;

ZKL_{ijk} is the zero kilometre level emissions of a gas l from vehicle type i and age class j;

DR_{ijk} is the deterioration rate for vehicle type i and age class j; and

$CumVKT_{ijk}$ is the cumulative VKT for vehicle type i and age class j, and fuel type k, in each state or territory

and where

$$CumVKT(l)_{ijk} = \Sigma_{t=1-n} A^{u=2}_{ijk} \quad (3.8)$$

where: $A^{u=2}_{ijk}$ is the average distance travelled (in km) by vehicle type i and age class j, using fuel type k=automotive gasoline, diesel, and LPG in each State or Territory summed over time.

Cold start emissions are derived using equation 3.9:

$$Ecs_{ijk} = CS_{ijk} \times EFcs_{ijk} \quad (3.9)$$

where: Ecs_{ijk} are the cold start emissions for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG;

CS_{ijk} is the number of cold starts for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG;

$EFcs_{ijk}$ is the cold start EF (g/start) for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG

Data on fuel consumption for individual vehicle types is derived from BREE 2013a and ABS (2013). The data on fuel consumption rates are taken from ABS (2013). The profile and age of the passenger vehicle stock in each State and Territory required for equation 3.7 is taken from ABS (2013). The vehicle stock from each historical year varies largely due to vehicle sales from each particular year, which in turn is largely driven by the prevailing economic conditions. For example the vehicle stock in 1991 is lower than surrounding years as a result of lower vehicle sales impacted by an economic recession affecting Australia at the time. Data required for estimating VKT for individual vehicle and age classes are given in Tables 3.A.17 to 3.A.19.

Emissions of CH_4 from motor-vehicles are a function of the emission and combustion control technologies present as well as vehicle operating conditions. EFs chosen for passenger and light commercial vehicles were obtained from Australian sources where these were available and applicable to the vehicle fleet and its various modes of operation and fuel types (see Tables 3A.6-3A.8). A major empirical study (*Second National In Service Emissions Study*) of emissions from the operation of light duty petrol vehicles was undertaken in 2009. The results of this study were analysed for the national inventory (Orbital Australia 2010). The study directly measured emissions from 347 petrol passenger vehicles and light commercial vehicles manufactured from 1994-2009. The 347 vehicles represented four ADR (Australian Design Rule, DIRD 1969-1988) age groupings. A petrol Composite Urban Emissions Drive Cycle (CUEDC) was developed as a means of better representing driving under Australian conditions. All vehicles undertook a hot start CUEDC while a subset of the vehicles also undertook a cold start. Emission measurements were allocated to hot urban, non-urban and cold driving conditions. Total hydrocarbon, CO, NO_x, CO_2 and CH_4 emissions were measured from bag samples. EFs (Table 3.A.5) and deterioration rates (3.A.11) were derived for ADR groupings for each gas and each driving condition. Using the EFs and deterioration rates a zero kilometre EF was derived. Results were assessed by cross-referencing the generated results to the zero kilometre capability of the vehicle fleet. This reference point is based on the assumption that at zero kilometres the vehicles were generally in compliance with emission standards of the day and that in general the deterioration over the ADR specified period is indicated to be in line with automotive engineering expectations. Orbital Australia (2010) details these checks.

Orbital Australia (2011b) was used to extend the direct measurement approach outlined above to older vehicles by utilising measurements taken for other studies including the pilot phase of the *Second National In Service Emissions Study* and the *First National In Service Emissions Study*. The outcomes from this report provided updated EFs and deterioration rates for petrol passenger vehicles and light commercial vehicles manufactured between 1986 and 1993. The use of disaggregated, country-specific EFs expressed in terms of emissions per kilometre travelled is consistent with the IPCC tier 3 methodologies. For vehicles not covered by the studies outlined above the choice of US versus European default factors has been dictated by the exhaust emission standards in

the Australian Design Rules (ADR) applicable to each particular vehicle vintage. Australian Design Rules have been harmonised with European Standards since 1996 in heavy duty vehicles. Therefore the IPCC default factors used for post 1995 heavy duty vehicles are based on European data (COPERT IV, EEA 2011). Prior to the harmonisation with European standards, US Federal Test Protocol standards were used as the basis for ADRs. Therefore USEPA default factors cited in IPCC 2006 are used for earlier vehicle vintages where required.

Australian design rules applied to Australia's vehicle fleet, their date of introduction and the European sources for these standards are outlined in Table 3.21. The age-band structure of the motor vehicle emission model is based on the applicability of a given ADR to a given vehicle vintage.

Table 3.21: Australian petrol passenger car exhaust emission standards, Australian heavy duty diesel exhaust emission standards

Petrol passenger vehicles		
Australian Standard	**Year introduced**	**Source standard**
ADR 79/00	2004	Euro 2
ADR 79/01	2006	Euro 3
ADR 79/02	2010	Euro 4
Heavy duty diesel exhaust		
Australian Standard	**Year introduced**	**Source standard**
ADR 70/00	1996	Euro 1
ADR 80/00	2003	Euro 3
ADR 80/02	2008	Euro 4
ADR 80/03	2011	Euro 5

Source: DIRD (2012a) DIRD (2012b)

There are no country-specific CH_4 EFs available for heavy-duty vehicles. These EFs have been taken from DCC 2006 or IPCC 2006 as indicated in Appendix 3.A.6. CH_4 EFs for post-2005 vintage vehicles (Euro 3) have been derived based on the Euro 1 COPERT IV EF and an emission reduction factor according to the method in EEA 2009. A summary of the EFs used to estimate CH_4 emissions from the Australian petrol, diesel, LPG and ethanol driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in appendix Table 3.A.6.

Emissions of non-CO_2 exhaust gases may increase as the vehicle ages due to the gradual wearing of components, poor maintenance, deactivation of catalyst materials, removal of emission control equipment, oxygen sensor failure, or modification of the engine. The rate of increase in emissions per kilometre per vehicle kilometres travelled is the deterioration rate. Deterioration rates are positive, indicating that emissions increase with mileage. Deterioration rates for each gas, vehicle design category and vehicle type combination are calculated by fitting a linear regression to the scatter of directly measured emissions by vehicle kilometres travelled.

For petrol passenger vehicles and light commercial vehicles manufactured prior to 1986 a study by EPA NSW (1995) analysed the combined emission test databases of EPA NSW and EPA Victoria to determine deterioration rates and zero VKT (i.e. new car) emissions for the two States' combined fleet. For vehicles manufactured from 1986 onwards the deterioration rates are taken from the Orbital Australia 2010 and Orbital Australia 2011b. In this year's inventory the model was updated to allow separate deterioration rates to be applied to passenger vehicles and light commercial vehicles.

The deterioration rates derived in the Orbital reports are based on a study of petrol vehicles. A separate study was undertaken to assess the appropriateness of applying the petrol deterioration rates to other fuels (Orbital Australia 2011c). Limited information was found on the deterioration rates of many vehicles using other fuels however there was evidence that the deterioration rate of diesel passenger vehicles is less than petrol vehicles. Based on the available information Australia has applied the petrol deterioration rates to the diesel and ethanol consumed in passenger and light commercial vehicles which is believed to be a conservative approach. The deterioration rates used to derive EFs for the passenger and light commercial vehicle fleet are shown in appendix Table 3.A.11. The data shows no evidence of deterioration in the level of N_2O emissions, therefore a deterioration rate of 0 is used.

The majority (345 out of 347) of vehicles tested in the *Second National In Service Emissions* study had a VKT between 0 and 300,000km. Most of the deterioration rates used in the transport model are sourced from this data set. Therefore Australia has applied a limit to the application of the deterioration rate based on total vehicle kilometres travelled. This limit is applied at an accumulated average VKT of 300,000km per vehicle.

N_2O EFs for Australia's petrol-fuelled passenger vehicle fleet are based on CSIRO testing (Weeks et al, 1993) of vehicles of vintage up to 1993, fitted with a range of emissions control technology. Test data on vehicles not fitted with catalysts are used for the pre 1976 and the 1976-85 age groupings and a weighted average of the catalyst equipped emissions used for the 1985-1997 and the post-1997 vehicle fleet. The EFs in Weeks et al are comparable to those reported in IPCC (2000) and by the USEPA and COPERT IV. N_2O EFs for light duty petrol vehicles of vintage 1994 onwards are estimated in the Orbital Australia 2010 report on NISE 2 data.

Australian emissions standards as set out in Australian Design Rules (ADRs) have tended to lag those applied in Europe and the United States - emission standards for petrol passenger vehicles equivalent to Euro 3 (ADR 79/01) were introduced in Australia in 2006. Consequently, the types of emissions control technology employed in Australia also tend to lag as these are introduced in order to comply with the emissions standards.

The EFs used to estimate N_2O emissions from the Australian petrol, ethanol, diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in appendix Table 3.A.8.

There are no country-specific N_2O EFs available for heavy-duty vehicles. These EFs have been taken from DCC 2006 and IPCC 2006 as indicated in appendix Table 3.A.9.

EFs from the 2006 IPCC *Guidelines* are used in the road transportation sector when they are the most appropriate factors for the vehicle standards and technology that exist in the Australian road transport fleet.

Australia's IEF for CH_4 from liquid fuels (Fuel Combustion sectoral approach) is most influenced by the contribution of CH_4 emissions for Road Transportation, Cars, and Petroleum. CH_4 implied emission factors for Road Transportation, Cars, and Petroleum have been trending down since the mid-1990s as the inventory reflects improved vehicle emissions control technology performance in the Australian fleet.

The Australian fleet has a relatively high non-CO_2 emissions profile, as Australian emissions standards have tended to lag behind those applied in Europe and the United States - emission standards for petrol passenger vehicles equivalent to Euro 3 (ADR 79/01) were introduced in Australia in 2006. Consequently, the types of emissions control technology employed in Australia in the period 1990-2004 also tend to lag as these are introduced in order to comply with the emissions standards. This is compounded in the current fleet by a relatively slow fleet turnover and transition to vehicles with improved emission control technologies.

Motorcycles (1.A.3.b.vi)

The estimation of emissions for motorcycles is given by equations 3.4 and 3.5. Fleet average EFs for motorcycles are provided in appendix Table 3.A.12.

Evaporative Fuel Emissions (1.A.3.b.v)

Road vehicles using automotive gasoline emit NMVOCs both from the exhaust and through evaporation. The evaporative NMVOC emissions include:

- Running losses resulting from evaporative emissions released during engine operation. Running losses occur when the capacity of the vapour control canister and purge system is exceeded by the vapour generation rate and are greatest at low average vehicle speeds. Running losses vary with the age and type of control system of the vehicle and the trip duration;
- Hot soak losses resulting from evaporation of fuel at the end of each trip. These emissions bear little relation to the VKT for an individual vehicle. A more realistic activity on which to base these emissions is the number of trips an average vehicle would make in a given time period;
- Diurnal losses resulting from vapour being expelled from fuel tanks due to ambient temperature rises. These emissions are strongly dependent on the Reid Vapour Pressure (RVP) of the fuel, the daily ambient temperature changes and where the vehicle is parked during the day. Emissions will vary significantly between identical vehicles in different geographical regions. Diurnal emissions only occur when the temperature is rising; and
- Resting losses resulting through the permeation of fuel through rubber hoses or open bottom carbon canisters. Resting losses have often been included in measurements of hot soak, diurnal and running losses (USEPA, 1991a).

EFs for evaporative emissions for each of the three passenger vehicle age classes have been estimated for average Australian temperatures and fuel properties and are presented in appendix Table 3.A.19.

Railways (1.A.3c)

Emissions are estimated using tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table 3.2 and non- CO_2 EFs are reported in Table 3.22. Given data on the composition and engine types in the local fleet, an average fleet EF has been calculated using the individual engine EFs in USEPA (1992). Data on fuel consumption is taken from BREE 2013a.

Table 3.22: Non-CO_2 emission factors for non-road sources

Source Category		CH_4	N_2O	NO_x	CO	NMVOC
				(g/MJ)		
Rail Transport [(a)]						
ADO		0.003	0.002	1.530	0.202	0.071
IDF		0.003	0.002	1.530	0.202	0.071
Coal		0.032	0.001	0.190	0.220	0.260
Marine Transport [(b)]						
Domestic						
Petrol –	Small Craft	0.360	0.001	0.254	20.300	3.240
ADO		0.004	0.002	1.105	0.246	0.075
IDF		0.007	0.002	1.580	0.163	0.046
Fuel Oil		0.003	0.002	2.000	0.044	0.063
NG		0.243	0.001	0.243	0.095	0.029
Coal		0.032	0.001	0.190	0.220	0.260
International						
ADO		0.007	0.002	1.580	0.163	0.046
IDF		0.007	0.002	1.580	0.163	0.046
Fuel Oil		0.003	0.002	2.000	0.044	0.063

Sources: (a) USEPA (1995a);
(b) Lloyd's Register of Shipping (1995, and previous issue).

Energy

Navigation (1.A.3d)

Emissions are estimated using tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table 3.2 and non- CO_2 EFs are taken from Lloyds Register of Shipping 1995 and are reported in Table 3.22.

Emissions from international bunker fuels are also estimated, but are excluded from national emission inventory aggregates by international agreement. Activity data for international bunkers is estimated by BREE as part of the AES. BREE also utilise data they published in their *Australian Petroleum Statistics* (APS, BREE 1996–2013) series. Monthly national and state petroleum statistical information are published in the APS. Sales of aviation turbine fuel, diesel and fuel oil for domestic and international uses are separated on a quarterly basis.

The APS explanatory note, which informs company reporting, states that the distinction between international and domestic fuel consumption data is undertaken according to the predominant mode of usage by the consumer.

3.5.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by the use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

3.5.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6 and the fuel combustion specific QA/QC outlined in section 3.2.6.

The primary sources of activity data for this sector are the Bureau of Resources and Energy Economics (BREE) and the Australian Bureau of Statistics (ABS). These two organisations have systematic quality assurance programmes in place. In addition, there are also a number of critical user organisations and alternative data sources available for this sector.

A mutual review was completed during 2011 between Australia and New Zealand on components of the national inventory. One of these components was Australia's non-CO_2 emissions relating to road transport (Ministry for the Environment, 2011). The final report recommended that Australia proceed with the planned improvements (as outlined in Australia's 2011 inventory submission) and recommended other actions (i.e. incorporating annual data on the urban/non-urban split) some of which were adopted in the 2012 inventory submission.

Comparisons of IEFs and with international data sources are conducted systematically for the Australian inventory. In the 2008 inventory submission it was found that the IEF for CH_4 from the combustion of liquid fuels in Australia (18.1 kg CH_4/TJ) was significantly higher than those of other Annex 1 parties (7.5kg CH_4/TJ). The largest contributor to Australia's high EFs was CH_4 emissions from road vehicles.

In response to a recommendation from an earlier ERT review, a study was commissioned to investigate the appropriateness of the fuel characteristics, including the CO_2 EF, for liquid fuels types used in the inventory. Three studies (Orbital 2010, 2011b and 2011c) have improved the emission estimates for fuel combusted by Australian passenger vehicles and light commercial vehicles (the largest contributors to CH_4 fuel combustion emissions).

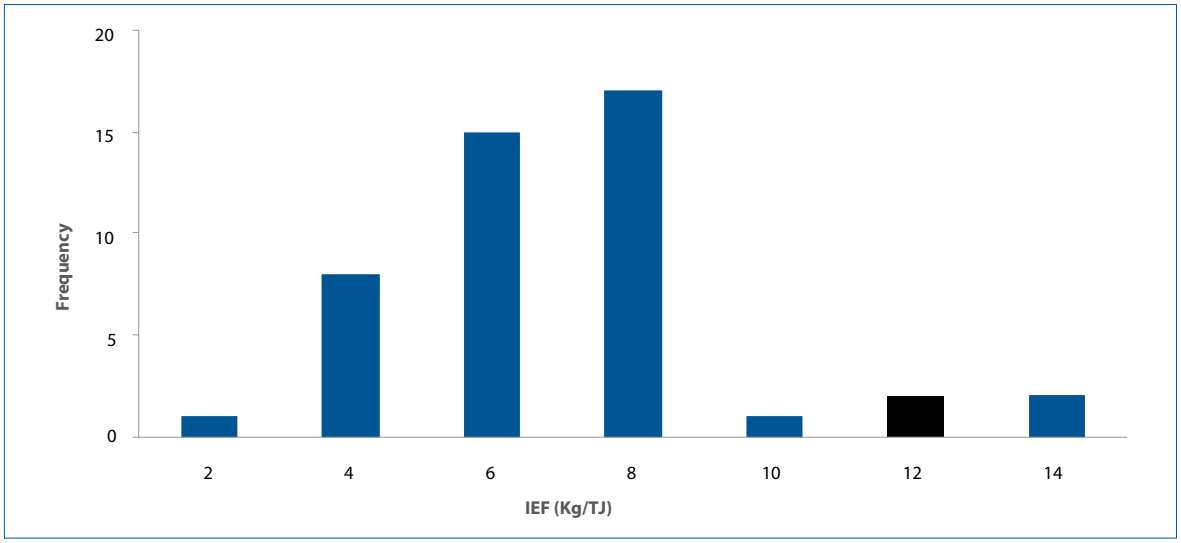
The report compared the energy contents, density, carbon content and EF of the fuel types used to produce the inventory compared to publically available Australian data and other public European and US sources. The report also compared inventory fuel characteristics to an unpublished Australian database accumulated from fuel testing. The report concluded that the CO_2 EFs for petrol, aviation turbine fuel, diesel, fuel oil and LPG are consistent with the Australian published data.

The outcomes of the studies were generally lower CH_4 EFs and deterioration rates then were previously applied. The effect of these updated factors was a reduction in the IEF for CH_4 from the combustion of liquid fuels in Australia, with a 2012 IEF of 11.3 kg CH_4/TJ. This value is still significantly higher than the Annex 1 population (see Figure 3.11).

This outcome is likely due to the high contribution of petrol passenger vehicles to total liquid fuel consumption, slow turnover in motor vehicle stocks and a relatively high EF for Australia for diesel oil.

Further improvements will be implemented for the road transport model as outlined in section 3.5.6.

Figure 3.11: 2011 methane implied emission factor (IEF) from liquid fuel combustion (kg/TJ) for Annex I countries and 2012 IEF for Australia



The Department of Infrastructure and Regional Development (DIRD) has developed a software tool to compute and track the carbon footprint associated with aircraft fuel uplifted in Australia, providing an assessment of the robustness of their results by comparing their calculated values with the APS. Their results showed that computed CO_2 estimates using the software tool and inventory estimates differed by 0.9% in 2010 and 1.1% in 2011 for domestic consumption, and 1.1% for international consumption in 2011. This is concluded to be a good independent verification of the estimates (data for comparison of 2012 results not available at time of publication).

Energy

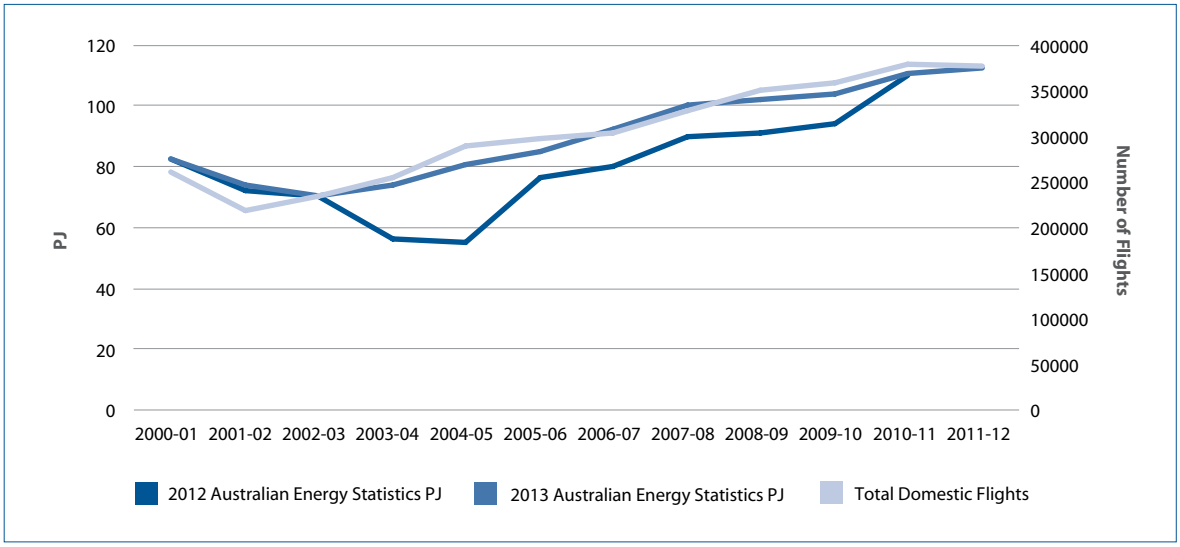
3.5.5 Recalculations Since the 2011 Inventory

Recalculations of CO_2 emissions from the transport sector are a result of revised fuel consumption data published in the *Australian Energy Statistics (BREE 2013a)*.

BREE undertook a review of data sources and methods in the development of the transport fuel combustion estimates published in the 2013 AES (BREE 2013a). BREE updated their data source for the transport sector to utilise transport statistics published by the Bureau of Infrastructure, Transport and Regional Economics (BITRE 2013). BITRE publishes annual transport statistics from the 1970's to the latest inventory year. These recalculations resulted in revised levels of fuel consumption throughout the full time series for most of the transport sector - primarily road transport fuels (petrol, diesel and LPG), and the domestic consumption of aviation turbine fuel.

Australia has undertaken an assessment of the recalculations by identifying key indicators for the affected transport sectors. The revised time series is shown to be an improvement across key transport fuels affected by the recalculation. For example, the chart below shows the relationship between domestic flight numbers and the reported fuel consumption in the current and previous AES. The growth in flight numbers shows much better alignment with the revised level of fuel consumption (BREE 2013a).

Figure 3.12: Domestic Aviation Turbine Fuel Consumption and Number of Domestic Flights



Source: BREE 2013a, BITRE 2013.

A method improvement was made to estimating non-CO_2 emissions from aircraft. The change has allowed more accurate estimation of emissions from larger aircraft operating on aviation turbine fuel by removing the consumption of aviation gasoline by small piston engine aircraft from the model. NonCO_2 emissions from aviation gasoline fuel are now estimated using a tier 1 approach, consistent with IPCC 2006 guidance. NonCO_2 emissions from aviation gasoline fuel are a very small source of emissions (< 2 Gg CO_2-e in 2012).

The effect of the recalculations on 1990 and 2011 is as follows:

- 2013 Submission – 62,031 Gg CO_2-e in 1990, 87,605 Gg CO_2-e in 2011; and
- 2014 Submission – 60,265 CO_2-e in 1990, 88,521 Gg CO_2-e in 2011.

Table 3.23: 1.A.3 Transport: recalculation of total CO_2-e emissions, 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.3.a Civil Aviation (a)				
1990	2923	2614	-309	-10.6%
2000	5010	4934	-76	-1.5%
2001	5470	5480	10	0.2%
2002	4843	4927	84	1.7%
2003	4723	4706	-16	-0.3%
2004	4874	4928	54	1.1%
2005	5067	5358	291	5.7%
2006	5161	5636	474	9.2%
2007	5328	6110	782	14.7%
2008	5953	6583	630	10.6%
2009	6003	6691	688	11.5%
2010	6150	6764	614	10.0%
2011	7252	7264	12	0.2%

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.3.b Road Transportation (b)				
1990	54331	52997	-1334	-2.5%
2000	66134	63824	-2310	-3.5%
2001	64591	63327	-1264	-2.0%
2002	66847	65194	-1652	-2.5%
2003	68384	67017	-1367	-2.0%
2004	71719	69478	-2241	-3.1%
2005	71348	69998	-1350	-1.9%
2006	71740	70418	-1322	-1.8%
2007	72848	71707	-1141	-1.6%
2008	73559	72584	-975	-1.3%
2009	72923	72220	-703	-1.0%
2010	73288	72872	-415	-0.6%
2011	74154	74917	763	1.0%
1.A.3.c Railways (c)				
1990	1739	1737	-1	-0.1%
2000	1566	1566	0	0.0%
2001	1491	1491	0	0.0%
2002	1567	1567	0	0.0%
2003	1639	1639	0	0.0%
2004	1819	1819	0	0.0%
2005	1893	1893	0	0.0%
2006	1901	1901	0	0.0%
2007	1942	1942	0	0.0%
2008	2316	2316	0	0.0%
2009	2386	2386	0	0.0%
2010	2597	2597	0	0.0%
2011	2703	2703	0	0.0%
1.A.3.d Navigation (d)				
1990	2998	2878	-120	-4.0%
2000	2377	2326	-50	-2.1%
2001	2131	2221	90	4.2%
2002	2132	2224	92	4.3%
2003	2132	2233	101	4.7%
2004	2300	2403	103	4.5%
2005	2572	2554	-18	-0.7%
2006	2440	2441	1	0.0%
2007	3236	3219	-17	-0.5%
2008	3264	3265	1	0.0%
2009	3284	3246	-38	-1.2%
2010	3583	3609	26	0.7%
2011	3453	3592	139	4.0%

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.3.e Other Transportation (e)				
1990	40	39	-2	-4.1%
2000	43	41	-2	-4.5%
2001	42	41	-1	-3.1%
2002	43	42	-2	-3.6%
2003	44	43	-1	-2.8%
2004	46	44	-2	-4.6%
2005	45	44	-1	-1.6%
2006	44	44	0	0.1%
2007	45	44	0	-0.5%
2008	44	44	0	0.1%
2009	43	44	1	1.9%
2010	43	44	1	3.4%
2011	42	45	2	4.9%

Recalculation explanation	
(a)	
Inventory model updates	Revision of Tier 2 model for Aviation Turbine fuel.
	Addition of Tier 1 model for Aviation Gasoline fuel.
BREE AES	Recalculation of fuel consumed in the aviation sector throughout the time series.
BITRE LTO data	New LTO data available for 2011. Revised LTO data available for 2009 and 2010
(b)	
BREE AES	Recalculation of ADO, Petrol and LPG consumed in the road transport sector throughout the time series.
(c)	
BREE AES	Recalculation of ADO consumed in the rail transport sector throughout the time series
(d)	
BREE AES	Recalculation of ADO and Black Coal consumed in the domestic marine transport sector throughout the time series.
(e)	Recalculation of Petrol consumed in the transport sector throughout the time series, a portion of which is allocated to Other Transportation.
BREE AES	

3.5.6 Planned Improvements

A number of mobile source categories are allocated to the stationary source in the inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. The department will continue to monitor the NGER data to investigate the magnitude of these emissions and whether the reliability, completeness and accuracy of the data are adequate to inform a reallocation of these emissions from the stationary sectors to the transport sector.

The Orbital Australia reports (Orbital Australia 2010 and Orbital Australia 2011b) provided detailed vehicle testing data that is at a greater level of disaggregation than is currently supported in the national inventory model. The model was expanded in the current submission however future improvements remain possible. The department plans to investigate and apply updates, as appropriate, to the issues listed below in future inventory submissions:

- Within the passenger vehicle group, EFs for large SUVs (sport utility vehicles) can vary significantly between specific vehicle make/models depending on the original ADR to which they are certified. These factors are also significantly different to the other vehicle sub-types in the passenger vehicle group. Separate EFs and DRs for SUV-Large are available. The department will investigate whether all the activity data is available to support further disaggregation of vehicle classifications in the next annual inventory submission; and
- Passenger vehicle and light commercial vehicle EFs from the NISE 2 dataset are available for an additional drive cycle (hot extra urban). The department will investigate whether the required data is available to support the further disaggregation of drive cycles in the next inventory submission.

The department will investigate EFs for new petrol passenger vehicles to take account of the latest exhaust emission standards adopted in Australia.

Australia's IEF for CH_4 from liquid fuels (Fuel Combustion sectoral approach) is an outlier, and Australia will continue to investigate revised EFs for non-CO_2 gases from liquid fuels. For example, Australia will investigate revised EFs for new heavy duty diesel vehicles to take account of the latest exhaust emission standards adopted in Australia

3.6 Source Category 1.A.4 – Other Sectors

3.6.1 Source Category Description

Source category *1.A.4 other sectors* is an aggregation of the following sources:

- Commercial/Institutional—a diverse category which includes direct emissions from water utilities, accommodation, communications, finance, insurance, property and business services;
- government and defence, education, health and wholesale and retail trade;
- Residential—emissions from fuel combustion in households, including lawnmowers; and
- Agriculture, forestry and fisheries—emissions from fixed and mobile equipment.

BREE report energy consumption for economic sectors is defined using the Australia New Zealand Standard Industrial Classification (ANZSIC). The mapping of ANZSIC codes against IPCC classifications is complete and given in Table 3.24.

Only the petroleum from ANZSIC sub-division 50-53 Other transport, services and storage is included in this category. The natural gas consumption is accounted for within the Other Transport (Natural Gas Transmission) sub-category. Similarly, only the natural gas consumption from sub-category 47 Railway Transport is included in this category. Any other fuel consumption within sub-category 47 is assumed to be accounted for within sector 1.A.3.

3.6.2 Methodology

The methodology for this sector consists of tier 2 approaches and country specific CO_2 EFs. Non-CO_2 EFs have been calculated using a sectoral equipment-weighted average approach.

CO_2 emission and oxidation factors are reported in Tables 3.2 and 3.3. Activity data are taken from the AES published by BREE (2013a). Non-CO_2 EFs for this sector, by ANZSIC Division, are reported in appendix Table 3.A.3.

Table 3.24: Relationship between IPCC source categories and ANZSIC sectors: Other Sectors

IPCC Source Category	ANZSIC Category			
	Division	Sub-division	Group/ Class	Description
4. Other Sectors				
A Commercial, Institutional	Division D	281		Water supply, sewerage and drainage services
	Division F			Wholesale trade
	Division G			Retail trade
	Division H, P, Q	57		Accommodation, cultural and personal
	Division I Transport, Postal and Warehousing	50-53		Other transport, services and storage
	Division J			Communication
	Division K, L			Finance, insurance, Property and business
	Division M			Government administration and defence
	Division N, O	84		Education, Health and community services
B Residential	Residential			Residential
C Agriculture, forestry, and fishing	Division A			Agriculture, Forestry and Fishing

Table 3.25: Summary of methods and emission factors: 1.A.4 Other Sectors

Source Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A4a Commercial/Institutional	T2	CS	T2	CS	T2	CS
1A4b Residential	T2	CS	T2	CS	T2	CS
1A4c Agriculture, Forestry and Fisheries	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific.

Residential - Biomass Combustion (1.A.4)

The *Residential* sector also includes specific treatment of the use of firewood and also in the combustion of fuels in mobile equipment such as lawnmowers.

This category is characterised by the use of wood in residential wood heaters. Emissions are modelled using an advanced tier 2 approach which takes into account factors such as wood heater technology and replacement of older models, user operation and Australian wood.

The estimation of emissions from residential firewood use requires a more complex approach to the estimation of emissions from fossil fuels reflecting information on heater design (technology type) and the operation of wood-burning appliances, which influences the mix of emissions per kilogram of firewood consumed.

The proportion of Australian households choosing firewood as their main heating fuel peaked in the early 1990s and has decreased slowly since then. New appliances, with lower emissions of some greenhouse gas species, came on the market in the early 1990s and they have gradually been replacing older, non-certified heater models. Poor user behaviour, which significantly increases emissions of pollutants, has been the target of education campaigns and, in the past few years, programs have been aimed specifically at households with excessive visible smoke. This has led to improved appliance use.

The residential wood heater methodology has been developed for Australian conditions (Todd 2003, 2005 and 2011). This methodology was recently updated (Todd 2011) to account for the latest information and trends. The model was validated against recent field studies of emissions from wood heaters used in Australian household and resulted in a minor increase to the CH_4 EF over the complete time series along with a small decrease in the CO_2 EF. The methodology incorporates factors such as appliance type and certification, wood type and moisture content and user behaviour. The composition of gaseous and particulate emissions when burning eucalypt firewood in typical Australian appliances is based on Gras (2002). A schematic diagram showing the methodology process is shown in Figure 3.23, and is also summarised in the algorithm below:

$$E_{k,n} = F_n \times S \times W \times fn_k\{\Sigma\ PEF_n\} \quad \text{..... 3.10}$$

Where: $E_{k,n}$ = emission of greenhouse gas k in year n

F_n = amount of fuel combusted (i.e. firewood use) in year n

S = softwood use correction factor

W = wet wood correction factor

fn_k = formula linking the greenhouse gas EF for gas k to the particulate EF.

PEF_n = weighted particulate EF for year n, which is summed over the mix of appliances and operator behaviour for that year, with l = 1 to 8

l(1) certified wood heater correctly operated

l(2) certified wood heater carelessly operated

l(3) certified wood heater very badly operated

l(4) non-certified wood heater correctly operated

l(5) non-certified wood heater carelessly operated

l(6) non-certified wood heater very badly operated

l(7) masonry open fireplace

l(8) factory built (metal) open fireplace

Description of factors

Certified and non-certified heater

- Emission factors

A base CH_4 EF for certified wood heaters of 261.3 Mg/PJ has been developed by Todd (2005). It has been derived from a large database on particulate emissions from heaters meeting the requirements of Australian Standard AS4013. Over 250 different heater models have been tested at the two NATA certified (National Association of Testing Authorities) laboratories in Australia, producing a database of over 2250 individual emission tests (heaters must have three repeat tests at each of high, medium and low burn rates).

A base CH_4 EF of 462.5 Mg/PJ has been applied to non-certified heaters, through the application of a factor of 1.77 to the certified wood heater EF. Todd (2005) based this approach on comparisons between US emission tests of non-certified heaters (referred to as 'Pre-Phase I Non-Catalytic Heaters' in US literature) and certified heaters

(referred to as Phase II Non-Catalytic Heaters) (USEPA 1996). The Australian emission test for wood heaters has differences to the US test (both in test fuel, and testing procedure); however, the Australian Standard was cross-checked with two models of heater that had passed both the US (Phase II) and found to be generally similar. Thus the US ratio has been applied to Australian heaters.

- Mix of certified and non-certified heaters and open fireplaces

A survey of households in 2000, carried out as part of a CSIRO study (Gras, 2002), found that 40% of heaters were less than 6 years old (i.e. installed in 1994 or later). Taking into account the number of open fireplaces also in use (derived by Todd 2005 from a 1999 ABS survey), certified wood heaters accounted for 30.6% of all wood-burning appliances in 2000. The population of certified wood heaters has been decreased linearly to 1994, where it is zero (Todd 2005). Todd (2011) extended the time series to 2010 based on data recent wood heater sales numbers from the home heating association.

Operator behaviour

- Emission factors

Three operator classifications have been adopted for these calculations.

a) 'Good' operation means a certified heater will perform as it did in the laboratory test.

b) 'Careless' operation (or poor operation) refers to operators who pay some attention to heater performance, but are not well enough informed. A survey in Tasmania (Todd 2001) suggested at least half the heater owners fall into this category. Careless operation has been assigned EFs 2 times greater than for good operators, applying to both certified and non-certified heaters (expert judgement by Todd 2005).

c) 'Very poor' operation refers to heater operators that regularly run the heater with a slow, smouldering fire. Todd (2001) indicates 10% of households with wood heaters are in this category. The increase in emissions compared to a well-operated heater has been set at a factor of 5 based on a small number of laboratory tests (Todd 2005).

Proportion of well/poorly operated wood heaters

The proportion of good, careless and very poor wood heater operators for 2000 was set by Todd (2005) and modified by Todd (2011) at 0.5, 0.4 and 0.1 respectively. This is based on surveys in 1999 and 1997 that showed most households thought they operated their heaters correctly, but more detailed questioning showed that few did everything correctly. National TV campaigns (in 1997 'Breathe the Benefits') and a wide range of other education campaigns at state level suggest user behaviour has improved over time, therefore Todd (2005) has used 0.7 (i.e. 70%) for 1990 as the proportion of heaters used carelessly. The trend in the proportion of households achieving improved wood heater operation evident up to 2000 has slowed based on a recent national survey of wood heater use. From 2001 to 2011 a reduced rate of improved operation has been used.

The very poor operation grouping represents those heaters that regularly emit copious quantities of visible smoke. A 1999 Hobart survey, and feedback from local government officers involved in wood-smoke reduction programs in all states, suggests that about 10% of chimneys/flues smoke excessively. Todd (2005) has allowed for a continuous improvement over the time series, setting 1990 at 0.2, i.e. (20%) of heaters smoked excessively.

The 2007 national survey of wood heater operation and firewood parameters (Todd 2008) identified common operating behaviour that will increase particulate emissions above that found in certification testing. Specifically, 25% of households blocked incoming combustion air by placing logs parallel to the fuel loading door, 17.5% failed to establish a hot fire after refuelling before decreasing the combustion air, and 22.5% used convections fans in ways likely to cause excessive cooling of the firebox. On the positive side 25% of households always established a hot fire before reducing combustion air and 45% of households did not attempt to burn their heaters overnight. The survey supported the earlier estimate that about 10% of households commonly operate their heaters in a

manner likely to produce excessive smoke. The survey also suggested at least half the households operated their heaters in a manner that would produce similar emissions to the certified test methods.

Open fireplaces

- Emission factors

No emission testing of masonry open fireplaces has been carried out in Australia. The US (USEPA 1996) value for the particulate EF for masonry open fireplaces (17.3g/kg) has been used by Todd (2005) to derive a base CH_4 EF of 1365.8 Mg/PJ. Even though the wood species used in Australia are different from the US, this is unlikely to have a significant effect on EFs. The CSIRO tests provide particulate EF of 2.3g/kg for factory-built open fireplace (sometimes referred to as heat-recovery fireplaces). This is used by Todd (2005) to derive a base CH_4 EF of 181.6 Mg/PJ. It is assumed that the operator of an open fireplace has little impact on the emissions (on average) and so no correction factors for careless or very poor operation have been used (Todd 2005).

- Proportion of open fireplaces

The proportion of open fireplaces in use is based on the same CSIRO survey and ABS surveys in 1999 and 2001 (Todd 2011).

Softwood fuel and wet wood

- Emission factors

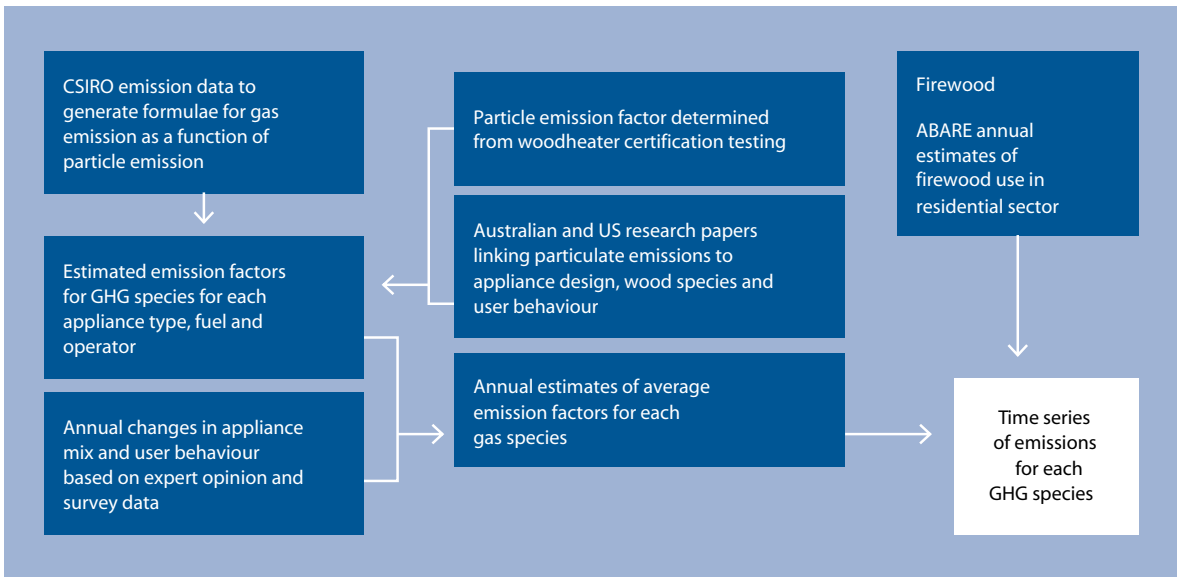
The use of wet firewood is often cited as one of the main reasons for high emissions from wood heaters. However, the CSIRO study, and other Australian studies (e.g. Todd *et al.* 1989a) have consistently shown that only very wet wood (i.e. unseasoned) influences emissions. High burn-rate tests carried out by the CSIRO have shown that very wet wood (moisture greater than 30%) leads to an increase in emissions by a factor of 3.5 (Todd 2005).

The use of softwood fuel in the CSIRO testing led to a large increase in emissions (by a factor of about 3.5). However, other comparative tests of hardwood and softwood emissions (Todd 1991) have shown smaller increases. Therefore, Todd (2005) has adopted a factor of 2.

- Proportion of wet wood and softwood

The 6.25% proportion of households using very wet wood (>30% moisture, wet weight basis) is based on a recent national survey of firewood moisture (Todd 2011). The proportion of softwood used as firewood is based on several surveys (Todd *et al.* 1989b, Driscoll *et al.* 2000, Gras 2002) that consistently show around 5% of firewood consumed is softwood.

Figure 3.13: Schematic diagram of the methodology process for estimation of emissions from wood heaters



The resulting emissions factor trends are shown below in Table 326. With Australian standards for wood heater emissions introduced in 1992, there has been an increasing uptake of certified heaters at the expense of older, non-compliant heaters, as well as open fireplaces. Together with improving user operation, these factors work to produce an overall trend for the more complete and efficient combustion of fuelwood. This is borne out in the increasing CO_2 EF (i.e. more carbon is oxidised under improved combustion conditions) and decreasing CH_4 EF. As a result, the implied CH_4 EF varies between 1297 Mg/PJ in 1990 and 713 Mg/PJ in 2012. This range is consistent with the 2006 IPCC defaults for residential CH_4 EFs for woodstoves (IPCC 2006, Vol. 2, Table 2.9), taking in account the inherent uncertainty of residential combustion CH_4 EFs of 50 to 150% (IPCC 2006, Vol. 2, Table 2.12).

Table 3.26: Residential biomass emission factors

Inventory Year	Greenhouse Gas Emission Factor (Mg/PJ)						
	CO_2	CH_4	N_2O	CO	NO_x	NMVOC	SO_2
1990	66.7	1,297.0	2.5	13,195.8	14.3	1,642.9	1.1
2000	75.1	844.2	2.0	9,874.9	20.3	1,069.3	1.1
2001	75.3	834.9	2.0	9,806.7	20.4	1,057.5	1.1
2002	75.4	826.0	2.0	9,741.3	20.6	1,046.2	1.1
2003	75.7	814.1	2.0	9,654.3	20.7	1,031.2	1.1
2004	75.8	804.2	2.0	9,581.6	20.9	1,018.6	1.1
2005	76.1	791.3	1.9	9,487.4	21.0	1,002.4	1.1
2006	76.3	778.4	1.9	9,392.5	21.2	986.0	1.1
2007	76.6	765.4	1.9	9,297.2	21.4	969.5	1.1
2008	76.8	752.3	1.9	9,201.2	21.5	952.9	1.1
2009	77.0	739.2	1.9	9,104.8	21.7	936.3	1.1
2010	77.3	725.9	1.9	9,007.8	21.9	919.5	1.1
2011	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2012	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1

Emissions from lawnmowers are estimated using tier 2 methods described by equation (3.1). CO_2 EFs are reported in Table 3.2 and non-CO_2 EFs are reported in Table 3.24. There are no fuel consumption statistics for these activities, instead allocation factors are used to derive this data from known consumption statistics. Lawn mowers are powered by small 2-stroke or 4-stroke engines and assumed to be utilised in the ratio of 60:40 (EPA NSW, 1995).

For the *1.A.4.c agriculture, forestry and fisheries* category, BREE statistics present a single total figure for diesel fuel consumed in agriculture, fisheries and forestry. However, the types of equipment used by these industries vary quite widely (tractors, log skidders, fishing boats etc.), and therefore EFs for non-CO_2 gases also vary widely. It is assumed that the agriculture, fisheries and forestry industries account respectively for 77%, 6% and 17% of total diesel fuel consumption by the sector as a whole. This estimate is based on the relative volumes of diesel fuel for which excise rebates were claimed, as advised by the Australian Customs Service, over the period 1988 to 1994 inclusive, and have been held constant throughout the period.

These ratios were applied to EFs for the different types of diesel engines used in the types of equipment typical of the three sectors, to estimate weighted sectoral EFs (Table 327).

Table 3.27: Non-CO_2 emission factors for non-road mobile sources

	CH_4	N_2O	NO_x	CO	NMVOC
			(g/MJ)		
Other Mobile Sources					
Recreational Vehicles					
Petrol	0.03	0.0009	0.37	7	1.08
Industrial Equipment					
ADO	0.0057	0.002	1.006	0.39	0.108
LPG	0.022	0.001	0.437	5.465	0.409
Farm Equipment					
ADO	0.01	0.002	1.36	0.541	0.189
Tractors	0.0096	0.002	1.362	0.543	0.183
Non-Tractors	0.011	0.002	1.351	0.531	0.21
Utility Engines					
Petrol	0.38	0.0009	0.087	13	3.45

Sources: IPCC (1997), USEPA (1995a), F. Carnovale pers. comm., 1995.

3.6.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

A revision of the AES was undertaken by BREE AES (2013a) in response to improved activity data available under the NGER. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2011. A consequence of this is a step change exists in some time series for individual fuel types within certain source categories in 2002-2003. See the Recalculations section below in 3.6.5 for a description of these changes and how they affect time series consistency in particular source categories. Note that under 3.6.6 Planned Improvements, any time series inconsistencies are planned to be fixed in future releases of the AES and will be subsequently reflected in the national inventory.

The time series variability of GHG IEFs are likely to be influenced by changes in fuel mix within categories.

3.6.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6.

3.6.5 Recalculations Since the 2011 Inventory

Recalculations to 1.A.4 other are detailed at the sub-category level in Table 3.28. Recalculations were made in response to revisions to AES. These revisions were in response to inclusion of improved activity data available under the NGER. Furthermore, the Mobile component of 1.A.4.b Residential, which comprises lawnmowers, was recalculated for all years in response to revisions in the AES to the consumption of gasoline in Road transport.

Table 3.28: 1.A.4 Other sectors: recalculation of total CO_2-e emissions, 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.4.a Commercial/institutional				
1990	3,564	3,564	0	0.0%
2000	4,490	4,490	0	0.0%
2001	4,210	4,210	0	0.0%
2002	4,348	4,348	0	0.0%
2003	4,286	4,286	0	0.0%
2004	4,315	4,315	0	0.0%
2005	4,380	4,380	0	0.0%
2006	4,591	4,591	0	0.0%
2007	4,619	4,619	0	0.0%
2008	4,666	4,666	0	0.0%
2009	4,538	4,448	-90	-2.0%
2010	4,611	4,519	-92	-2.0%
2011	4,614	4,582	-32	-0.7%
1.A.4.b Residential				
1990	8,102	8,091	-11	-0.1%
2000	8,882	8,868	-13	-0.2%
2001	8,979	8,970	-9	-0.1%
2002	8,883	8,872	-11	-0.1%
2003	8,957	8,941	-16	-0.2%
2004	8,740	8,726	-15	-0.2%
2005	8,680	8,675	-5	-0.1%
2006	8,795	8,796	0	0.0%
2007	9,066	9,065	-1	0.0%
2008	9,065	9,065	0	0.0%
2009	9,220	9,225	6	0.1%
2010	9,337	9,347	10	0.1%
2011	9,553	9,568	14	0.1%
1.A.4.c Agriculture/fisheries/forestry				
1990	3,390	3,390	0	0.0%
2000	4,386	4,386	0	0.0%

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
2001	5,381	5,381	0	0.0%
2002	5,463	5,463	0	0.0%
2003	6,083	6,083	0	0.0%
2004	6,089	6,089	0	0.0%
2005	6,429	6,429	0	0.0%
2006	5,968	5,968	0	0.0%
2007	5,877	5,877	0	0.0%
2008	5,939	5,939	0	0.0%
2009	5,917	5,917	0	0.0%
2010	6,062	6,062	0	0.0%
2011	6,284	6,089	-195	-3.1%
Recalculation explanation				

3.6.6 Planned Improvements

In the 2012 AES (BREE 2013a), BREE has further incorporated improved activity data available under the NGER into the time series. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period 2003 to 2011. An undesirable outcome of this improved data is that a step change exists in some time series for individual fuel types within certain source categories. BREE are exploring the possibility of extending the revision through to the earlier part of the time series in future AES releases and these revisions will be incorporated into future recalculations of the national inventory when available.

3.7 Source Category 1.A.5 – Other (Not Elsewhere Classified)

Emissions from 1.A.5 *other* are estimated using a mix of tier 1 and tier 2 approaches using EFs set out in Tables 3.2 and 3.3.

Table 3.29: Summary of methods and emission factors: Other (Not Elsewhere Classified)

Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A5 Other	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, CS= Country-specific.

3.7.1 Source Category Description

The source category *1.A.5 other* consists of emissions arising from the oxidation of lubricants, as well as fuel used in mobile equipment within defence operations.

3.7.2 Methodology

This sector includes emissions of CO_2 arising from the oxidation of lubricants. Lubricants, together with bitumen and solvents, are non-fuel products of crude oil, which are included in the energy statistics compiled by BREE. It is assumed that 60% of lubricants are not oxidised during engine operation, i.e. not actually combusted (Australian Institute of Petroleum, pers. comm. 1996). Therefore the stated BREE consumption of lubricants and greases is reduced by 60% before emissions are estimated. Emissions of gases other than CO_2 are included with the emissions arising from fuel combustion in the engine type concerned in the relevant sector. Some lubricants may be incinerated subsequent to use. Any emissions from this source are included in the Waste sector.

Emissions from military vehicles are estimated using tier 1 methods described by equation 3.3 and 3.4. CO_2 EFs are reported in Table 3.2 and non- CO_2 EFs are reported in appendix Table 3.A.12.

The allocations of fuel to military transport are estimated for 2011 and 2012 from direct reporting of fuel consumption by the Department of Defence. This new data has facilitated an update of the proportions of each fuel allocated to sector 1.A.5. Allocations were made in 2008, 2009 and 2010 were based on data soured directly from the Department of Defence (2010–12), and allocations for 2011 and 2012 based on DCCEE 2011 and DRET 2012 (see Section 3.5.2). Allocations were updated for 1995-2007 by linearly extrapolating the proportions between the data points in1994 and 2008. The shares used to allocate fuel consumption are reported in Table 3.A.13.

It is assumed that solvents are either emitted as NMVOC, in which case they are reported in the *solvents* sector, or as CO_2, following incineration, in which case they are reported in the *waste* sector. It is assumed that all fossil carbon in bitumen is sequestered.

3.7.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

3.7.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6.

3.7.5 Recalculations Since the 2011 Inventory

Recalculations made to *1.A.5 other* are detailed at the sub-category level in Table 3.30.

Table 3.30: 1.A.5 Other: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.A.5.a Stationary - lubricants				
1990	561	561	0	0.0%
2000	569	569	0	0.0%
2001	589	589	0	0.0%
2002	600	600	0	0.0%
2003	617	617	0	0.0%
2004	670	670	0	0.0%
2005	709	709	0	0.0%
2006	488	488	0	0.0%
2007	455	455	0	0.0%
2008	472	472	0	0.0%
2009	480	480	0	0.0%
2010	522	522	0	0.0%
2011	655	655	0	0.0%
1.A.5.b Mobile – Military transport (a)				
1990	504	500	-5	-0.9%
2000	636	629	-7	-1.1%
2001	631	633	2	0.4%
2002	577	585	9	1.5%
2003	555	556	0	0.0%
2004	570	578	7	1.3%
2005	589	618	28	4.8%
2006	602	649	47	7.8%
2007	938	1,007	69	7.4%
2008	979	1,034	55	5.7%
2009	942	1,006	64	6.8%
2010	984	1,042	58	5.9%
2011	946	946	1	0.1%
Recalculation explanation				
(a)	There were minor increases in emissions from military transport for 2007-2010 due to minor recalculations in liquid fuel consumption reported by BREE in the *Australian Energy Statistics* (BREE 2013a).			

3.7.6 Planned Improvements

All relevant data are kept under constant review.

3.8 Source Category 1.B.1 – Solid Fuels

3.8.1 Source Category Description

This source category covers fugitive emissions from the production, transport and handling of coal, and emissions from decommissioned mines. It does not include emissions arising from the conversion of coal into coke. Coverage of emissions for 1.B.1 Solid Fuel emission categories, by gas, are shown in Table 3.31. CH_4 and CO_2 emissions are reported for both underground and surface coal mines. Estimates for CO_2 emissions from decommissioned mines are not currently available, but will be considered for reporting in the inventory if data becomes available under NGER. CO_2, CH_4 and N_2O emissions are also reported from flaring.

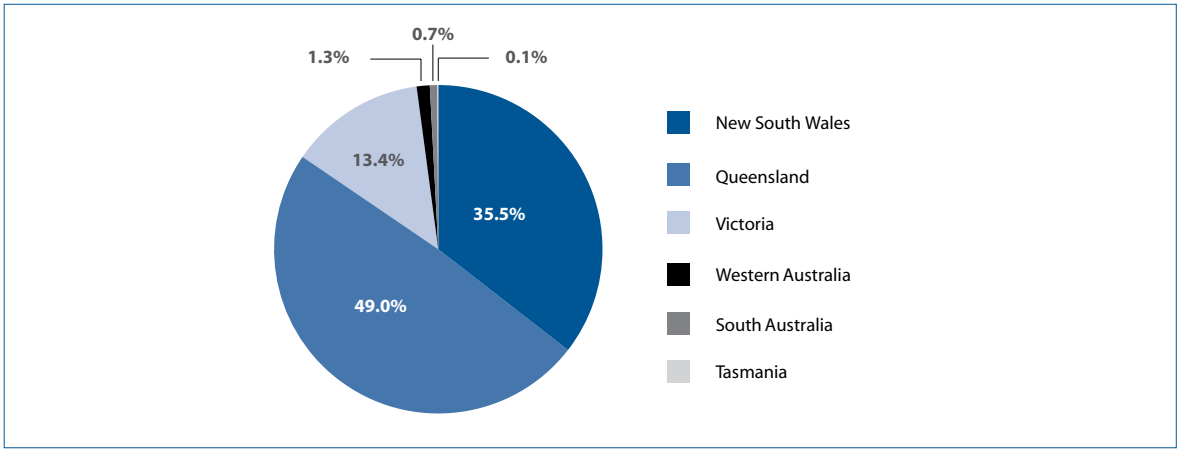
In 2012, there were 48 underground mines and 89 open cut mines operating nationally, while emissions are estimated for 108 decommissioned mines.

Table 3.31: 1.B.1 Solid Fuels – Emissions source coverage

IPCC Category	CO_2 emissions	CH_4 emissions	N_2O Emissions
1.B.1.a.i Underground mines			
Mining	YES	YES	
Post-mining		YES	
1.B.1.a.ii Surface mines			
Mining	YES	YES	
Post-mining		IE (surface mining)	
1.B.1.b Solid fuel transformation		**IE (IP – metals)**	
1.B.1.c Other			
Decommissioned mines		YES	
Flaring	YES	YES	YES

The great majority of Australia's resources and production of black coal are located on the east coast of Australia in New South Wales and Queensland. A very small quantity of black coal is also mined in Tasmania. In Victoria, large quantities of brown coal are mined in open cut operations. A relatively small quantity of sub-bituminous coal is mined in Western Australia, and a minor quantity of low rank sub-bituminous coal is mined in South Australia. The share of coal production from Australian states for 2012 is shown in Figure 3.14.

Figure 3.14: Share of coal production from Australian states - 2012



Energy

In New South Wales, the principal coal fields are the Southern, Newcastle, Hunter and the Western New South Wales. In Queensland, the main coal fields are the Northern Bowen Basin, the Central Bowen Basin and the Southern Basin. Since 1990 there has been strong growth in production from the Hunter and Bowen Basins and declines from the Southern and Newcastle Basins (see Figure 3.16).

There can be wide variations in both the gas content and the composition of the gas across Australian coal basins, and across coal fields within the basins. The variability and characteristics of coal gas in eastern Australia have been described by Thomson (2010) as a response to a number of distinct geological and biogenic processes, namely:

- the coalification processes;
- tectonic history;
- magmatic activity;
- groundwater flow; and
- biogenesis.

The methane in coal layers has its origins largely in the coalification process that arises from pressure and heat associated with the deep burial of biomass within sedimentary basin deposits. The burial of biomass reached a peak depth during the mid-cretaceous period when it was estimated to be around 2.5 to 4 km deep, resulting in coal layers reaching saturation with thermogenic CH_4. As gas is generated during the coalification process, coal is able to store the gas within its micropore structure. The upper limit of gas able to be held within coal follows an adsorption isotherm, which describes the pressure/temperature relationship at the point where the coal is fully saturated with gas. The isotherm is useful for representing a theoretical cap on the gas content of coal at any given depth. In the Permian coal basins of Australia's east coast, coal layers greater than 500-600m in depth will tend to be close to saturation with thermogenic methane (Thomson 2010).

It is rare, however, for coals saturated with methane to be mined. This is because uplifting and rifting of the strata in geological periods following the coalification process provided opportunities for gas to escape through fracture systems, resulting in the upper coal layers becoming under-saturated with methane. For Australia, this started from the late Cretaceous period with New Zealand rifting away from the Australian east coast, with the associated uplifting and subsequent erosion of the coal bearing regions.

The under-saturated coal layers were then receptive to new sources of gas. Extensive magmatism activity in the Tertiary period introduced CO_2 into the upper, under-saturated coal layers. In more recent times, methanogen bearing groundwater flows through the surface fracture system have introduced biogenic methane into the upper coal layers (Thomson 2010).

A generalised model to describe the variation of gas in coal along the east coast coal bearing regions as a result of these processes has been described (Thomson 2010), and is shown in Figure 3.15. Localised geological features can also have a large influence on subsurface gas characteristics at a mine level scale. For example, faults and dykes can provide opportunities for gas to escape or be trapped and influence groundwater flows for biogenesis. In summary, the coal gas type and distribution characteristics of the eastern coalfields can be viewed as a result of the history of large scale processes overlaying localised geological features. Most near surface coal deposits on the east coast are under-saturated, as a function of their geological history. The surface zone is characterised by a very low gas content, predominantly in the form of CO_2.

Coal mining on the west coast of Australia is confined within a small coal field within the Collie basin. The Collie basin coal deposits were formed by the transport of material rather than the bed forming *in situ*. The coal beds are also commonly associated with a sandstone roof providing opportunities for gas to escape over time. The understanding of the geological characteristics, current and historical mining practices, and anecdotal evidence suggested the basin is characterised by low gas content. Mine specific emission data based on measurement is now available through NGER reporting, and is incorporated in this inventory. The data confirms that the Collie Basin coal deposits are characterised by very low gas.

Figure 3.15: Generalised model of gas variation in the subsurface for east coast Australia

Zone 1	Surface zone to ~ 100m of very low gas – CO_2 dominant
Zone 2	Biogenic zone, 100 to 250/300m Methane increasing with depth
Zone 3	Mixed gas zone. Biogenic and thermogenic undersaturated CH_4 Magmatic CO_2 present
Zone 4	Thermogenic methane, increasing to saturation with depth

Source: Thomson (2010)

3.8.2 Methodology

Fugitive emissions from coal mining activities are estimated using a mix of tier 3 and tier 2 methods. Estimates for underground mines are prepared using a tier 3 method. Data on measured CH_4 emissions for individual mines are obtained from coal mining companies reporting under NGER. For the 2012 year, data on measured CH_4 and CO_2 emissions is available for all 48 underground mines. Time series consistency has been maintained for the underground mine emissions estimates with the use of NGER data (see section 3.8.3).

Fugitive emissions from surface mining are estimated using state-specific default CH_4 emission factors, as well as incorporating facility-specific NGER data for CH_4 and CO_2 emissions, where available and appropriate.

For decommissioned mines, a country-specific tier 2 approach is used with EFs (m^3 CH_4/tonne coal produced) derived from measurement data obtained for mines with similar characteristics. Flaring uses a Tier 2 approach and a country-specific CO_2 EF.

Table 3.32: Summary of methods and emission factors: 1.B.1 Solid Fuels

Source category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Underground mining	T3	PS	T3	PS	NA	NA
Surface mining	T3	PS	T2, T3	CS, PS	NA	NA
Post mining	NA	NA	T2	CS	NA	NA
Decommissioned mines	NA	NA	T2/T3	CS	NA	NA
Flaring	T2	CS	T2	CS	T2	CS

Notes: T2 = tier 2, T3 = tier 3, CS = Country-specific, PS = Plant-specific.

Activity data

Data on coal production provides activity data for the sector and are used as drivers for the estimation of emissions from mines in years where directly measured emissions data is not available. The production data for each mine are published annually in the statistical publications of:

- New South Wales - Coal Services Pty Ltd (2013) (formerly the Joint Coal Board)
- Queensland - Department of Natural Resources and Mines (DNRM 2013)
- Western Australia - Department of Mines and Petroleum (DMP 2013)
- Tasmania - Mineral Resources Tasmania (MRT 2012)

- South Australia - Mineral Resources Division (DMITRE 2013)
- Victoria - Department of Primary Industries (DSDBI 2013)

Underground Mining (1.B.1ai)

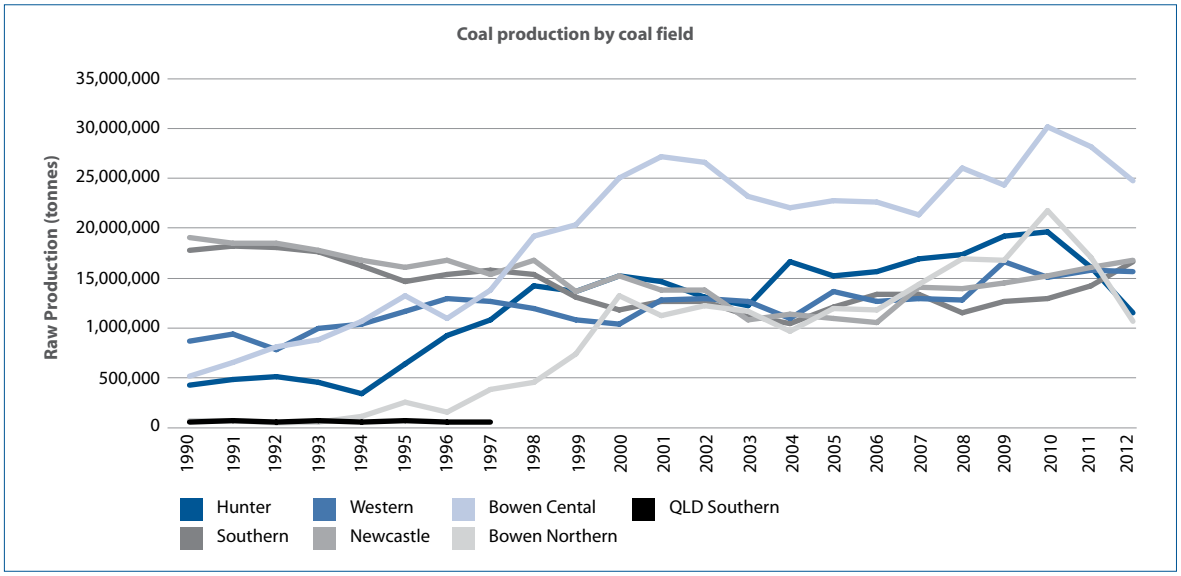
Mining activities

Emissions derived from direct measurement account for the majority of emissions from underground mines reported in the inventory. Emissions are estimated using methods set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (the Determination) and are based on the measurement of gas concentration and flow within mine ventilation systems. In addition, mines are subject to state government legislation, including the *Coal Mine Health and Safety Act 2002 (NSW),Coal Mine Health and Safety Regulation 2006 (NSW), Coal Mining Safety and Health Act 1999 (Qld)* and the *Coal Mining Safety and Health Regulation 2001 (Qld),* which establish mandatory monitoring and reporting regulations for mines. The Determination builds on these existing state regulatory processes.

Coal companies reporting measured CH_4 from underground mines under NGER are also required to measure and report CO_2 emissions. This is significant as, prior to NGER reporting, there was little data available on fugitive CO_2 emissions from Australian coal mining.

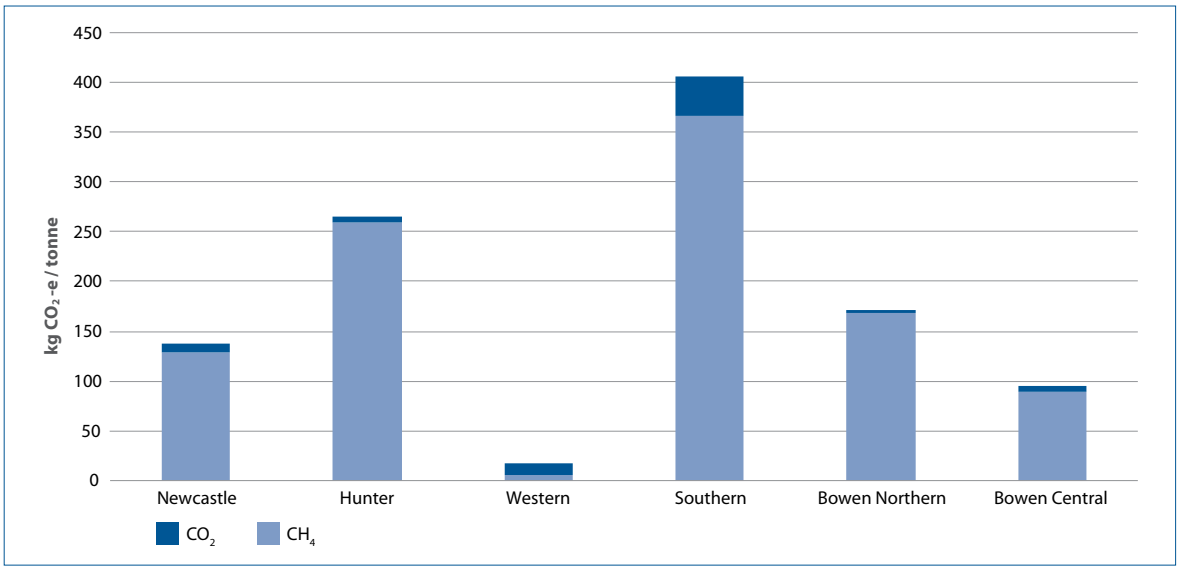
The NGER emission data for underground mine emissions has shown that the gas type and content of different coal fields varies significantly. This is evident in Figure 3.17, which details the average gas content profile of underground production by coal field. The gassiest coal field is the Southern New South Wales, while the least gassy field is the Western New South Wales (which is mainly CO_2).

Figure 3.16: Underground black coal production by coal field



Source: Queensland Department of Natural Resources and Mines (DNRM 2013), Coal Services Pty Ltd (2013).

Figure 3.17: The gas content profile of Australian underground production by coal field



Source: NGER data.

Choice of emission factor

Estimates based on direct measurements were reported for all underground mines under NGER in 2012. Emissions for underground coal mines, which were closed prior to the introduction of NGER, and for which tier 3 data were not available, have been estimated by applying an average IEF for their respective coal fields. This is consistent with the decision tree for use of facility-specific EFs, as set out in section 1.4. In applying the decision tree, it was decided that the NGER data demonstrated that facility-specific EFs, aggregated into subgroups based on spatial correlation (i.e. by coal field), were sufficiently different from the national country-specific EFs and drew on the general understanding that mines within coal fields shared common characteristics due to their shared geological history and structure. Detailed discussion as to how time series consistency has been maintained with the inclusion of NGER data for underground mines is given in section 3.8.3.

Post Mining Activities

Emissions from post mining activities reflect the fugitive escape of gases from the coal after mining, i.e. during preparation, transportation, storage or crushing, and are based on the measurements of Williams *et al.* (1993) and Williams *et al.* (1996). In these studies, the amount of gas retained in coal from gassy underground mines in New South Wales and Queensland, once the coal reached the surface, was analysed. Most of this gas is likely to desorb from the coal before combustion (i.e. during preparation, transportation, storage or crushing) and can therefore be classified as fugitive emissions from post mining activities. These studies related emissions E_{pm} to the quantity of black coal from underground Class A (gassy) mines QTY_a an emission factor EF_{pm} and C_{pm} the volume-to-mass conversion factor for post mine emissions, which equals 0.6767 kg/m^3:

$$E_{pm} = QTY_a \cdot EF_{pm} \cdot C_{pm} \quad \text{(1B1_5)}$$

The emission factor, E_{pm}, is the average of the results of the two empirical studies. It was found that the amount of gas retained was quite variable, but adopted an average gas EF of 1.7 m^3/t raw coal, of which 75% was CH_4 and 25% CO_2 (Williams *et al.* 1993). An estimated factor, equal to 20% of the *in situ* CH_4 content of coal (6.78m^3/tonne in this case), is applied (Williams *et al.* 1996). It is assumed that post mining emissions are associated only with black coal mined in underground gassy mines, and not with black coal mined in underground Class B (non-gassy) mines.

Surface Mining (1.B.1aii)

A mix of tier 3 and country-specific tier 2 methods are used to estimate fugitive methane and carbon dioxide emissions across Australia's regional coal basins.

Table 3.33: Summary of methods and emission factors: 1.B.1 Solid Fuels: Surface mining

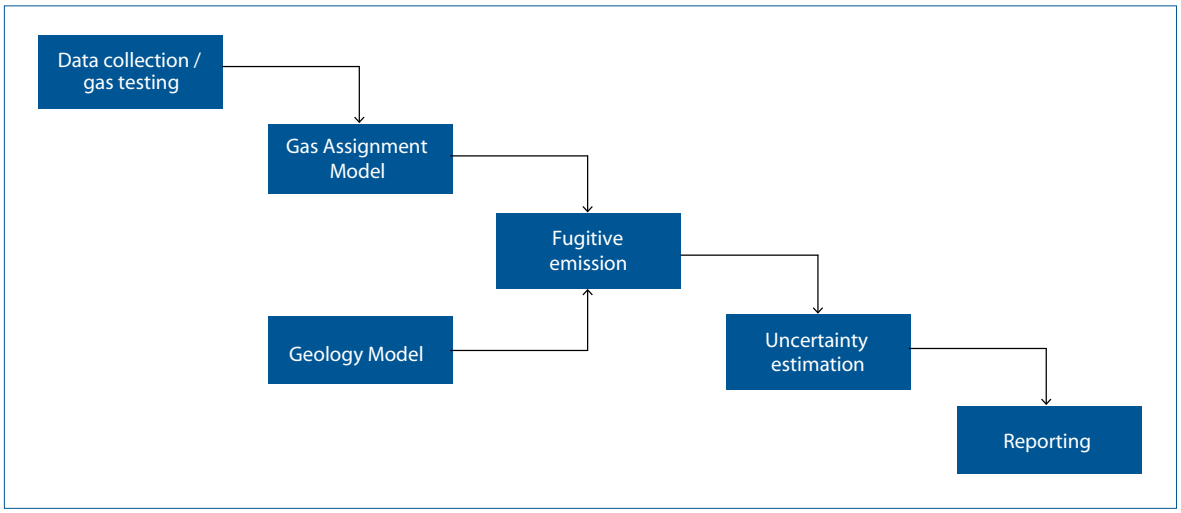
Coal field	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Bowen (Qld)	T3	PS	T2	CS	NA	NA
Surat (Qld)	T3	PS	T2, T3	CS, PS	NA	NA
Hunter (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
Newcastle (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
Western (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
La Trobe (Vic)	NA	NA	T2	CS	NA	NA
South Australia	NA	NA	T2	CS	NA	NA
Collie (WA)	T3	PS	T3	PS	NA	NA

Notes: T2 = tier 2, T3 = tier 3, CS = Country-specific, PS = Plant-specific.

Higher tier, facility-specific, NGER method

The Department of the Environment has invested in a comprehensive program of measurement technique research and development since 2007 in order to underpin emissions estimation processes under NGER. An important outcome of the program has been the development of guidelines for the application of the existing NGER mine-specific (method 2/3) approach to estimating emissions from open cut mines. These guidelines have been published by the Australian Coal Association Research Program, ACARP in December 2011, *Guidelines for the Implementation of NGER Method 2 or 3 for Open Cut Coal Mine Fugitive GHG Emissions Reporting* (C20006). These guidelines have been incorporated into a legislative instrument, the *NGER (Measurement) Determination 2008,* for the application by mines for the estimation of fugitive emissions under NGER. As indicated elsewhere, mine estimates are subject to the full audit and compliance processes that apply for other NGER reports.

Figure 3.18: Surface mines: emissions estimation process flowchart for companies



Source: ACARP 2011.

The key components of the mine-specific method for estimating emissions from open cut mines (Figure 3.18) are:

- a framework for data collection, including borehole sampling and gas testing of coal and gas bearing strata, which ensures representative and unbiased sampling;
- guidelines and standards for data analysis and interpretation;
- an approach for estimating gas in near-surface zones characterised by very low gas contents;
- guidelines on utilising the collected data to produce a model of gas distribution describing the gas content and composition with a defined 3 dimensional volume. This is incorporated within the mine's 3-dimensional geological model to establish the *in situ* gas stock residing within the mine strata (e.g. geological models used for JORC Code [5] resource evaluation, or for mine planning where JORC Code compliance is not applicable, are suitable);
- guidelines on estimating the emissions released from the *in situ* gas stock as blocks of strata within the mine are extracted for coal production; and
- minimum qualifications of persons who are permitted to estimate emissions from an open cut mine using the higher order method.

The NGER (Measurement) Determination 2008 sets out requirements for the sampling and analysis to be undertaken by facilities to determine the gas content contained in rock strata within a coal mine; the parameters for the low gas zone, and the application of a gas distribution model to develop an emissions estimate for a surface mine as well as the determination of a low gas zone.

A description of the conceptual framework supporting the facility-specific NGER method is detailed below.

A. For estimating total surface mine fugitive emissions in a year:

$$E_j = \gamma_j \Sigma_z (S_{j,z})$$

where:

E_j is the fugitive emissions of gas type (j) that result from the extraction of coal from the mine during the year (CO_2-e tonnes).

γ_j is the factor for converting a quantity of gas type (j) from cubic metres at standard conditions of pressure and temperature to CO_2-e tonnes, as follows:

(a) for methane—$6.784 \times 10^{-4} \times 21$;

(b) for carbon dioxide—1.861×10^{-3}.

$\Sigma_z (S_{j,z})$ is the total of gas type (j) in all gas bearing strata (z) under the extraction area of the mine during the year, in cubic metres.

B. For estimating the total gas contained by gas bearing strata for (A) above

(1) For $S_{j,z}$ for gas type (j) contained in a gas bearing strata (z) under the extraction area of the mine during the year, in cubic metres, is:

$$S_{jz} = M_z \times \beta_z \times GC_{jz} - \Sigma_t Q_{ij,\,cap,\,z} - \Sigma t\, Q_{ij,flared,z} - \Sigma_t Q_{ijtr} - \Sigma_t E_{j,vented,z}$$

where:

M_z is the mass of the gas bearing strata (z) under the extraction area of the mine during the year, in tonnes.

β_z is the proportion of the gas content of the gas bearing strata (z) that is released by extracting coal from the extraction area of the mine during the year, as follows:

[5] The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves developed by the Joint Ore Reserves Committee (JORC).

(a) if the gas bearing strata is at or above the pit floor—1;

(b) for gas released below the pit floor.

GC_{jz} is the content of gas type (***j***) contained by the gas bearing strata (***z***) before gas capture, flaring or venting is undertaken at the extraction area of the mine during the year, measured in cubic metres per tonne of gas bearing strata at standard conditions.

$\sum Q_{ij,cap,z}$ is the total quantity of gas type (***j***) in coal mine waste gas (***i***) captured for combustion from the gas bearing strata (***z***) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

$\sum Q_{ij,flared,z}$ is the total quantity of gas type (***j***) in coal mine waste gas (***i***) flared from the gas bearing strata (***z***) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

$\sum Q_{ijtr}$ is the total quantity of gas type (***j***) in coal mine waste gas (***i***) transferred out of the mining activities at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

$\sum_{Ej,vented,z}$ is the total emissions of gas type (***j***) vented from the gas bearing strata (***z***) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

(2) In subsection (1), $\sum Q_{ijtr}$ applies to carbon dioxide only if the carbon dioxide is captured for permanent storage.

(3) For GC_{jz} in subsection (1), the content of gas type (***j***) contained by the gas bearing strata (***z***) – see **C** below.

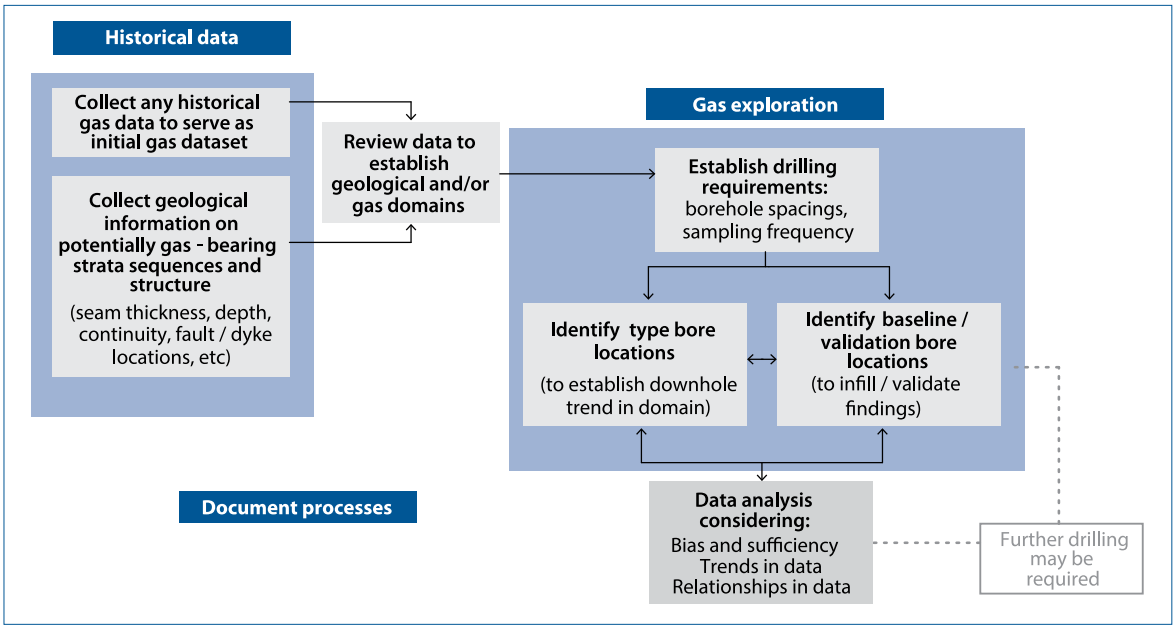
C. For estimating the content of gas type (***j***) contained by the gas bearing strata (***z***) total gas contained by gas bearing strata for (**B**) above:

Data collection and gas testing

A minimum of 3 boreholes that capture the full variance of the gas trends with depth must be located within each gas domain (i.e. area of common gas characteristics). Assessment of the requirement for any additional boreholes is carried out via an iterative process of data review during the gas exploration process to ensure that a sufficient number of unbiased samples have been collected (Figure 3.19).

Sample selection involves the collection of core samples that are representative of the strata that their results will be characterising, and to limit any air contamination both in the field and in the laboratory. Gas testing involves the measurement of each sample's gas content (desorption) and composition according to the Australian Standard AS3980-1999.

Figure 3.19: Surface mine sample collection process flowchart (source: ACARP 2011).



The low gas zone

In most mine sites, there is a portion of strata immediately below the surface that is lacking in quantifiable quantities of coal seam gases. Gas properties in strata with no or low gas volumes are difficult to measure accurately due to inherent uncertainties associated with sampling and testing processes.

A gas dataset of over 2,000 samples from New South Wales and Queensland were analysed to provide an alternative method for the estimation of emissions from low gas zones in the subsurface. It was found that there is a 'low' or 'no' gas zone present at most open cut coal mines from surface down to a clearly apparent boundary at varying depths. There is a key set of common characteristics observed in these low gas zones:

- over 95% of samples reported gas contents under 0.5 m^3/t;
- over 95% of samples are commonly carbon dioxide (CO_2) and nitrogen (N_2) in gas composition;
- at the horizon where the gas contents increase to over 0.5 m^3/t, the gas compositions simultaneously switch to close to 100% methane (CH_4); and
- this horizon is closely related to the 2 main weathering profiles at the deposit:
  - base of oxidation or water table horizon, and
  - base of weathering (or fresh rock horizon).

Samples within the low gas zone are assigned a default emissions factor. Therefore, all gas bearing strata (i.e. coal and carbonaceous strata with a density less than 1.95 g/cm^3) are assigned default value, obtained from half the measurable quantities of both components observed in this zone: i.e. 0.25 m3/t at 50% CO_2 gas composition.

Process used for inclusion of NGER surface mine emission data into the national inventory

NGER emissions for surface mines have been incorporated into the national inventory, having regard to the following procedures and issues:

1) Consistency with the IPCC guidelines and comparison with international practice;

2) Previous ERT report comments - that have both recommended and encouraged Australia to incorporate NGER emission data for surface mines, when available, into the National inventory; and

3) Inventory quality control procedures for data

   a. NGER data has been subject to quality control procedures specific to inventory purposes, consistent with the national inventory Quality Assurance/Quality Control Plan, as set out in section 1.6 of the NIR.

   b. A decision making process with respect to the use of facility specific EFs is set out in section 1.4.1.

The major issue for which the inventory compilation process must control for relates to the question of whether the sample of mines that have estimated emissions using the higher tier methods contains a sampling bias and is not representative of the entire population of coal mines in Australia. At this stage, there is insufficient evidence to indicate that this is the case. This is due to the differing characteristics of individual coal fields, and because companies may select between Method 1 and Method 2//3 when estimating emissions under NGER. Some mines have not estimated emissions using the higher teier methods (non-reporting mines).

Consequently, the reported facility-speciifc emissions data has been divided into subgroups based on individual coal basins or coalfields with the use of data and approaches to the treatment of non-reported data set out as below.

In Queensland basins, other than Surat, the number of NGER reporters reporting facility–specific emission estimates using higher order NGER methods is considered to be not sufficient for the sample to be representative of the sub-population of the coal basin. There are too many non-reporters. In these cases, the facility-specific NGER emission factors for reporting mines may be incorporated into the inventory but the tail of non-estimating mines is constrained such that the total IEF for the coal field is equal to the pre-existing country-specific emission factors. This means that total emissions for these coal fields are not affected by the inclusion of facility–specific data, for this submission.

In the following basins - Gunnedah, Western, Surat and Collie coal fields - where previously there has been no empirical data available, the number of reporting mines under NGER is much higher and is considered to be sufficiently representative to be included in the inventory. In these cases, facility-specific NGER data have been incorporated into the inventory but the emission factors of these reporting mines have, conservatively, not been extrapolated to the non-reporting mines. In the absence of any pre-existing empirical data for these coal fields the pre-existing country-specific emission factors have been used for the tail of non-estimating mines.

In two fields, Hunter and Newcastle, where empirical data has previously existed (Williams et al 1993), the number of reporting mines under NGER is considered to be sufficiently representative to be included in the inventory. In these cases, facility-specific NGER data have been incorporated into the inventory but the emission factors of these reporting mines have, conservatively, not been extrapolated to the non-reporting mines. While the facility-specific NGER EF for reporting mines may be incorporated into the inventory, the tail of non-reporting mines is constrained by the calibration of the non-reporting mines to a pre-existing, known and unbiased distribution for the population.

This calibration involves an upward adjustment of EFs for non-reporting mines to account for the possibility of sampling bias being introduced in the inventory arising from NGER reporters being able to choose to use either a the higher tier method or existing default emission factor approach. The sampling bias adjustment method used for the set of non-NGER data coal mines is as follows:

1) Take the mine EF dataset that was used in the original, Williams et al 1993 study to derive the existing country-specific emission factor for NSW of 3.2 m^3 CH_4/tonne.
2) Model the probability density function of those EFs.
3) Assess the percentage of Hunter/Newcastle mines for which NGER data is not available for inventory compilation as compared to the total number of active mines in the Hunter/Newcastle, (i.e. 20%).

4) Assume that the EFs of the 20%, non-NGER mine group sit within the top 20% of the distribution model developed in (2).
5) Find the mean of that top 20% of the distribution by integrating that area under the probability density function and apply as an emission factor to that set of non-NGER data mines.

In practice, the use of facility–specific data have been implemented for the Gunnedah, Western, Surat, Collie, Hunter and Newcastle basins. The remaining basins in Queensland, Victoria, South Australia do not use NGER reported data and retain the use of existing tier 2 country-speciifc methods (see below).

Black coal mine production

A study of methane flux measurements from open cut coal mines in New South Wales and Queensland (Williams *et al.* 1993) forms the basis for Australia's country-specific, default emission factors. The study used the empirical results to estimate EFs (in m^3/tonne raw coal) applicable to open cut black coal mining in each state (NSW and QLD), as shown in Table 3.34.

Brown coal (lignite) mine production

Open cut mining of brown coal (lignite) occurs in Victoria for combustion in electricity generation. A methane emission factor for Victorian brown coal mining of 0.0162 m^3 per tonne of raw coal mined is applied. The emission factor is based on a gas measurement program conducted in 2013, which consisted of 96 samples taken from six boreholes across three brown coal mining deposits (HRL 2013).

Surface mining of a low rank sub-bituminous coal occurs in South Australia for combustion in electricity generation. Coal mined in South Australia has an energy content of 13.5 GJ/t. Based on the IEA fuel type classification, which classes non-agglomerating coals under 17.435 GJ/t as being lignite (IEA 2005), the methane EF from open cut brown coal mining of 0.0162 m^3/t (as used for Victorian brown coal) has been applied.

Table 3.34: Tier 2 default CH_4 emission factors for surface mining

State	EF CH_4 m^3/t raw coal mined	Volume-to-mass conversion factor [(c)]kg/m^3
NSW	3.2 [(a)]	0.6767
Bowen (Qld)	1.2 [(a)]	0.6767
Tasmania	1.0 [(b)]	0.6767
South Australia	0.0162[(e)]	0.6767
Victoria	0.0162[(e)]	0.6767

(a) Source: Williams *et al.* (1993) and confirmed by Australian Coal Association.
(b) Source: D Cain, Australian Coal Association, pers. comm. (1993) .
(c) These factors are derived by treating CH_4 as an ideal gas, i.e. 16 g (1 gmole) occupies 23.645 at 15 °C and 1 atmosphere.
(d) Source: IPCC 2006.
(e) Source: HRL 2013.

Energy

Decommissioned Mine Emissions (1.B.1.c Other)

CH_4 emissions are also known to occur under certain conditions following closure/abandonment of coal mines. Leakage into the atmosphere through fractured rock strata, open vents and seals occurs over daily to decadal timescales.

The Australian methodology is based on the approach developed in the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. The decline of emissions following mine closure are modelled using emission decay curves (EDCs) for dry gassy and non-gassy mines. In addition, the EDCs are adjusted on a mine–by–mine basis, according to the flooding characteristics of each mine.

Key data required for the approach include:

- mine closure history;
- emissions at time of closure;
- dry mine EDCs for gassy and non-gassy Australian mines;
- mine void size; and
- mine water inflow rates.

The approach seeks to maximise the use of publicly available data and is best described as a high tier 2 and tier 3 approach. It is consistent with a tier 3 approach in that it estimates emissions on an individual mine basis. However, other mine-specific data characteristic of higher level tier 3 approach are absent, such as characteristics of the mined coal seam, permeability and direct measured emissions.

The EDC methodology used for estimating CH_4 emissions from decommissioned mines can be described as:

$$E_{dm} = (E_{tdm} \cdot EF_{dm} \cdot (1 - F_{dm})) - E_{rec} \quad \text{(1B1_7)}$$

Where: E_{dm} is the emissions (Gg methane/year) for a mine at a particular point in time.

E_{tdm} is the annual emission rate of the mine at point of decommissioning (Gg methane/year)

EF_{dm} is the emission factor for a mine at a point in time since decommissioning. It is derived from the EDC (formulae 1B1_8 and _9). The EF is dimensionless.

F_{dm} is the fraction of mine flooded at a point in time since decommissioning.

E_{rec} is the quantity of methane emissions avoided by recovery.

Emission Decay Curves

An EDC describes the decline in fugitive CH_4 emissions over time following mine closure. Hyperbolic curves have been found to function best in portraying the rapid decline in emissions in first few years, followed by a slow decline over time of the remaining emissions.

Australian-specific EDCs were utilised for gassy and non-gassy mines respectively. The EDCs represent the dry mine case and have been developed from studies of long term (1982 -2006) direct gas emission measurements from Australian mines (Lunarzewski 2005 and Armstrong *et al.* 2006). The EDCs are shown in Figure 3.20, and are described in the following formulae:

Gassy mines

$EF_{dm} = (1 + A * T)^b - C$ ..... (1B1_8)

Non-gassy mines

$EF_{dm} = (1 + A * T)^b - C$ ..... (1B1_9)

where: EF_{dm} is the emission factor (Gg methane/year) for a mine at any point in time since decommissioning (the emission factor is dimensionless).

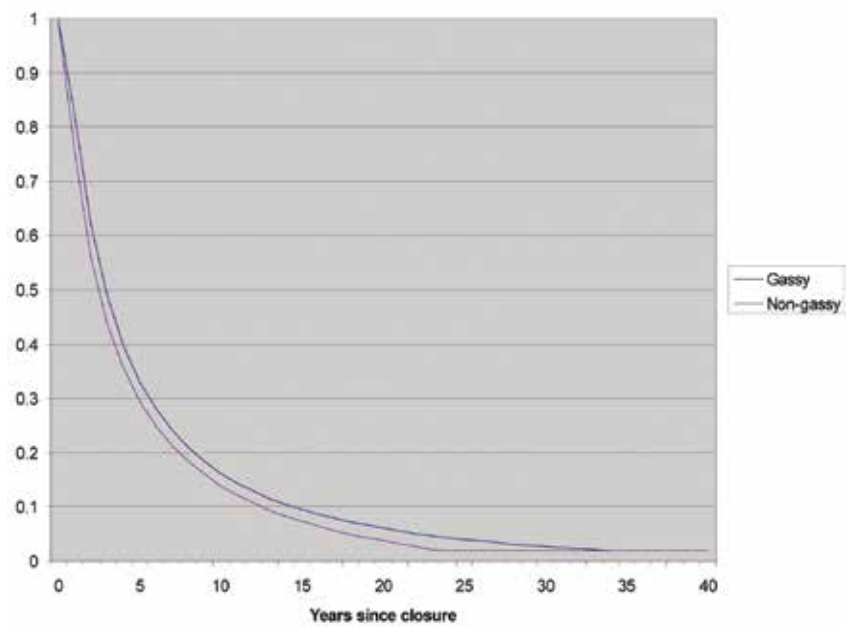
T is the time (years) elapsed since decommissioning of mine.

A, b and C are coefficients unique to the decline curves (see Table 3.35).

Table 3.35: Coefficients used in Australian emission decay curves from decommissioned mines

Mine category	Coefficients		
	A	B	C
Gassy Mines	0.23	-1.45	0.0242
Non-Gassy mines	0.35	-1.01	0.0881

Figure 3.20: Emission decline curves for gassy and non-gassy Australian decommissioned coal mines



Sources: Lunarzewski 2005 and Armstrong *et al.* 2006

Mine Production Data

Mine production data are obtained from:

- Coal Services Pty Ltd (2013), for New South Wales mines from 1972 to 2012; and
- Queensland Department of Natural Resources and Mines (DNRM 2013), Mines and Energy, from 1979 to 2012.

In both datasets, details were obtained for mine type (underground/open cut), annual run-of-mine production, and time of closure. Only underground mines were included in the study. Open cut mines were not included in the study as they are associated with relatively low CH_4 emissions. This approach is consistent with that presented in the 2006 IPCC *Guidelines for National Greenhouse Gas Inventories*.

Emissions at Closure

In order to estimate the decline of emissions over time following closure, it is first necessary to establish emissions at year zero, i.e. emissions at the point prior to closure. The approach used is consistent with that used to estimate CH_4 emissions from active underground coal mines (see 1.B.1ai). Final mine production at closure is taken as the last full year of production.

Decommissioned mines are defined as Class A (gassy) or Class B (non-gassy) based on existing classifications used to calculate previous *National Greenhouse Gas Inventories*. For earlier mines, for which class tends to be unknown, mines were classified according to their geological proximity to other mines for which class was known.

Adjustment of EDC for flooding mines

It is common for decommissioned mines to become flooded over time. The flooding of mines is known to result in a very rapid decline in the release of CH_4, thus having a substantial impact on the shape of the EDC, and on overall emissions.

The approach uses emission values calculated using dry mine EDCs (formulae 1B1_8 and 1B1 _9) and makes adjustments based on the proportion of the mine flooded at that time. For example, if a mine is 50% flooded 10 years post closure then the emission value derived from the EDC is adjusted at that point in time by 50%.

The following information is required in order to estimate the flooding rate of any particular mine:

- size of the mine void volume; and
- rates of mine water inflow.

Estimating mine void volume

The quantity of run-of-mine coal production removed from the mine is used as a basis for estimating the mine void volume remaining at the time of closure. Total historical mine run-of-mine coal production is converted from tonnes to cubic metres by dividing the total tonnage by 1.425, representing the specific gravity of an average Australian worked coal seam Lunarzewski (2006).

Mine water production data are difficult to obtain on a mine by mine basis, particularly for older, decommissioned mines. The approach taken is to develop a set of basin/state average mine water inflow rates based on available data.

The primary source of mine water production rates for individual mines were obtained from publicly available Environmental Impact Statements (EIS) for mining development projects. EIS provides a good coverage of ground water hydrology, providing data on mine water production rates for proposed mines, extensions, nearby existing mines, and the flooding status of surrounding mines.

Water production rates for three regions were calculated using these data sources. The Southern New South Wales region contained mine water production rates ranging between 1 – 5.0 ML/Day and an average value of 2.5 ML/day. The Central New South Wales region ranged between 0.4 and 3 ML/Day and an average value of 1.2 ML/Day and Queensland ranged between 0.1 and 0.4 ML/Day and an average value of 0.2 ML/Day.

The following assumptions were necessary in estimating mine water inflow rates:

1. the mine floods at a linear rate;
2. mine water production is the same for each mine on a basin/state scale; and
3. CH_4 is produced evenly throughout the mine and flooding reduces the emissions proportionately to the void volume flooded.

Fully Flooded Mine Emissions

Once a mined void area has been fully flooded, the associated primary gas sources can no longer release gas into the workings. However, remaining free gas in the strata and desorbing gas from unflooded secondary gas sources could continue to leak into the atmosphere (ground surface) via fractured rock strata i.e. geological faults, cracks, and fissures (structurally induced pathways). A constant of 2% of the emissions at the time of mine closure has been adopted to represent emissions once fully flooded (Lunarzewski 2006).

Mine Flaring Emissions (1.B.1.c. Other)

Data for 2009 to 2012 on the recovery and flaring of CH_4 from coal mines is available from mines reporting under NGER. Time series consistency for coal mine flaring is maintained by the inclusion of flaring data obtained from a 2006 unpublished report on coal mine methane prepared for the Australian Greenhouse Office (AGO 2006b), which provided flared gas quantities by mine for 2005. For those respective mines, the 2005 flared quantity was then prorated according to the total mine methane emissions for other years to produce a time series. Information regarding when flaring systems were first installed at the respective mines were also taken in to account in producing the time series.

The mine flaring emissions have been reported under 1.B.1.c. Other – Flaring. Although the Solid Fuel CRF Table 1.B.1 does not facilitate the reporting of N_2O emissions from flaring, the UNFCCC reporting tool does allow reporting, and the inclusion of N_2O is evident under Solid Fuels in the CRF Summary Table 2.

The emission estimation methodology utilises a combustion CO_2 EF of 51.9 Gg/PJ and an energy content of 37.7 GJ/m3 for coal mine waste gas flared, derived from industry data. A flaring oxidation factor of 98% is used, consistent with the IPCC *Good Practice Guidance 2000* and 2006 *IPCC Guidelines*.

3.8.3 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Underground Mines

The transition to the use of NGER data for underground coal mines has had to be carefully managed to ensure that time series consistency has been respected. It is *Good Practice* to perform the splicing using more than one technique before making a final decision and to document why a particular method was chosen. The surrogate method, involving the use of coal production data and an EF derived from actual mine measurements, was chosen as the most appropriate splicing technique. This choice was made because run-of-mine coal production data is available for individual mines for all years and is an underlying activity data parameter that best explains emission trends.

Interpolation was considered as a complementary approach where emissions data are available from non-NGER sources for a previous year and which could be used to provide an EF per unit of coal production for earlier years. In accordance with *Good Practice Guidance* (IPCC 2000), interpolated estimates were compared with surrogate data as a QA/QC check.

For a number of years, data on emissions for certain underground mines have been available from estimates published within company environmental reports or from industry reports to the Australian Greenhouse Office (AGO 2006b). This emissions data has been used for each mine for the years for which they are available. For earlier years, where such emissions data are not available, an EF per unit of production for each mine was established and applied to production levels back through the time series from 1990 to the year when data on emissions first becomes available (Figure 3.21). For the years between the latest company report and the year of the NGER data, the EF for each mine was calculated by interpolating between the EF for the latest year for which company data was available and the EF based on NGER data for the year 2009.

A small number of underground mines closed in the period 1990-2005 for which there are no mine-specific measured data available. Emissions for each year were recalculated using a basin-specific factored, calculated from the NGER data for 2009 and multiplied by production. A similar approach has been adopted for the inclusion of emissions of CO_2 for all mines (Figure 3.22).

Figure 3.21: Time series consistency method for determining underground coal mine emission factors - methane

Methane	1990-2004	2005 Industry survey	2006-2008	2009-10 NGER	2011 NGER	
"Actual" data reported by companies represents the best available and most representative for the year – backcast based on latest available year of actual data. Basin specific factors (based on NGER data) used for mines for which NGER data was not available	EFs held constant	Actual data	Interpolated EFs	Actual data	Actual data	NGER data backcast only until an actual emissions data year is available using interpolation to fill intervening years

Figure 3.22: Time series consistency method for determining underground coal mine emission factors – CO_2

Carbon dioxide	1990-2008	2009-10 NGER	2011 NGER	
Basin specific factors (based on NGER data) used for mines for which NGER data was not available	EFs held constant	Actual data	Actual data	Emissions for all earlier years are estimated using the production EF based on mine-specific NGER data.

Surface mines

The introduction of NGER data for surface coal mines in this inventory submission has been undertaken in a manner that maintains that time series consistency. To achieve this, a set of rules has been applied that both, takes into account the new understanding of gas content gained from NGER data and maintains the relevance of the original 1993 study. Details of the rules used to compile surface mine emissions in this inventory submission are detailed below:

1) Where the NGER data is an improvement on the default EF because coal fields are beyond the area of the original study (Gunnedah, Western, Surat coal fields)
   a) For methane and carbon dioxide. Then – apply the earliest NGER facility-specific EF back through the entire time series.
2) Where the new data improves on the old EF because comprehensive NGER measurement provides updated and improved data of the original study area measured in 1993 (Hunter and Newcastle).
   a) For methane
      i) Then – apply the earliest NGER facility-specific EF back through the time series by interpolating back until year of original study (1993).
      ii) And –if mine was not part of original study – then
         1. Ignore 1993 default – run NGER to 1990
   b) For carbon dioxide
      i) Then – apply the earliest NGER facility-specific EF back through the entire time series.
   c) Where a methane EF is derived for a mine from a probability density function model based on original data.
      i) Then – apply that modelled EF back through the entire time series.

3.8.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6.

Implied emission factors

Methane emissions

Australia uses mine site direct measurement tier 3 and country-specific tier 2 methods for estimating CH_4 emissions. Australia's CH_4 IEFs have been compared statistically against EFs reported by other countries. Overall, Australia's IEFs are not significantly different to the means of the IEFs of all other reporting parties.

In 2012, Australia's IEF for underground mines was 7.73 kg CH_4/t compared to 7.86 kg CH_4/t (n = 21) for the 2011 mean of countries. The result of a t-test comparison of the means showed that Australia's CH_4 from underground mining is not significantly different to that of the mean for all countries.

Australia's IEF for surface mining in 2012 was 0.9 kg CH_4/t compared to 0.77 (n = 18) for the 2011 mean of countries and was at the high end of the distribution range. However, the result of a t-test comparison of the means showed that Australia's CH_4 from surface mining is not significantly different to that of the mean for all reporting parties.

Carbon dioxide emissions

Australia's reports CO_2 emissions from underground mines. All CO_2 emissions are based on direct measurement. The IEF for underground mining in 2012 was 13.08 kg CO_2/t. Statistical comparison with other countries was not possible as very few countries report CO_2 emissions from coal mining.

Trends in implied emission factors

IEFs from coal mining activities are influenced over time by changes in the share of production from mines of varying gas content and gas type and the quantity of CH_4 recovered. This is evident in a declining trend of the CH_4 IEF for underground mines, which reflects a relative increase in production from less gassy mine regions and compared to production from high gas coalfields. Figure 3.23 details the declining trend of the underground coal mine IEF since 1990 and the corresponding fall in production from the New South Wales Southern Coalfield, which has the highest IEF of Australian coalfields.

The IEF for all coal mining activities has also declined since 1990 reflecting the additional influence of a relative increase of open cut mine production compared to underground production. The trend in production also varies over time, reflecting the effects of opening and closure of large mines, commodity prices and global demand.

NGER auditing process

Under the NGER scheme, coal mining companies which have annual emissions that exceed 125 000 Gg CO_2-e are required to undertake an pre-submission audit report to provide assurance over their NGER emissions report. Audit reports must be submitted to the Clean Energy Regulator by the reporting due date of 31 October. The audit must be a reasonable assurance engagement, it must be conducted in accordance with the *National Greenhouse and Energy (Audit) Determination 2009*, and it must be undertaken by a Category 2 or 3 registered greenhouse and energy auditor. More information on the audit requirements is available at the Clean Energy Regulator website at www.cleanenergyregulator.gov.au/.

Minimum qualifications for an Estimator for surface mine emissions using the NGER higher tier method.

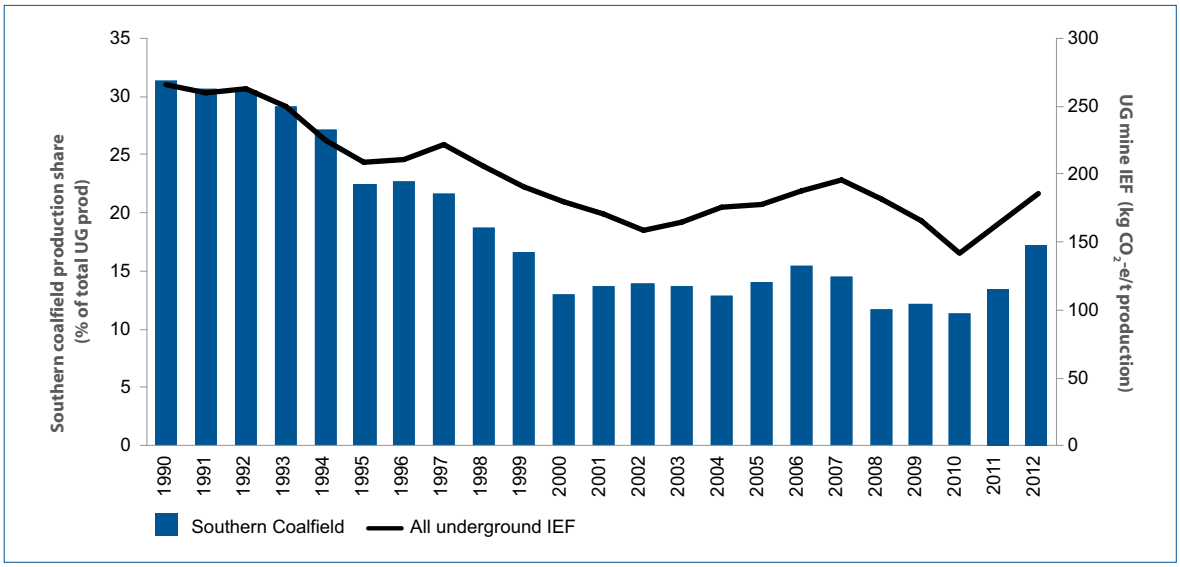
The NGER legislation sets out minimum qualifications of the estimator of surface mine emissions using the NGER higher tier method. The Estimator is a person, or team of persons, meeting the minimum qualifications described below, who estimates the fugitive emissions from an open cut coal mine.

> *The minimum qualifications of an Estimator are 5 years experience in the assessment of coal deposit continuity and dimensions including the identification of geological features that affect coal seam geometry such as seam splitting, subcrop lines, washouts, and otherwise deterioration in thickness of the coal seams, including (but not limited to) the presence of any adverse structural features (for example faults, folds or igneous intrusions).*

Review of brown coal (lignite) surface mining emission factor

Australia undertook an independent technical review of the new emission factor prior to adoption of greenhouse and inventory reporting. The review found conformity with IPCC guidelines and consistency with other comparable international greenhouse gas inventories. It found the emission factor constituted best practice for estimating emissions from surface coal mining (Pitt and Sherry 2013).

Figure 3.23: Decline of the overall underground coal mine implied emission factor compared with the fall in production from the high gas content Southern Coalfield



Source: Coal Services Pty Ltd 1990-2012 and NGER data.

3.8.5 Recalculations Since the 2011 Inventory

Black coal surface mining

Uptake of the higher tier method by NGER reporters has resulted in the increasing availability of NGER, mine–specific emission data available for compiling surface mine emissions for the inventory. The incorporation of this NGER data introduces a major improvement in the estimation of emissions from open cut mines, compared to the default EF approach predominantly used by other Parties.

Emissions for black coal surface mines have been recalculated as a result of the incorporation of NGER mine-specific emission data. This has resulted in a decline in CH_4 emissions for all years compared to the previous submission. However, CO_2 emissions have increased for all years due to the NGER data providing information on CO_2 emissions for the first time.

The NGER, facility-specific method for surface mines is a significant improvement over the use of default emission factors and involves extensive measurement of *in-situ* gas within each respective coal mine's coal and carbonaceous rock strata, via borehole drilling and sampling. The use of NGER data also addresses comments made in previous ERT reports which have both recommended and encouraged Australia to incorporate NGER data for surface mines.

Brown coal (lignite) surface mining

A project was undertaken in 2013 by brown coal mine facilities to measure the gas content of brown coal deposits within the Victorian Latrobe Valley. The project consists of 96 samples taken from six boreholes across three mine facilities.

This study constituted the first measurement of *insitu* gas for Australian brown coal deposits and provides a basis for updating the previous brown coal fugitive emission factor. The previous factor was referenced from a Coal Industry Advisory Board publication (IEA 1992) and was not based on any measurement.

Decommissioned mines

To improve consistency with underground mine emission estimates, emissions from decommissioned underground coal mines have been recalculated across the time series. In previous submissions, mine emissions at the point of closure were estimated using the underground mine default emission factor. However, this approach was inconsistent with the current method for estimating underground mine emissions in 1.B.1.a.i, which utilises mine specific data. The estimation of emissions at the point of closure have now been aligned with underground mine emissions, as reported in 1.B.1.a.i.

Table 3.36: 1.B.1 Solid Fuels: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO2-e)		(Gg CO2-e)	(%)
1.B.1.a.i Underground Mines				
1990	15,546	15,546	0	0.0%
2000	16,996	16,996	0	0.0%
2001	16,390	16,390	0	0.0%
2002	15,136	15,136	0	0.0%
2003	14,111	14,111	0	0.0%
2004	14,787	14,787	0	0.0%
2005	16,054	16,054	0	0.0%
2006	16,919	16,919	0	0.0%
2007	18,924	18,924	0	0.0%
2008	18,601	18,601	0	0.0%
2009	18,024	18,024	0	0.0%
2010	17,119	17,119	0	0.0%
2011	18,297	17,985	-312	-1.7%
1.B.1.a.ii Surface Mines				
1990	3,385	2,872	-513	-15.2%
2000	5,511	4,938	-573	-10.4%
2001	5,984	5,700	-284	-4.8%
2002	6,580	6,534	-47	-0.7%
2003	6,917	6,403	-514	-7.4%
2004	7,185	6,960	-226	-3.1%
2005	7,828	7,311	-517	-6.6%
2006	8,028	7,427	-601	-7.5%
2007	8,341	7,451	-891	-10.7%
2008	8,461	7,274	-1187	-14.0%
2009	9,140	8,127	-1012	-11.1%
2010	9,712	8,381	-1331	-13.7%
2011	9,988	7,869	-2119	-21.2%
1.B.1.c Decommissioned Mines				
1990	356	394	39	10.8%
2000	593	814	221	37.3%
2001	644	944	300	46.6%
2002	943	1,204	261	27.7%
2003	1,273	1,921	648	50.9%

	2013 submission	2014 submission	Change	
	(Gg CO2-e)		(Gg CO2-e)	(%)
2004	1,774	1,451	-323	-18.2%
2005	1,296	1,466	170	13.1%
2006	773	1,186	413	53.4%
2007	1,737	1,218	-519	-29.9%
2008	1,808	1,392	-416	-23.0%
2009	1,460	1,122	-337	-23.1%
2010	1,216	981	-235	-19.3%
2011	800	621	-179	-22.4%

3.8.6 Planned Improvements

Higher tier method for open cut coal mines

Uptake of the higher tier method is expected to continue over future years as new mining areas are opened up, resulting in an increase in mine–specific emission data available for compiling open cut mine emissions for the inventory. Due to the significant increase in availability of measurements, this will result in the progressive improvement in the estimation of emissions from open cut mines, compared to the default EF approach previously used by Australia.

3.9 Source Category 1.B.2 – Oil and Natural Gas

3.9.1 Source Category Description

The IPCC *Guidelines* defines a three level hierarchical structure for source categories related to the oil and gas industries. At the top level of the hierarchy is:

- emissions related to oil (1B2a);
- emissions relating to gas (1B2b); and
- venting and flaring emissions relating to both oil and gas (1B2c).

The main emission sources included in the first two categories are leakage, evaporation and storage losses. Emissions from venting and flaring are activities that are managed as part of normal operations at field processing facilities and oil refineries.

The approach used for defining vents and leaks is provided below, and has been developed with a view to completeness and consistency with American Petroleum Institute's (APIs) 2009 *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry*:

- vents are emissions that are the result of process or equipment design or operational practices; and
- leaks are emissions from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and other leakage sources from pressurised equipment not defined as a vent.

Liquefaction of natural gas for export takes place at the North West Shelf liquefied natural gas (LNG) plant near Dampier in Western Australia, and at Darwin in the Northern Territory. Combustion of raw natural gas used in the gas processing, and liquefaction for energy purposes, is reported under *stationary energy* 1.A.1.C Manufacture of Solid Fuels and Other Energy Industries. Venting of CO_2 extracted from raw gas and flaring of unusable gas produced at various stages of processing are separately accounted for under venting and flaring.

Natural gas leakage in residential and commercial sectors (1.B.2.b.v.i) is included in the methodology for the estimation of emissions for natural gas distribution. Therefore, these emissions are reported under 1.B.2.b.iv Natural gas distribution.

Emission data obtained from NGER for Natural gas leakage in industrial plants and power stations (1.B.2.b.v.ii) has been included in 1.B.2.b.ii Natural gas production/processing.

For the years 1990 to 2008, emissions for the upstream oil and natural gas categories were largely based on estimates published by the Australian Petroleum Production and Exploration Association (APPEA 1990–2008). This covered the inventory categories:

- Oil and gas exploration;
- Crude oil production;
- Natural gas production and processing;
- Venting; and
- Flaring.

APPEA EFs were largely based on oil and gas industry factors from the E and P Forum 1994. APPEA estimated flaring emissions using country-specific EFs applied to a measured activity parameter (volume flared). Venting emissions are reported from measured data (tier 3).

NGER facility data were available for the first time for the compilation of the 2009 inventory. The NGER data has now replaced the APPEA data, which had ceased to be collected. The NGER methodologies for facilities to estimate emissions were designed to be consistent with those used to compile the previous APPEA inventories. This ensured time series consistency in methodologies and emissions between the 2009 year and previous years. The EFs are listed under each respective source category description.

Emissions from natural gas distribution and transmission are based on country-specific EFs and activity data derived from statistics published by the Australian Gas Association and the Energy Supply Association of Australia (ESAA). Oil and natural gas production activity data are obtained from the Bureau of Resources and Energy Economics monthly series, *Australian Petroleum Statistics*.

Fugitive emissions associated with various segments of the coal seam gas production chain are reported, inclusive with emissions from natural gas, under the national inventory reporting source categories of *Exploration (gas)* and *Natural Gas Production & Processing*, consistent with UNFCCC reporting requirements.

Fugitive emissions associated with the transportation of the coal seam gas are reported, inclusive with emissions from natural gas, under the national inventory reporting source categories of *Natural gas transmission* and *Natural Gas Distribution.*

A table summarising the inventory sectors which include fugitive emissions from coal seam gas, and the emission types that are covered, is presented in Table 3.37.

Table 3.37: Inventory coverage of fugitive emission sources from coal seam gas

Operation phase	Inventory category	Activities	Venting	Flaring	Leakages
Pre-production	Exploration	Well drilling Well testing Well completion and workovers	YES	YES	Included in Venting
Production and Processing	Production and Processing	Gas well head to tie-in points on gas transmission systems	YES	YES	YES
Transportation	Natural Gas Transmission	High pressure gas transport	YES	NO	YES
	Natural Gas Distribution	Low pressure gas transport	YES	NO	YES

Descriptions of emission estimation methods are provided in the following section under the respective inventory categories.

3.9.2 Methodology

Oil (1.B.2a)

Oil and Gas Exploration (1.B.2ai and 1.B.2.bi)

Emissions may occur during the process of drilling for oil and gas either during exploration or development drilling, whenever gas or liquid hydrocarbons are encountered. Emission sources include flaring, degassing of drilling muds and venting during well completions.

Short term testing activities of hydrocarbon flows and pressure may be undertaken following drilling. In the absence of collection infrastructure, which is generally the case in exploration, the hydrocarbons will usually be flared as a means of disposal. CO_2, some unburnt CH_4, and other non-CO_2 gases are released as a result of the flaring. Emissions are estimated using the EFs reported in Table 3.38. For reporting purposes, exploration emissions from 1.B.2.a Oil and 1.B.2.b Natural gas have been combined under Natural gas exploration from 1990 to 2008 due to the APPEA data source not providing the required splits in emission sources. However, from 2009 onwards, the NGER data has provided the necessary data splits and, therefore, emissions have been reported in both the natural gas exploration and oil exploration categories.

Table 3.38: Oil and gas exploration fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / combustion (kt)					
		CO_2	CH_4	NMVOC	N_2O	NO_x	CO
Exploration (for both oil and gas)	Offshore testing:						
	- Gas Flared	2750	35.0	15.0	0.081	1.5	8.7
	- Oil Flared	3200	0.33	2.97	0.22	3.7	18.0
	Onshore Production testing:						
	- Gas Flared	2750	35.0	15.0	0.081	1.5	8.7
	- Liquids Flared	2750	0.33	2.97	2.2	3.7	18

Source: APPEA 1998-2006, E and P Forum 1994 and *NGER (Measurement) Determination 2008* (Cwlth)

Emissions occur during drilling via the degassing of drilling mud. On drilling through hydrocarbon strata, methane gas can be entrained within the drilling mud and vented at the surface. The 2009 *American Petroleum Institute Compendium* (API) provides EFs based on specific drilling mud types as follows:

- Water based drilling mud 0.2605 tonnes CH_4/drilling day; and
- Oil based and synthetic mud 0.0586 tonnes CH_4/drilling day.

Source: API 2009, Table 5-17.

The number of drilling days were estimated using the number of wells drilled for offshore/onshore and coal seam gas type wells, acquired from APPEA (2009–2013), state agencies (DTI 2013 and DNRM 2013b) and industry project sources. The average drill days per well were estimated using APPEA (2009–2013) data utilising the average drilling rate from spud date to target depth, by well type. A factor of 50% was used to represent the portion of a well drill period which encounters hydrocarbons. The proportions of wells drilled with various types of drilling mud were derived from data on mud types used in Western Australia (WA Department of Industry and Resources; *Petroleum Guidelines – Drilling fluid Management 2006*, DIR 2006).

Methane emissions can also occur in association with final well clean-ups, production testing and well stimulation associated with the transition to gas well production. The 2009 API provides methane EFs for gas well completions as follows:

- Onshore gas well completions 25.9 tonnes/completion day; and
- Offshore gas completions 131.5 tonnes/completion day.

Source; API 2009 Table 5-23.

The 2009 API EFs represent a significant increase on those provided in the 2004 API from this source (API 2004 Table 5-21). Completion days were derived from well completion data obtained from APPEA, state agencies and industry project sources. Length of completion was assumed to average one day. Further work will be undertaken to refine the estimate of completion by well type for future submissions.

The estimate of well completion emissions also assumes that none of the vented completion emissions are flared or captured. Flaring of gas often occurs as part of well head operations depending on practices, regulations and opportunity to capture gas in existing infrastructure. It would be expected that some portion of the vented methane emissions estimated from well completions would be flared and reported under the flared component of oil and gas exploration in the Inventory. Work will be undertaken to better understand the flared quantity of well completion emissions so as to avoid future double counting. However, for this inventory, an assumption of nil flaring from well completions is used in order to produce a conservative inventory estimate.

Crude Oil Production (other than venting and flaring) (1.B.2aii)

Emissions of CH_4 and NMVOCs may occur during oil production, including field processing, as a result of:

- leakages at seals in flanges, valves, and other components in a variety of process equipment; and
- storage tanks and losses of gases during oil production.

EFs for crude oil production are shown in Table 3.39.

Table 3.39: Oil exploration fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO_2	CH_4	NMVOC	N_2O	NO_x	CO
Crude oil production	Production leaks		0.057				
	Internal floating tank		0.00004	0.0002			
	Fixed roof tank		0.0002	0.112			
	Floating tank		0.0002	0.0009			

Source: APPEA 1998-2006, E and P Forum 1994 and *NGER Measurement Determination 2008* (Cwlth)

Crude Oil Transport (1.B.2aiii)

The marine, road or rail transport of crude oil results in emissions of NMVOCs, CH_4, and dissolved CO_2. The extent of emissions depends on the gas control technology employed during transfer operations, fuel properties (e.g. vapour pressure and gas composition), ambient temperatures, trip duration, and the leak integrity of tanks.

Emissions associated with the marine transport of crude oil are of three types: loading, transit, and ballasting. From the use of data from the United States Environmental Protection Agency (USEPA), it is estimated that 745 kg CH_4 is emitted per PJ of oil tankered (IPCC, 1997, Volume 3). Using the USEPA finding that CH_4 makes up 15% of the mass of total organic emissions (USEPA, 1995b), the NMVOC EF for marine transport is estimated to be 4,200 kg per PJ of oil tankered.

Fugitive emission estimates are reported for three categories of oil: indigenous crude oil used within Australia, exported crude oil and imported crude oil. Fugitive emissions from the cargoes of ships engaged in international trade are a component of international bunker fuels, which are excluded from national inventories.

The volume of indigenous crude oil transported by ship to Australian refineries is assumed to equal indigenous crude oil production, minus crude oil exports, minus the lesser value of the following:

- Sales of petroleum products in Victoria (BREE 1996–2013), or
- Production of crude oil in Victoria (BREE 2013a).

The sales data is used when it is lower than the production data because any production exceeding sales in Victoria is assumed to be exported to a different Australian State/Territory. The production of crude oil in Victoria is used when it is lower than sales because any sales exceeding production are assumed to have been imported into the state.

Crude Oil Refining and Storage (1.B.2aiv)

Crude oil is refined to numerous products via a wide variety of physical and chemical processes. During such processing, fugitive emissions of NMVOCs and CH_4 are generated. Fugitive emission sources at crude oil refineries include valves, flanges, pump and compressor seals, process drains, cooling towers, and oil/water separators.

Crude oil is stored at pipeline pump stations and refineries. During such storage, NMVOCs and CH_4 are emitted from normal processes such as tank breathing, and working and standing losses. Storage or tank losses are a complex function of a number of variables including tank characteristics, fuel properties, meteorological conditions, vapour emission control, and liquid throughput. In the absence of data at the individual refinery level, national CH_4 emissions from crude oil refining and storage may be calculated using default EFs according to IPCC Guidelines. The mid-range IPCC default EFs are adopted for crude oil refining and storage, i.e. 745 kg/PJ for refining and 140 kg/PJ for storage.

Fugitive emissions of NMVOCs resulting from crude oil refining and storage have been estimated for Victoria (Carnovale *et al.* 1991). Based on the Victorian data, it is estimated that the NMVOC EF associated with fugitive and tank storage/loading is 20,000 kg/PJ of oil refined.

The NGER data has provided data on the emissions associated with the burning of refinery coke to restore the activity of the catalyst during the petroleum refining process. National CO_2 emissions from this source for 2012 were 1.65 million tonnes CO_2-e. Refineries utilised NGER methodologies involving measurement of flue flow rates, flue gas composition and reference to the *Fluid Catalytic Cracking* handbook used in the petroleum refining industry.

Consistent with previous practice, and in order to maintain time series consistency, this source of emissions has continued to be included within total refinery fuel combustion. This remains consistent with practice followed by most other countries. Furthermore, the IPCC *Guidelines* are ambiguous as to whether emissions from this source should be reported as fuel combustion or fugitive emissions.

Oil refinery flaring

The composition of refinery flare feed-gas is highly variable and depends on plant processing, process upsets and flare operation. In this inventory the composition of refinery gas directed to flares is assumed to be 30% CH_4, 30% NMVOCs and 40% H_2 (by volume). An average flare combustion efficiency of 98% is used, based on studies by USEPA (1995b).

For the years 1990 to 2008, the quantity of gas flared is calculated as 0.6% of the total ABARE (1990–2008) annual refinery feedstock as no detailed data has been available on refinery flaring volumes. The methodology considered the range and age of technologies of the Australian refining industry and publicly available information on annual flaring emissions from Australian facilities. These assumptions were reviewed in GHD (2006b).

Facility level data on flaring volumes have become available for the first time in 2009 through NGER. Analysis has shown that the flared quantity based on NGER data is consistent with the assumptions used to derive the activity data prior to 2009. Given that flaring quantities depend on facility-specific technology types and processes, as well as the episodic nature of flaring, it was decided that it was not appropriate to interpolate the NGER activity data back through the time series.

The EFs for flaring are country-specific factors used consistently throughout the time series, and are provided in Table 3.40 below.

Table 3.40: Emission factors for flaring of gas at oil refineries

Unit	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs
Kg/t gas flared	2,695	6.8	0.081	1.5	8.7	12
Gg/PJ energy flared	47.2	0.12	0.001	0.026	0.15	0.21

Source: DCCEE estimates, following methodology of E & P Forum (1994).

Petroleum Product Distribution (1.B.2av)

The distribution of petroleum products represents a significant source of fugitive NMVOC emissions. Emission sources include motor vehicle refuelling, service station tank filling and breathing losses, major fuel-terminal storage, tank filling losses, refuelling of aircraft, and other mobile sources.

The NMVOC EFs for fuel storage tanks are a complex function of a number of variables and are shown in Table 3.41 on the basis of emissions per sales volumes of each product distributed in Australia. These EFs are calculated from a weighted average analysis of fuel transfer and storage regulations in different regions of Australia (see Appendix 3.A.23 and 3.A.24).

Table 3.41: NMVOC emission factors for petroleum product distribution (kg/kl distributed)

Emission Source	Emission factor (kg/kl distributed)		
	Petrol	Diesel	Avgas
Motor Vehicle/Equipment Refuelling	1.40[a]	0.084[b]	N/A
Service Station/Premises, Storage/Transfer	0.66[c]	0.006[d]	N/A
Bulk Fuel Terminal, Storage/Transfer	1.08[c]	0.009[d]	N/A
Aircraft, Refuelling/Storage	N/A	N/A	2.69[e]
Total all sources	3.14	0.099	2.69

Sources: (a). USEPA (1995b) Uncontrolled refuelling and spillage.
(b). USEPA (1992) Uncontrolled refuelling and spillage.
(c). See Appendix Table 3.A.23 and 3.A.24.
(d). Scaled according to ratio of diesel/petrol emission rate for tank breathing and emptying as reported in USEPA (1992).
(e). Australian Environment Council (AEC 1988).

A number of assumptions were made in compiling these EFs. Emissions from refined petroleum products in storage and in transit are assumed to be negligible, meaning that all emissions are associated with transfer and fuelling operations. Emissions associated with the normal distribution of LPG are also assumed to be negligible (EPA Victoria 1991; EPA NSW 1995). From a consideration of EFs (USEPA 1992), and the predominant modes of distribution of avtur and fuel oil, emissions of NMVOCs from the distribution of these fuels are estimated to be negligible.

Natural Gas (1.B.2b)

See *Oil and Gas Exploration (1.B.2.bi)* under the *Oil (1.B.2a)* for description.

Natural Gas Production and Processing (other than venting and flaring) (1.B.2bii)

This category represents leakage emissions from natural gas production and processing, and includes emissions from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and other leakage sources from pressurised equipment not defined as a vent.

EFs for natural gas production and processing leaks are country-specific factors and are shown in Table 3.42. These factors are based on APPEA (1998–2006) data which utilised EFs from the E and P Forum 1994.

Table 3.42: Fugitive emission factors for natural gas

Inventory category	Operation /source	Emissions (t) / Output (kt)					
		CO_2	CH_4	NMVOC	N_2O	NO_x	CO
Venting		M	M	M	0	0	0
Flaring		2900	35	15	0.81	1.5	8.7
Natural Gas Production and processing	Fugitive emissions – general leaks		0.058	0.007	0	0	0

Source: APPEA 1998-2006 and E and P Forum 1994. M = directly measured emissions

Natural Gas Transmission and Distribution (1.B.2bii)

Natural gas transmission

Australia has an extensive system of long distance natural gas transmission pipelines. As with oil and gas production, emissions may occur as a result of compressor starts (for which gas expansion is typically used to start gas turbine power units), blowdowns for maintenance at compressor stations, maintenance on pipelines, leakage, and accidents.

The Australian high pressure gas transmission system is of relatively recent vintage (the oldest line dates from 1969), has been built to high quality standards and is well maintained. Work undertaken by the Pipeline Authority (the organisation formerly responsible for operation of the Moomba to Sydney pipeline) concluded that losses from a typical gas transmission pipeline in Australia are 0.005% of throughput.

The factor of 0.005% and the throughput data are used in conjunction with national average pipeline gas composition figures for each year, as given in Table 3.43. Throughput data are obtained from NGER (2009–2012) the Australian Gas Association (AGA) and the Energy Supply Association of Australia (ESAA). *IPCC Good Practice Guidance* (2000) recommends an approach where emissions are also linked to the length of pipeline rather than solely using throughput. Consistent with this approach, emissions are calculated for a reference year and emissions for other years scaled against the reference year according to the change in pipeline length.

Natural gas distribution

The boundary between natural gas transmission and distribution is generally taken to be the city gate regulator stations at which gas pressures are reduced from transmission pressures (up to about 15 MPa) to sub-transmission pressures. Most of the gas lost from gas transmissions and distribution systems is by way of leakage from the low-pressure network. The amount of leakage depends on the number and condition of joints in the pipes. The high pressure and trunk main pipes are welded steel, so flanged joints are typically only at valves and compressors. Pressures are so high that any major leaks that might occur are obvious, dangerous and quickly attended. Other causes of fugitive emissions from gas distribution systems (up to and including customer meter) are:

- third party damage (e.g. excavators);
- purging of new mains;
- unburnt gas from gas compressors (if there are any on the distribution system);
- gas lost to atmosphere on start-up and shut down of compressors; and
- regulating and relief valves.

There are no Australian data on fugitive emissions from the customer side of the meter, but these may arise from such sources as:

- leaking lines at fittings;
- purging of lines during appliance installation and maintenance;
- leaking appliance valves;
- extinguished pilot lights without automatic cut-off; and
- leakage when intermittently operated appliances (e.g. cookers) are ignited and extinguished.

Emissions from the distributor side of the meter are not measured directly, but must be based on estimates of unaccounted for gas (UAG). Components of UAG include: leakage emissions, meter inaccuracies, use of gas within the system itself, theft of gas, variations in temperature and pressure and differences between billing cycles and accounting procedures between companies delivering and receiving the gas.

The ratio of emissions to UAG for Australian utilities has been estimated at 80% (Dixon 1990) and 70–80%

(Hutchinson *et al.* 1993). A leakage component for UAG of 90% is used for 1990 (NGGIC 2006), reflecting an additional allowance for the additional emissions from the customers side of the meter, which were not covered in the two studies. An analysis of industry data on the progressive upgrade of the gas distribution infrastructure in response to a variety of drivers, including greenhouse gas emissions concerns, concluded that a figure in the range of 50–60% is more realistic for current circumstances (Energy Strategies 2005). Accordingly, the new estimate for leakage under UAG adopts a figure of 55% from 2003 onwards.

The data sources necessary to calculate emissions from natural gas distribution are:

- estimates of UAG as a percentage of gas issued annually by gas utilities in each State, published in the Energy Supply Association of Australia series; *Electricity, Gas Australia* (ESAA 2005–2013);
- annual gas utility sales in each State and Territory, published in the Energy Supply Association of Australia series; *Electricity, Gas Australia* (ESAA 2005–2013); this figure is sales through the low pressure distribution system, and excludes sales made through high pressure mains to electricity generators and large industrial customers; and
- the composition of pipeline gas supplied in each State and Territory pipeline system (Table 3.43).

Table 3.43: Natural gas composition and emission factors, 2012

Pipeline	Longford, Melbourne (Victoria)	Moomba, Sydney, Adelaide (NSW, SA)	Roma, Brisbane (Qld)	Denison, Gladstone (Qld)	Dampier, Perth (WA)	Dongarra, Perth (WA)	Amadeus, Darwin (NT)	Australia (weighted average)
kg CO_2/GJ	0.9	0.8	0.8	0.7	1.0	1.5	0.0	0.88
kg CH_4/GJ	15.5	15.6	15.0	16.0	13.9	16.2	12.6	14.9
kg NMVOC/GJ	2.5	2.4	3.2	1.8	4.3	1.8	5.8	3.2
Weighted state averages:								
kg CO_2/GJ			0.8		1.1			
kg CH_4/GJ			15.1		14.3			
kg NMVOC/GJ			3.1		3.9			

Note: In previous years, EFs for both combustion and fugitive natural gas emissions have been calculated from pipeline gas composition data, published by the Australian Gas Association (AGA 1988–2002). However, as from 2001 the Association no longer collect this data from its members. It has been assumed that all natural gas EFs are unchanged from 2000.

Oil and Gas Production Venting and Flaring (1.B.2c)

Venting refers to emissions that are the result of process or equipment design or operational practices. Venting at oil and gas processing facilities is mainly associated with the release of CO_2, which is extracted from the raw gas stream in the course of gas processing. Because separation of the other components of the gas stream from the CO_2 is incomplete, the vented CO_2 contains small quantities of CH_4. The quantities of CO_2 and CH_4 vented will depend on the concentration of CO_2 in the raw gas, which varies significantly between gas fields, and on the mode of operation and efficiency of the CO_2 stripping plant. Gas processing facilities monitor the volumes of the vent gas and CO_2 and CH_4 concentrations as a part of routine plant operation. The venting of CH_4 also occurs from gas assisted pumps and cold process vents.

Flaring refers to the controlled combustion of a mixed flammable gas stream. At oil and gas processing plants, flared gas may arise from crude oil processing or natural gas processing. Where there is no market for gas separated from the wellhead production stream, the gas is reinjected or flared. With the growth in markets for natural gas and an increase in its value, some Australian petroleum production facilities now operate as combined

oil and gas facilities, with both oil and gas as marketable products. At such facilities, smaller quantities of gas are flared as part of normal operation of the various processing units. Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas.

Venting – Gas

From 1990 to 2008, estimates of emissions are based on APPEA 2007 data. The APPEA data consists largely of direct monitored emissions associated with control vent releases, equivalent to a *tier 3* estimation, as well as estimates of emissions from cold process vents. The NGER approach for 2009 onwards has enhanced the methodologies available for technology types by utilising the *American Petroleum Institute Compendium* (API 2009) methodologies for vents.

Flaring – Oil and Gas Combined

EFs can be found in Table 3.38 and are country-specific, sourced from the APPEA industry inventory. The NGER EFs are consistent with those used for the APPEA inventory, thus ensuring time series consistency.

Prior to 2009, the APPEA data did not provide splits for flaring between oil and gas sources and, therefore, flaring emissions were reported in the oil/gas combined category. With the introduction of the NGER for the inventory year 2009, separate emissions data has been available for the individual oil and gas flaring categories and therefore the flaring emissions have been reported for 2009 onwards in those respective categories. Consideration will be given in future inventory submissions as to how the historical time series for oil/gas combined flaring may be split to create time series consistent allocation between sectors.

3.9.3 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Time series consistency is maintained through the use of consistent methodologies and data over time. For the upstream oil and gas categories where NGER data are replacing APPEA data for 2009 – NGER methodologies were designed to be consistent with those used to compile the previous APPEA inventories. This ensured time series consistency in methodologies and emissions between the 2009 year and previous years.

3.9.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6. APPEA's inventories have been independently verified through the Greenhouse Challenge Program by PricewaterhouseCoopers and KPMG.

In response to the ERT's recommendations for Australia's 2013 submission, Australia has strengthened its sub-sectoral QC measures for this source category. Checks have been introduced into the QC process to look at trends in emissions by gas type at the sub-sectoral levels to complement the pre-existing checks for CO_2-equivalent emissions.

3.9.5 Recalculations Since The 2011 Inventory

Emissions have generally increased throughout the fugitive emissions from oil and natural gas extraction, resulting from:

- the incorporation of improved well drilling data in the gas exploration emissions time series; and
- the incorporation of improved crude oil production data in the crude oil transport time series.

Well drilling data from state departments (DIT 2013 and DNRM 2013b) relating to certain well types was previously only available from 2006 onwards, however, a complete time series from 1990 onwards became available for the first time this year. These revised time series included recalculations for previously supplied data for years 2006-2011. The incorporation of these data into the inventory is responsible for the majority of the increases observed in fugitive emissions from natural gas extraction, resulting in improvements in accuracy and time series consistency. The remainder of the revisions relate to emissions from venting and flaring of natural gas, resulting from QC procedures facilitated by the accumulation of four years of NGER (2009-2012) data.

The entire crude oil transport times series was recalculated, incorporating a new data source for Victorian crude oil production (BREE 2013a), which replaced the Gippsland Basin production data (DPI 2012) used in last year's inventory. This data replacement occurred because the 2012 data were not available for this year's inventory compilation, and the 1990-2011 data were also replaced to ensure time series consistency was maintained. This resulted in minor emission reductions across the fugitive emissions from crude oil transport time series.

Table 3.44: 1.B.2 Oil and gas: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1.B.2.a Oil				
1990	461.1	461.1	0.0	0.0%
2000	545.0	545.0	0.0	0.0%
2001	564.1	564.1	0.0	0.0%
2002	569.4	569.4	0.0	0.0%
2003	547.3	547.3	0.0	0.0%
2004	512.3	512.3	0.0	0.0%
2005	512.2	512.2	0.0	0.0%
2006	463.8	464.0	0.2	0.0%
2007	498.6	498.7	0.1	0.0%
2008	483.8	484.0	0.2	0.0%
2009	377.6	377.5	-0.1	0.0%
2010	374.8	356.9	-17.9	-4.8%
2011	352.1	352.0	-0.1	0.0%
1.B.2.b Natural gas				
1990	4,362.4	4,342.2	-20.2	-0.5%
2000	2,963.9	3,000.0	36.1	1.2%
2001	3,149.3	3,183.7	34.4	1.1%
2002	3,276.0	3,324.4	48.4	1.5%
2003	3,248.2	3,346.5	98.3	3.0%
2004	3,347.9	3,429.0	81.1	2.4%
2005	3,385.7	3,463.0	77.3	2.3%
2006	3,382.5	3,539.1	156.6	4.6%
2007	3,366.3	3,481.0	114.7	3.4%
2008	3,712.5	3,979.7	267.2	7.2%
2009	3,801.2	3,916.4	115.2	3.0%
2010	4,108.8	4,157.6	48.8	1.2%
2011	4,612.9	4,750.9	137.9	3.0%

3.9.6 Planned Improvements

NGER data will continue to be analysed for incorporation into the inventory where appropriate.

Further work will be undertaken to refine inputs into the estimation of venting emissions from oil and gas exploration. This will include allocating emissions between the respective oil and gas exploration categories.

Consideration will be given in future inventory submissions as to how the historical time series for oil and gas combined flaring may be split to create a time series consistent with the years 2009 onwards.

Fugitive emissions from coal seam gas

The department is collaborating with CSIRO Division of Energy Technology (Advanced Coal Technology) on a joint project which will run for 12 months. Research findings are expected to be available in the first half of 2014. The project is intended to provide preliminary data based on field measurements, and modelling of methane emissions from a sample of coal seam gas production facilities in Queensland and New South Wales.

The primary aims of the project are to:

- Make measurements at selected coal seam gas operations to quantify fugitive emission fluxes from various parts of the production process (e.g. wells, surface infrastructure), including:
  - measurements using flux chambers around wellheads to determine leakage arising from gas migration around the outside of a well casing or through a well casing; and
  - measurement of emission rates from equipment components at CSG production facilities.

The DE/CSIRO joint collaborative project will sample around 40 wells. The wells will be sampled multiple times during the project. The field sampling strategy associated with the project is intending to test the variance of a range of factors that may influence emissions. In addition to the production locality (basin) and well type (i.e. vertical or horizontal), other factors to be considered include:

- extraction technology - whether or not the well has been hydraulically fractured;
- age of the well;
- gas production rate;
- an allowance for a management factor; and
- type of surface equipment installed at the well.

The field data collected during this project will inform development of emission factors for coal seam gas fugitive emissions arising from well casing and general infrastructure leaks.

Appendix 3.A Additional Information on Activity Data

Table 3.A.1: Non-CO_2 Emission Factors 1.A.1 Energy Industries

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1.A.1.b Petroleum Refining (ANZSIC Class 1701)						
Natural Gas	1.1	0.1	722.9	56.6	1.1	2.3
Crude Oil	3.8	0.6	1,234.8	254.6	67.4	57.0
Kerosene	3.8	0.6	1,234.8	254.6	67.4	57.0
ADO	3.8	0.6	1,234.8	254.6	67.4	57.0
Fuel Oil	0.8	0.6	330.9	44.8	0.8	1,282.1
LPG	4.0	0.6	1,322.0	349.0	45.0	2.3
Naphtha	0.8	0.6	383.8	54.0	0.8	57.0
Refinery Gas and Liquids	0.8	0.6	383.8	54.0	0.8	2.3
Refinery Coke	0.8	0.6	383.8	54.0	0.8	370.0
1.A.1c Coke Oven Operation (ANZSIC Subdivision 21)						
Black Coal	1.0	0.8	237.0	201.0	1.0	370.0
Coke Oven Gas	1.0	0.8	287.0	36.7	1.0	370.0
Fuel Oil	1.0	0.6	502.0	75.0	0.9	1,282.1
Briquette Manufacture (ANZSIC Subdivision 17)						
Brown Coal	1.3	0.8	287.0	105.0	1.0	150.0
Coal Mining (ANZSIC Division B)						
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Natural Gas	1.1	0.1	86.24	14.0	1.1	2.3
Automotive Gasoline	8.6	0.6	1,306.0	476.0	163.0	15.0
ADO	3.6	0.6	1,166.3	221.4	70.0	57.0
LPG	0.1	0.6	154.0	13.0	5.0	2.3
Petroleum products nec	0.8	0.6	383.8	54.0	0.8	57.0
Ethanol	8.6	0.6	1,306.0	476.0	163.0	0
Oil and Gas Extraction (ANZSIC Division B)						
Natural Gas	7.8	0.1	1,76.3	42.7	2.3	2.3
Ethane	1.1	0.1	492.6	41.8	1.1	2.3
ADO	3.8	0.6	1,234.8	254.6	67.4	57.0
Fuel Oil	0.8	0.6	530.9	44.8	0.8	1,282.1
LPG	4.0	0.6	1,322.0	349.0	45.0	2.3
Petroleum products nec	4.0	0.6	1,320.0	346.8	45.5	57.0
Other Transport, Services and Storage (Natural Gas Transmission) (ANZSIC Subdivision 50-53)						
Natural Gas	7.8	0.1	187.9	46.0	2.4	2.3
Gas Production and Distribution (ANZSIC Subdivision 27)						
Natural gas	8.0	0.1	190.0	46.0	2.4	2.3
LPG	4.0	0.6	1,322.0	349.0	45.0	2.3

Source: Derived from Table 3.A.4.

Table 3.A.2: Non-CO_2 Emission Factors 1.A.2 Manufacturing and Construction

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Iron and steel (ANZSIC Group 211-12)						
Black coal	1.1	0.8	450.5	82.2	1.0	370.0
Natural Gas	0.9	0.1	914.6	68.2	1.1	2.3
Coke Oven Gas	1.1	0.1	274.0	36.7	1.0	370.0
ADO	2.5	0.5	553.6	175.5	43.3	57.0
LPG	22.0	0.5	437.0	5,465.0	409.0	2.3
1.A.2.b Non-Ferrous Metals (ANZSIC Group 213-14)						
Black Coal	1.2	0.8	316.9	103.6	1.0	370.0
Coke	1.2	0.8	316.9	103.6	1.0	370.0
Wood and Wood Waste	4.2	4.1	75.0	680.0	6.8	0
Natural Gas	1.1	0.1	519.2	43.6	1.1	2.3
ADO	5.2	0.6	906.7	341.0	93.0	57.0
Fuel Oil	2.0	0.6	294.0	38.5	0.8	1,282.1
Naphtha	2.0	0.6	294.0	38.5	0.8	57.0
Other Petroleum and Coal Product Manufacturing (ANZSIC Class 1709)						
Brown Coal Briquettes	1.0	0.8	488.5	77.1	1.0	150.0
Natural Gas	1.1	0.1	199.0	21.3	1.1	2.3
ADO	4.4	0.6	823.0	301.1	81.2	57.0
Fuel Oil	0.5	0.6	274.1	34.5	0.7	1,282.1
Liquefied Aromatic Hydrocarbons	0.5	0.6	274.1	34.5	0.7	57.0
LPG	1.5	0.6	281.9	294.5	20.2	2.3
Basic Chemical Manufacturing (ANZSIC Subdivision 18-19)						
Black Coal	1.3	0.8	287.0	105.0	1.0	370.0
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Natural Gas	1.1	0.1	492.6	41.8	1.1	2.3
Ethane	1.1	0.1	482.6	41.8	1.1	2.3
ADO	1.0	0.6	505.0	77.0	1.6	57.0
Liquefied Aromatic Hydrocarbons	1.3	0.8	287.0	105.0	1.0	57.0
LPG	5.8	0.6	487.0	1,303.1	39.9	2.3
Naphtha	1.0	0.6	501.7	75.0	0.9	57.0
Petroleum products nec	1.0	0.6	501.7	75.0	0.9	57.0
Chemicals, Rubber and Plastic Products (ANZSIC Subdivision 18-19)						
Black Coal	1.3	0.8	287.0	105.0	1.0	370.0
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Natural Gas	1.2	0.1	190.6	22.4	1.1	2.3
ADO	1.1	0.6	500.2	84.6	5.6	57.0
LPG	6.8	0.6	465.8	1,581.0	115.2	2.3
1.A.2.D Pulp, Paper And Print (ANZSIC Subdivisions 14-16)						
Black coal	1.3	0.8	287.0	105.0	1.0	370.0
Wood and Wood Waste	4.2	4.1	75.0	680.0	6.8	0

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Natural Gas	1.2	0.1	58.4	13.8	1.1	2.3
ADO	5.7	0.6	1,006.0	390.0	108.0	57.0
LPG	1.1	0.6	165.8	212.7	15.5	2.3
Petroleum products nec	0.3	0.6	155.6	13.5	0.6	57.0
1.A.2.E Food Processing, Beverages, Tobacco (ANZSIC subdivision 11-12)						
Black coal	1.3	0.8	207.1	105.9	1.0	370.0
Brown coal briquettes	1.3	0.8	207.1	105.9	1.0	150.0
Wood and Woodwaste	4.2	4.1	75.0	680.0	6.8	0
Bagasse	9.3	4.1	84.0	1,625.0	16.3	0
Natural Gas	1.1	0.1	49.5	11.0	1.7	2.3
ADO	4.9	0.6	868.2	329.1	90.6	57.0
Fuel Oil	0.6	0.6	154.2	13.2	0.6	1,282.1
LPG	1.3	0.8	207.1	105.9	1.0	57.0
Ethanol	0.6	0.6	154.2	13.2	0.6	2.3
Textile, Clothing, Footwear and Leather (ANZSIC Subdivision 13)						
Black Coal	1.3	0.8	287.0	105.0	1.0	370.0
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Natural Gas	1.2	0.1	58.0	13.7	1.1	2.3
Fuel Oil	0.4	0.6	155.7	13.6	0.6	1,282.1
Petroleum products nec	0.4	0.6	155.7	13.6	0.6	57.0
Fabricated Metal Products (ANZSIC Subdivision 22)						
Natural Gas	1.1	0.1	41.0	8.5	2.2	2.3
ADO	0.8	0.6	330.9	44.8	0.8	1,282.1
LPG	22.0	0.6	437.0	5,465.0	409.0	2.3
Machinery and Equipment (ANZSIC Subdivision 24)						
Natural Gas	1.1	0.1	542.2	44.9	1.1	2.3
ADO	2.8	0.6	651.0	194.3	44.9	57.0
LPG	21.1	0.6	435.6	5,242.0	392.2	2.3
Furniture and Other Manufacturing (ANZSIC Subdivision 25)						
Natural gas	1.1	0.1	189.3	20.3	1.1	2.3
1.A.2.F(II) Construction (ANZSIC Division E)						
Natural Gas	1.0	0.1	58.0	10.0	0.3	2.3
Kerosene	1.0	0.6	160.0	15.0	0.3	57.0
ADO	5.7	0.6	1,005.4	389.7	107.9	57.0
Fuel Oil	5.7	0.6	1,005.4	389.7	107.9	1,282.1
LPG	1.0	0.6	160.0	15.0	0.3	2.3
Glass and Glass Products (ANZSIC Group 201)						
Natural Gas	1.0	0.1	1010.0	75.0	1.1	2.3
LPG	1.0	0.6	502.0	75.0	0.6	2.3
Ceramics (ANZSIC Group 202)						
Black coal	1.0	0.8	502.0	75.0	1.0	370.0
Wood and Wood Waste	4.2	4.1	75.0	680.0	6.8	0

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Natural Gas	1.0	0.1	1,002.1	74.5	1.1	2.3
ADO	5.7	0.6	1,006.0	390.0	108.0	57.0
Fuel Oil	1.0	0.6	493.7	73.5	0.9	1,282.1
LPG	8.2	0.6	474.1	1,932.7	141.6	2.3
Petroleum products nec	1.0	0.6	493.7	73.5	0.9	57.0
Cement, Lime, Plaster and Concrete (ANZSIC Group 203)						
Black coal	1.0	0.8	500.0	75.7	1.0	370.0
Coke	1.0	0.8	500.0	75.7	1.0	370.0
Tyres	0.9	0.6	322.8	43.5	0.9	57.0
Wood and Wood Waste	4.2	4.1	75.0	680.0	6.8	0
Natural Gas	1.0	0.1	815.5	61.8	1.1	2.3
Coke Oven Gas	1.0	0.8	500.0	75.7	1.0	370.0
ADO	5.3	0.6	946.6	359.9	98.7	57.0
Fuel Oil	0.9	0.6	946.6	359.9	98.7	57.0
Solvents	0.9	0.6	322.8	43.5	0.9	57.0
LPG	21.7	0.6	435.6	5,398.1	404.0	2.3
Petroleum products nec	0.9	0.6	322.8	43.5	0.9	57.0
Other Non-Metallic Mineral Products (ANZSIC Group 209)						
Black coal	1.1	0.8	465.5	80.0	1.0	370.0
Coke	1.1	0.8	465.5	80.0	1.0	370.0
Natural Gas	0.9	0.1	900.1	67.8	1.1	2.3
ADO	5.7	0.6	1,006.0	390.0	108.0	57.0
Fuel Oil	0.4	0.6	477.1	70.6	0.9	1,282.1
LPG	19.7	0.6	441.3	4,884.1	365.1	2.3
Petroleum products nec	0.4	0.6	477.1	70.6	0.9	57.0
1.A.2.F(iv) Mining (non-Energy Minerals (ANZSIC subdivisions 08-10)						
Black coal	1.0	0.8	493.0	78.0	1.0	370.0
Coke	1.0	0.8	493.0	78.0	1.0	370.0
Natural Gas	1.1	0.1	86.2	14.0	1.1	2.3
Coke Oven Gas	3.9	0.1	122.6	28.0	1.6	370.0
ADO	3.7	0.6	1,190.4	226.2	71.1	57.0
Fuel Oil	0.8	0.6	330.9	44.8	0.8	1,282.1
LPG	1.1	0.6	330.9	44.8	0.8	2.3
Petroleum products nec	0.8	0.6	383.8	54.0	0.8	57.0

Source: Derived from Table 3.25.

Table 3.A.3: Non-CO_2 Emission Factors: Other Sectors

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
281 Water, Sewerage and Drainage						
Natural Gas	1.2	0.1	58.0	14.0	1.1	2.3
Kerosene	0.1	0.6	154.0	13.0	0.5	57.0
ADO	5.7	0.6	1006.0	390.0	108.0	57.0
50-53 Other Transport, Services and Storage (part)						
ADO	0.6	0.6	53.0	13.0	0.9	57.0
Div. F, G Wholesale and Retail Trade						
Wood and Wood Waste	3.4	4.1	75.0	330.0	5.6	0
Natural Gas	1.1	0.2	42.3	45.5	2.8	2.3
Town Gas	1.1	0.2	42.3	15.6	2.8	2.3
ADO	0.6	0.6	53.2	13.1	0.9	57.0
Fuel Oil	0.6	0.6	53.2	13.1	0.9	1282.1
LPG	0.6	0.6	53.2	13.1	0.9	2.3
Div. H, P, Q Accommodation, Cultural and Personal						
Wood and Wood Waste	3.4	4.1	19.0	330.0	5.6	0
Natural Gas	1.1	0.1	44.8	9.7	2.0	2.3
ADO	0.6	0.6	53.0	13.0	0.9	57.0
LPG	0.6	0.6	53.0	13.0	0.9	2.3
Div. J Communication						
Natural Gas	1.1	0.1	41.0	8.5	2.2	2.3
Kerosene	0.6	0.6	53.0	13.0	0.9	57.0
ADO	0.6	0.6	53.0	13.0	0.9	57.0
Div. K, L Finance, Insurance, Property and Business						
Natural Gas	1.1	0.1	41.0	8.5	2.2	2.3
Div. M Government Administration and Defence						
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Wood and Wood Waste	4.2	4.1	57.0	680.0	6.8	0
Natural Gas	1.1	0.1	46.6	10.3	1.8	2.3
Kerosene	0.4	0.6	84.4	13.0	0.8	57.0
ADO	0.4	0.6	84.4	13.0	0.8	57.0
LPG	0.4	0.6	84.4	13.0	0.8	2.3
Div. N, O Education, health and community services						
Black Coal	1.3	0.8	287.0	105.0	1.0	370.0
Brown Coal Briquettes	1.3	0.8	287.0	105.0	1.0	150.0
Wood and Wood Waste	4.2	4.1	75.0	680.0	6.8	0
Natural Gas	1.1	0.1	44.8	10.4	1.8	2.3
Town Gas	1.1	0.1	44.8	10.4	1.8	2.3
Kerosene	0.4	0.6	53.0	13.0	0.7	57.0
ADO	0.4	0.6	53.0	13.0	0.7	57.0
LPG	0.4	0.6	53.0	13.0	0.7	2.3

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Residential						
Wood and Wood Waste [(a)]						
Natural Gas	1.6	0.1	30.0	16.0	3.1	2.3
Town Gas	1.6	0.1	39.0	16.0	3.1	2.3
ADO	4.7	0.6	48.0	13.0	1.9	57.0
LPG	4.7	0.6	48.0	13.0	1.9	2.3
1.A.4.c Agriculture, Forestry & Fisheries: (ANZSIC Division A)						
Natural Gas	1.1	0.1	41.0	476.0	2.2	2.3
Gasoline	8.6	0.6	1306.0	476.0	163.0	15.0
ADO	8.6	0.6	1306.0	14.0	163.0	57.0
LPG	1.3	0.6	154.0	14.0	0.5	2.3

Source: Derived from Table 3.A.4.

(a) See Table 3.A.4 for Residential biomass EFs.

Table 3.A.4: Derivation of non-CO_2 emission factors for stationary energy

			Emission Factors(Mass/Mass or Volume or Energy)						Conversion Factors		Emission Factors (Mass/Gross Energy Use)				
Sector	Fuel	Equipment	CH_4	N_2O^a	NO_x	CO	NMVOC	Units	Value	Units	CH_4	N_2O^a	NO_x	CO	NM-VOC
											Mg/ PJ				
Electricity Generation/Utility															
1	Natural Gas	Boiler[b]	4.8		8,800	640	23.24	kg/10^6m^3	38.9	MJ/m^3	0.1	0.1	226	16	0.6
2	Residual Oil	Boiler[c]	0.034		8	0.6	0.091	kg/10^3L	42.9	MJ/L	0.8	0.6	186	14	2.1
3	Distillate Oil	Boiler[d]	0.002		3	0.6	0.06	kg/10^3L	45.6	MJ/L	0.04	0.6	64	13	1.4
4	Black Coal	Tangentially Fired[e]	0.02		7.2	0.25	0.04	kg/t	23.5	GJ/t	0.9	0.8	306	11	1.7
5	Black Coal	Pulverised Wall[f]	0.02		10.85	0.25	0.04	kg/t	23.5	GJ/t	0.9	0.8	462	11	1.7
6	Brown Coal	Tangentially Fired[g]									0.9	1.4	136	17	1.7
4	Natural Gas	Turbine[h]	7.95		190	46	2.37	ng/J	1.0		8.0	0.1	190	46	2.4
7	Natural Gas	Internal Combustion[i]	240		1,331	340	80	ng/J	1.0		240	0.1	1,331	340	80
8	Fuel Oil	Internal Combustion[j]	4		1,322	349	45	ng/J	1.0		4.0	0.6	1,322	349	45
9	Diesel	Internal Combustion[k]	4		1,322	349	45	ng/J	1.0		4.0	0.6	1,322	349	45
Other Energy Transformation and Industrial															
10	Natural Gas	Boiler[l]	47.8		2,240	560	44.16	kg/10^6m^3	38.9	MJ/m^3	1.2	0.1	58	14	1.1
11	Residual Oil	Boiler[m]	0.12		6.6	0.6	0.034	kg/10^3L	42.9	MJ/L	2.8	0.6	154	14	0.8
12	Distillate Oil	Boiler[n]	0.006		2.4	0.6	0.024	kg/10^3L	45.6	MJ/L	0.1	0.6	53	13	0.5
13	Black Coal	Boiler[o]	0.03		6.8 5	2.5	0.025	kg/t	23.9	GJ/t	1.3	0.8	287	105	1.0
14	Wood	Boiler[p]	0.042		0.75	6.8	0.068	kg/t	10.0	GJ/t	4.2	4.1	75	680	6.8
15	Bagasse	Boiler [q]									10.0	4.1	84	1,625	16.3
16	Natural Gas	Kiln[r]									1.0	0.1	1,010	75	1.1
17	Fuel Oil	Kiln[r]									1.0	0.6	502	75	0.8
18	Black Coal	Kiln[r]									1.0	0.8	502	75	1.0

			Emission Factors(Mass/Mass or Volume or Energy)						Conversion Factors		Emission Factors (Mass/Gross Energy Use)				
											CH_4	N_2O^a	NO_x	CO	NM-VOC
Sector	Fuel	Equipment	CH_4	N_2O^a	NO_x	CO	NMVOC	Units	Value	Units	Mg/ PJ				
19	Black Coal	Coke Oven[r]									1.0	0.8	287	201	1.0
20	Natural Gas	Dryer[r]									1.0	0.1	58	10	1.1
21	Fuel Oil	Dryer[r]									1.0	0.6	160	15	0.8
22	Black Coal	Dryer[r]									1.0	0.8	215	170	1.7
Commercial															
23	Natural Gas	Boiler[s]	43.5		1,600	330	84.48	kg/10^6m^3	38.9	MJ/m^3	1.1	0.1	41	8.5	2.2
24	Residual Oil	Boiler[t]	0.057		6.6	0.6	0.136	kg/10^3L	42.9	MJ/L	1.3	0.6	154	14	3.2
25	Distillate Oil	Boiler[u]	0.026		2.4	0.6	0.041	kg/10^3L	45.6	MJ/L	0.6	0.6	53	13	0.9
26	Black Coal	Boiler[v]	0.03		3.75	3	0.025	kg/t	23.9	GJ/t	1.3	0.8	157	126	1.0
27	Wood	Boiler[w]	0.034		0.19	3.3	0.056	kg/t	10.0	GJ/t	3.4	4.1	19	330	5.6
Residential															
28	Natural Gas	Heater[x]	61.2		1,500	640	118.8	kg/10^6m^3	38.9	MJ/m^3	1.6	0.1	39	16	3.1
29	Black Coal	Hot Water Heater[y]	2.5		4.55	137.5	5	kg/t	23.9	GJ/t	105	0.8	190	5,753	209
30	Wood	Fireplace[z]	43.5		1.3	126.3	71.0	kg/t	16.2	GJ/t	2,686	4.1	80	7,796	4,382
31	Wood	Stove[aa]	2.4		1.4	115.4	21.9	kg/t	16.2	GJ/t	148	4.1	86	7,123	1,352
32	LPG	Furnace[ab]	0.02		1.7	0.2	0.04	kg/10^3L	25.3	MJ/L	0.8	0.1	67	7.9	1.6
33	Distillate Oil	Furnace[ac]	0.214		2.2	0.6	0.085	kg/10^3L	45.6	MJ/L	4.7	0.6	48	13	1.9
34	Gas	Miscellaneous [ad]									1.1	0.1	41	8.5	2.2
35	Oil	Miscellaneous [ad]									1.3	0.6	154	14	3.2
36	Black Coal	Miscellaneous [ad]									1.3	0.8	157	126	1.0

Sources:

[a] IPCC (1997, Volume 3) Assume value is independent of equipment category, i.e. fuel dependent only (0.1, 0.6, 0.8 and 4.1 Mg/PJ for natural gas, oil, coal and wood combustion, respectively).

[b] USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from natural gas fired utility/large industrial boilers (>29 MW).

[c] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from residual oil (No. 4 - 6) fired utility boilers (normal firing).

[d] Distillate oil fired utility boiler data not available. Assume emissions equal those of residual oil fired utility boiler scaled by relative emissions of industrial boiler category (USEPA, 1986, Pg 1.3-2) .

[e] USEPA (1995b) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration (tangentially fired boiler).

[f] USEPA (1995b) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration.

[g] Assume CH_4 and NMVOC EFs identical to black coal combustion. CO and NO_x EFs based on average of SECV data (1994). N_2O emission rate based on mid-range value as reported by IEA Coal Research (1993).

[h] USEPA (1995b) Pg 3.1-3 and 3.1-5. Uncontrolled emissions of CO and NO_x for large stationary natural gas turbines. NMVOC and CH_4 emissions estimated from ratio of NMHC and CH_4, respectively: to Total Organic Compounds for selective catalytic reduction controlled turbines.

[i] USEPA (1995b) Pg 3.4-3. Assume dual fuel EFs.

[j] USEPA (1995b) Pg 3.4-3. Assume diesel EFs.

[k] USEPA (1995b) Pg 3.4-3.

[l] USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from natural gas fired 'small industrial' boilers (3-29 MW).

[m] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from residual oil fired industrial boilers.

[n] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from distillate oil fired industrial boilers.

[o] USEPA (1995b) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for spreader stoker firing configuration.

[p] USEPA (1995b) Pg 1.6-6 to 1.6-7. Uncontrolled emissions from wood waste combustion in stoker boiler. Assume wood moisture content of 50% as recommended by USEPA. Assume CH_4/TOC as for [z].

[q] IPCC (1997a) data for NO_x and CO converted to gross calorific equivalent by dividing by 1.05. CH_4 and NMVOC emission rates estimated by scaling relative to wood boiler data (see [p]).

[s] USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from natural gas fired 'commercial' boilers (0.1-2.9 MW).

[t] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from residual oil (No. 5 and 6) fired commercial boilers (0.1-2.9 MW).

[u] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from distillate oil fired commercial boilers (0.1-2.9 MW).

[v] USEPA (1995b) Pg 1.1-6 and 1.1-23. Uncontrolled emissions for overfeed stoker firing configuration.

[w] USEPA (1995b) Pg 1.6-6 to 1.6-7. Uncontrolled emissions from wood waste combustion in Dutch oven boiler. Assume wood moisture content of 50% as recommended by USEPA. Assume CH_4/TOC as for [z].

[x] USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from natural gas fired residential furnaces (< 0.1 MW).

[y] USEPA (1995b) Pg 1.1-7 and 1.1-23. Uncontrolled emissions for hand fired units.

[z] USEPA (1995b) Pg 1.9-3. Assume CH_4 constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion).

[aa] USEPA (1995b) Pg 1.10-3. Assume CH_4 constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion).

[ab] USEPA (1995b) Assume propane combustion (commercial boiler) and CH_4 to constitute 34% of total organic emissions (as recommended by USEPA for residential gas fired furnace).

[ac] USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH_4 from distillate oil fired residential furnace (< 0.1 MW).

[ad] Assume EFs for commercial boilers (0.1 - 2.9 MW).

Table 3.A.5: Passenger and light commercial vehicles: CH_4, NO_x and CO emission factors split by urban/non-urban road conditions and hot/cold operation at vehicle group's average VKT

Vehicle Age	Passenger Car			LCV		
	Urban		Non-urban	Urban		Non-urban
	Hot	Cold		Hot	Cold	
	EF (g/km)	EF (g/km)	EF (g/km)	EF (g/km)	EF (g/km)	EF (g/km)
CH_4						
Post-2005	0.005	0.022	0.005	0.007	0.029	0.008
2004-2005	0.015	0.034	0.011	0.026	0.057	0.021
1998-2003	0.022	0.051	0.015	0.047	0.083	0.028
1994-1997	0.081	0.080	0.054	0.098	0.167	0.056
1985-1993 (2-way cat)	0.087	NA	0.048	NA	NA	NA
1985-1993 (3-way cat)	0.103	0.065	0.055	0.130	0.002	.111
CO						
Post-2005	0.205	2.234	0.315	0.218	2.853	0.453
2004-2005	0.757	3.956	0.887	1.459	7.402	1.286
1998- 2003	1.879	8.503	1.534	5.429	14.627	3.430
1994-1997	7.663	16.206	5.195	14.802	28.031	10.544
1985-1993 (2-way cat)	12.318	23.736	7.845	NA	NA	NA
1985-1993 (3-way cat)	15.611	22.019	9.958	30.732	41.299	26.293
NO_x						
Post-2005	0.052	0.133	0.045	0.145	0.328	0.124
2004-2005	0.090	0.281	0.107	0.271	0.360	0.304
1998-2003	0.365	0.837	0.547	1.442	1.768	1.915
1994-1997	0.769	1.366	1.045	1.734	1.982	2.168
1985-1993 (2-way cat)	0.961	1.133	1.420	NA	NA	NA
1985-1993 (3-way cat)	0.885	1.246	1.261	3.046	3.225	3.169

Note: As deterioration rates are assumed to be 0 for N_2O the EF at the vehicles group's average VKT is the same as at 0 VKT. The cold start EFs are reported in the table above as g/km.

Source: Orbital Australia 2010 and Orbital Australia 2011(c)

Table 3.A.6: Passenger and light commercial vehicles: Zero kilometre CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation

fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post-2005	0.002	Orbital Australia 2010	0.053	Orbital Australia 2010	0.001	Orbital Australia 2010	0.002	Orbital Australia 2010	0.073	Orbital Australia 2010	0.003	Orbital Australia 2010
2004-2005	0.005		0.073		0.002		0.017		0.138		0.013	
1998-2003	0.003		0.098		0.000		0.013		0.155		0.000	
1994-1997	0.076		0.228		0.049		0.054		0.384		0.012	
1985-1993 (3-way cat)	0.052	Orbital Australia 2011(b)	0.336	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)
1985-1993 (2-way cat)	0.014		0.207		0.010		0.000		0.000		0.000	
1976-1985	0.125	Carnovale 1991	0.434	USEPA (as cited in IPCC 2006)	0.065	Carnovale 1991	0.140	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.487	USEPA (as cited in IPCC 2006)	0.087	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
Pre-1976	0.133		0.461		0.112		0.150		0.521		0.100	
LPG												
Post-2005	0.080	COPERT IV	0.240	COPERT IV (converted to a per start EF)	0.025	COPERT IV (Highway)	0.080	Petrol LCV EF x Pass car LPG to petrol ratio	0.240	Petrol LCV EF x Pass car LPG to petrol ratio	0.025	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.080		0.240		0.025		0.080		0.240		0.025	

fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
1998-2003	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985-1997 (3-way cat)	0.024		0.096		0.011		0.024		0.096		0.011	
1985-1997 (2-way cat)	0.033		0.131		0.014		0.033		0.131		0.014	
1976-1985	0.031		0.125		0.014		0.031		0.125		0.014	
Pre-76	0.032		0.126		0.014		0.032		0.126		0.014	
ADO												
Post-2005	0.003	COPERT IV	0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)	0.003	COPERT IV	0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)
2004-2005	0.007		0.018		0.002		0.007		0.018		0.002	
1998-2003	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985-1997 (3-way cat)	0.001		0.003		0.000		0.001		0.003		0.000	
1985-1997 (2-way cat)	0.001		0.004		0.001		0.001		0.004		0.001	
1976-1985	0.001		0.004		0.001		0.001		0.004		0.001	
Pre-76	0.001		0.004		0.001		0.001		0.004		0.001	
Ethanol[a]												

fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Post-2005	0.037	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.049	Hot EF x Petrol Non-urban to Hot Urban ratio	0.037	Passenger car EF x LCV to car ratio	NA		0.049	Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.037				0.049		0.037				0.049	
1998-2003	0.037				0.025		0.053				0.048	
1985-1997 (3-way cat)	0.206	Post 97 EF x earlier petrol age class relativity			0.158		0.211				0.159	
1985-1997 (2-way cat)	0.592				0.331		0.581				0.449	
1976-1985	0.661				0.344		0.740				0.460	
Pre-1976	0.703				0.592		0.793				0.529	

(a) raw ethanol content of blended fuel
Sources (as indicated in table):FORS (1996); Carnovale *et al.* (1991); IPCC (2006); Orbital Australia (2010); Orbital Australia (2011b)

Table 3.A.7: Medium and heavy duty trucks and buses: Zero kilometre CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation

Fuel type	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)
1996 - 2002	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV
Pre 1996	0.140		0.110		0.140		0.110		0.140		0.110	
LPG												
Post 2002	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.067	DCC 2006	0.029	Passenger car LPG COPERT IV non-urban to urban ratio
1996 - 2002	0.220		0.096		0.220		0.096		0.120		0.053	
Pre 1996	0.220		0.096		0.220		0.096		0.120		0.053	
ADO												
Post 2007	0.0025	COPERT IV (x EF reduction %)	0.0051		0.00525	COPERT IV (x EF reduction %)	0.0042		0.00525	COPERT IV (x EF reduction %)	0.0021	
Post 2003 - 2007	0.046		0.07735	Hot urban EF x COPERT IV non-urban to urban ratio	0.098		0.0637	Hot urban EF x COPERT IV non-urban to urban ratio	0.10325		0.0413	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.157	COPERT IV	0.037		0.157	COPERT IV	0.07		0.157	COPERT IV	0.0628	
Pre 1996	0.157		0.037		0.157		0.063		0.157		0.0628	

Table 3.A.8: Passenger and light commercial vehicles: Zero kilometre N_2O emissions factors split by urban/non-urban road conditions and hot/cold operation

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF g/start	Source	EF (g/km)	Source	EF g/start	Source	EF g/start	Source	EF (g/km)	Source
Petrol												
post 2005	0.001	Orbital Australia 2010	0.037	Orbital Australia 2010	0.001	Orbital Australia 2010	0.003	Orbital Australia 2010	0.144	Orbital Australia 2010	0.001	Orbital Australia 2010
2004-2005	0.008		0.121		0.009		0.006		0.087		0.009	
1998 - 2003	0.030		0.332		0.029		0.041		0.156		0.029	
1994 – 1997	0.037		0.231		0.012		0.025		0.137		0.012	
1985 – 1993 (3-way cat)	0.057	Orbital Australia 2011(b)	0.194	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.002	Orbital Australia 2011(b)	0.005	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)
1985 – 1993 (2-way cat)	0.000		0.000		0.000		0.000		0.000		0.000	
1976 – 1985	0.004	Weeks et al 1993	0.041	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.005	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.047	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
Pre 76	0.003		0.036		0.002		0.003		0.041		0.002	
LPG												
post 2005	0.005	COPERT IV	0.027	COPERT IV (converted to a per start EF)	0.001	COPERT IV (Highway)	0.008	Petrol LCV EF x Pass car LPG to petrol ratio	0.081	Petrol LCV EF x Pass car LPG to petrol ratio	0.003	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.013		0.069		0.002		0.026		0.178		0.018	

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF g/start	Source	EF (g/km)	Source	EF g/start	Source	EF g/start	Source	EF (g/km)	Source
1998 - 2003	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.006		0.017		0.001		0.006		0.017		0.001	
1985 – 1997 (2-way cat)	0.003		0.008		0.002		0.003		0.008		0.002	
1976 – 1985	0.003		0.008		0.000		0.003		0.008		0.000	
Pre 76	0.002		0.005		0.000		0.002		0.005		0.000	
ADO												
post 2005	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)
2004-2005	0.004		0.045		0.006		0.004		0.045		0.006	
1998 - 2003	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.001		0.003		0.002		0.001		0.003		0.002	
1985 – 1997 (2-way cat)	0.001		0.002		0.001		0.001		0.002		0.001	
1976 – 1985	0.001		0.002		0.000		0.001		0.002		0.000	
Pre 76	0.000		0.001		0.000		0.000		0.001		0.000	
Ethanol[a]												

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF g/start	Source	EF (g/km)	Source	EF g/start	Source	EF g/start	Source	EF (g/km)	Source
post 2005	0.030	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.015	Post 97 hot Ef x Petrol Non-urban to Hot Urban ratio	0.049	Passenger car EF x LCV to car ratio	NA		0.049	ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.030				0.007		0.059				0.059	
1998 - 2003	0.030				0.025		0.082				0.082	
1985 – 1997 (3-way cat)	0.030	Post 97 EF x earlier petrol age class relativity			0.029		0.049				0.049	
1985 – 1997 (2-way cat)	0.012				0.011		0.015				0.015	
1976 – 1985	0.004				0.010		0.005				0.005	
Pre 76	0.003				0.010		0.003				0.002	

(a) raw ethanol content of blended fuel
Sources (as indicated in table): Weeks *et al.* (1993),IPCC (2006), Orbital Australia (2010); Orbital Australia (2011b)

Table 3.A.9: Medium and heavy duty trucks and buses: Zero kilometre N_2O g/km emission factors split by urban/non-urban road conditions and hot/cold operation

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
Fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV
1996 - 2002	0.006		0.006		0.006		0.006		0.006		0.006	
Pre 1996	0.006		0.006		0.006		0.006		0.006		0.006	
LPG												
Post 2002	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.011	DCC 2006	0.011	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.020		0.020		0.020		0.020		0.011		0.011	
Pre 1996	0.020		0.020		0.020		0.020		0.011		0.011	
ADO												
Post 2002	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.030		0.030		0.030		0.030		0.030		0.030	
Pre 1996	0.030		0.030		0.030		0.030		0.030		0.030	

Table 3.A.10: Vehicle emission factors for indirect gases by year of vehicle manufacture (g/km)

	Passenger Car			LCV			Medium Duty Truck			Heavy Duty Truck			Bus		
Fuel type	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC
Petrol															
post 2005	0.044	0.108	0.077	0.139	0.047	0.236	2.52	10.87	1.04	2.52	10.87	1.04	3.91	48.61	3.47
2004-2005	0.075	0.399		0.275	0.669										
1998 - 2003	0.167	0.037		0.820	1.664										
1994 – 1997	0.498	6.906		1.456	10.108										
1985 – 93 (3-way cat)	0.669	10.378	0.294	0.000	0.000	0.236									
1985 – 93 (2-way cat)	0.619	0.083	0.260	0.000	0.000	0.791									
1976 – 1985	1.400	14.900	1.419	2.853	25.977	4.314									
Pre 76	2.460	24.000	2.275	5.014	41.842	6.914									
LPG															
Post 97	0.472	2.327	0.199	0.472	2.327	0.199	4.83	24.00	4.21	4.83	10.87	4.21	2.76	24.00	2.41
1985 – 97 (3-way cat)	0.942	10.305	0.755	0.942	10.305	0.755									
1985 – 97 (2-way cat)	1.947	14.614	0.669	1.947	14.614	0.669									
1976 – 1985	2.931	39.881	3.647	2.931	22.875	3.647									
Pre 76	5.150	64.238	5.846	5.150	36.846	5.846									
ADO															
Post 97	0.250	0.116	0.062	0.250	0.116	0.062	5.20	6.44	1.15	5.20	24.00	1.15	4.90	2.88	1.56
1985 – 97 (3-way cat)	0.500	0.515	0.237	0.500	0.515	0.237									
1985 – 97 (2-way cat)	1.034	0.731	0.210	1.034	0.731	0.210									
1976 – 1985	1.556	1.994	1.144	1.556	1.994	1.144									
Pre 76	2.734	3.212	1.833	2.734	3.212	1.833									

Note: For light duty vehicles hot urban EFs are reported in the table above.

Table 3.A.11: Passenger and light commercial vehicles: non-CO_2 emission factor deterioration rates (g/km/km)

	Vehicle Age Class							
	Pre-1979[c]	1980-85[c]	1985-93[a c]	1985-93 [b d]	1994-97[e]	1998-03[e]	2004-05[e]	2006-current[e]
Passenger Cars								
CH_4	6.35E-07	4.76E-07	3.85E-07	5.85E-07	2.5E-08	1.38E-07	1.52E-07	1.54E-07
N_2O	0	0	0	0	0	0	0	0
CO	1.45E-04	1.27E-04	4.71E-05	1.06E-04	4.31E-06	1.43E-05	5.83E-06	4.74E-06
NO_x	0.00E+00	6.48E-06	1.54E-06	2.98E-06	1.54E-06	1.76E-06	2.73E-07	3.04E-07
NMVOC[d]	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06
Light Commercial Vehicles								
CH_4	0	0	0	0	2.35E-07	2.08E-07	1.46E-07	1.55E-07
N_2O	0	0	0	0	0	0	0	0
CO	0	0	0	0	2.22E-05	2.29E-05	1.35E-06	6.23E-06
NO_x	**0**	**0**	**0**	0	1.49E-06	4.46E-06	0	1.08E-07
NMVOC[d]	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06

Notes: (a) 3-way catalyst
(b) 2-way catalyst.

Sources: (c) EPA NSW 1995
(d) Orbital Australia (2011c)
(e) Orbital Australia (2010).

Energy

Table 3.A.12: Road transport: non- CO_2 emission factors

Source Category		Emission Factor (g/km)				
Sector	**Fuel Type**	**CH_4 [a]**	**N_2O [b]**	**NO_x [c]**	**CO [c]**	**NMVOC [c]**
Medium Trucks	NG [e]	0.101	0.001	1.200	0.200	0.010
Heavy Trucks	NG [e]	0.101	0.001	1.200	0.200	0.010
Buses	NG [e]	0.101	0.001	1.200	0.200	0.010
Motorcycles	Petrol	0.150	0.002	0.210	19.270	4.580
Passenger Cars	NG [e]	0.261	0.001	0.190	0.110	0.020
Light Commercial Vehicles	NG [e]	0.261	0.001	0.190	0.110	0.020

Sources: (a) Hoekman (1992)
(b) Weeks *et al.* (1993)
(c) Carnovale *et al.* (1991)
(d) EPA NSW (1995)
(e) de Maria (1992).

Table 3.A.13: Shares used to allocate BREE fuel consumption to unlisted categories 2012

ANZSIC category fuel consumption reported by BREE	General use	Military	Small marine craft	Off-road vehicles	Utility engines
Road transport automotive gasoline	96.86%	0.02%	2.39%	0.10%	0.63%
Road transport ADO	99.88%	0.12%			
Water transport ADO	79.65%	20.35%			
Water transport fuel oil	100%				
Air transport aviation gasoline	99.91%	0.09%			
Air transport aviation turbine fuel	92.57%	7.43%			

Sources: Derived from Farrington 1988, ABS 2006 and Department of Industry 2013.

Table 3.A.14: Shares of total road fuel consumption by vehicle and fuel type 2012

Vehicle Type	Fuel Type			
	Automotive Gasoline	ADO	LPG	NG [a]
Passenger cars	0.861	0.148	0.649	0.007
Light commercial vehicles	0.130	0.229	0.260	0.011
Medium duty trucks	0.001	0.223	0.006	0.017
Heavy duty trucks	-	0.353	0.009	-
Buses	0.002	0.048	0.075	0.966
Motor cycles	0.006	-	-	-

Source: (a) ABS 2013a
(b) Pekol Traffic and Transport 2013

Table 3.A.15: Australian petrol-fuelled vehicle stock age distribution and fuel consumption rates: 2012

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2012 [b]	323,268	0.105	15,777	0.126	70	0.202	18	0.202	323	0.146
2011	651,917	0.105	37,858	0.129	197	0.173	28	0.251	1,029	0.144
2010	700,148	0.105	48,486	0.129	265	0.173	37	0.251	933	0.144
2009	621,991	0.105	50,312	0.129	208	0.173	45	0.251	837	0.144
2008	673,823	0.105	62,371	0.129	333	0.173	69	0.251	1,246	0.144
2007	727,985	0.105	65,440	0.129	556	0.173	171	0.251	1,109	0.144
2006	692,381	0.107	62,535	0.1385	648	0.174	69	0.253	1,131	0.136
2005	720,896	0.107	92,788	0.1385	519	0.174	47	0.253	813	0.136
2004	679,467	0.113	87,433	0.14	538	0.196	73	0.265	492	0.148
2003	662,169	0.113	80,535	0.14	396	0.196	51	0.265	921	0.148
2002	582,706	0.113	64,039	0.14	482	0.196	36	0.265	756	0.148
2001	552,362	0.113	57,480	0.14	364	0.196	27	0.265	568	0.148
2000	542,859	0.113	53,233	0.14	265	0.196	14	0.265	945	0.148
1999	491,848	0.113	55,736	0.14	252	0.196	17	0.265	729	0.148
1998	494,532	0.113	50,671	0.14	323	0.196	36	0.265	755	0.148
1997	400,072	0.113	41,254	0.14	291	0.196	27	0.265	685	0.148
1996	307,962	0.117	38,555	0.1335	236	0.242	25	0.310	553	0.142
1995	279,655	0.117	35,544	0.1335	227	0.242	24	0.310	523	0.142
1994	239,575	0.117	34,375	0.139	249	0.293	40	0.338	442	0.154
1993	187,837	0.117	26,289	0.139	221	0.293	25	0.338	367	0.154
1992	154,139	0.117	25,835	0.139	268	0.293	12	0.338	368	0.154
1991	127,552	0.117	21,034	0.139	234	0.293	6	0.338	302	0.154
1990	125,358	0.117	23,106	0.139	318	0.293	19	0.338	311	0.154
1980 – 1989 [a]	336,719	0.117	90,921	0.139	4,411	0.293	136	0.338	1,111	0.154
1979 and earlier	201,984	0.117	40,962	0.139	20,508	0.293	263	0.338	305	0.154

Notes: (a) Fuel consumption rates average for period 1980–89.

(b) Assumes new cars on road for average of 6 months in the first year.

Source: DE estimates derived from ABS 2012a, ABS 2012b.

Table 3.A.16: Australian diesel-fuelled vehicle stock age distribution and fuel consumption rates: 2012

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2012 [b]	73,908	0.100	73,300	0.114	8,399	0.268	2,780	0.598	2,142	0.288
2011	128,965	0.070	123,794	0.139	15,616	0.274	3,696	0.577	4,701	0.287
2010	123,981	0.105	124,209	0.139	24,731	0.274	6,220	0.577	4,542	0.287
2009	89,916	0.105	102,048	0.139	18,764	0.274	3,395	0.577	3,699	0.287
2008	90,268	0.105	112,657	0.139	23,110	0.274	4,454	0.577	4,897	0.287
2007	68,719	0.105	87,136	0.139	28,469	0.274	8,529	0.577	3,485	0.287
2006	53,647	0.125	77,117	0.118	21,625	0.288	4,998	0.556	3,369	0.294
2005	38,865	0.125	60,498	0.118	22,085	0.288	5,285	0.556	3,312	0.294
2004	33,196	0.126	53,818	0.123	20,868	0.289	4,997	0.543	2,449	0.299
2003	28,275	0.126	44,200	0.123	15,582	0.289	4,195	0.543	2,244	0.299
2002	23,845	0.126	39,779	0.123	17,601	0.289	3,219	0.543	2,205	0.299
2001	20,040	0.126	28,252	0.123	12,364	0.289	2,331	0.543	2,146	0.299
2000	18,634	0.126	32,841	0.123	12,256	0.289	2,421	0.543	2,909	0.299
1999	15,447	0.126	30,407	0.123	12,309	0.289	2,519	0.543	2,430	0.299
1998	14,547	0.126	27,695	0.123	11,802	0.289	2,857	0.543	2,471	0.299
1997	12,675	0.112	23,755	0.123	9,383	0.289	2,185	0.543	2,122	0.299
1996	11,098	0.112	21,157	0.127	8,291	0.299	1,826	0.533	2,113	0.302
1995	10,980	0.112	19,284	0.127	9,092	0.299	2,119	0.533	2,368	0.302
1994	11,653	0.124	19,387	0.124	10,067	0.295	2,227	0.529	2,312	0.325
1993	10,666	0.124	16,774	0.124	7,864	0.295	1,406	0.529	1,862	0.325
1992	12,620	0.124	15,010	0.124	7,736	0.295	786	0.529	1,875	0.325
1991	10,803	0.124	11,086	0.124	6,512	0.295	566	0.529	1,393	0.325
1990	10,194	0.124	13,153	0.124	9,797	0.295	1,256	0.529	1,497	0.325
1980 – 1989 [a]	38,283	0.124	46,471	0.124	69,555	0.295	8,965	0.529	5,936	0.325
1979 and earlier	879	0.124	2,202	0.124	14,723	0.295	3,247	0.529	522	0.325

Notes: (a) Fuel consumption rates average for period 1980–89.

(b) Assumes new cars on road for average of 6 months in the first year.

Source: DE estimates derived from ABS 2012a, ABS 2012b.

Table 3.A.17: Australian LPG-fuelled vehicle stock age distribution and fuel consumption rates: 2012

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2012[b]	1,865	0.128	1,175	0.15	49	0.551	3	0.530	14	0.431
2011	3,701	0.126	1,346	0.1545	56	0.462	10	0.587	170	0.392
2010	8,276	0.126	4,327	0.1545	70	0.462	28	0.587	246	0.392
2009	10,423	0.126	5,043	0.1545	73	0.462	12	0.587	368	0.392
2008	12,838	0.126	7,319	0.1545	54	0.462	15	0.587	519	0.392
2007	13,635	0.126	6,468	0.1545	63	0.462	29	0.587	338	0.392
2006	14,577	0.137	8,050	0.156	80	0.263	8	0.485	324	0.352
2005	15,488	0.137	7,239	0.156	70	0.263	8	0.485	219	0.352
2004	16,956	0.153	6,827	0.148	58	0.161	5	0.413	158	0.450
2003	19,974	0.153	7,128	0.148	56	0.161	3	0.413	128	0.450
2002	19,005	0.153	6,955	0.148	81	0.161	0	0.413	132	0.450
2001	19,159	0.153	7,269	0.148	49	0.161	3	0.413	284	0.450
2000	20,383	0.153	7,591	0.148	40	0.161	6	0.413	184	0.450
1999	22,965	0.153	6,883	0.148	20	0.161	0	0.413	167	0.450
1998	20,689	0.153	5,897	0.148	26	0.161	4	0.413	57	0.450
1997	21,353	0.153	5,020	0.148	35	0.161	5	0.413	51	0.450
1996	18,759	0.164	4,927	0.1635	24	0.193	0	0.250	45	0.490
1995	15,254	0.164	4,532	0.1635	24	0.193	0	0.250	124	0.490
1994	13,508	0.158	4,502	0.1705	21	0.222	0	0.216	145	0.332
1993	12,446	0.158	3,331	0.1705	29	0.222	0	0.216	78	0.332
1992	10,571	0.158	2,667	0.1705	39	0.222	0	0.216	55	0.332
1991	8,511	0.158	2,201	0.1705	45	0.222	0	0.216	61	0.332
1990	6,039	0.158	2,589	0.1705	37	0.222	0	0.216	73	0.332
1980 – 1989 a	20,378	0.158	11,619	0.1705	887	0.222	8	0.216	156	0.332
1979 and earlier	10,687	0.158	7,575	0.1705	1,979	0.222	181	0.216	39	0.332

Notes: (a) Fuel consumption rates average for period 1980–89.

(b) Assumes new cars on road for average of 6 months in the first year.

Source: DE estimates derived from ABS 2012a, ABS 2012b.

Table 3.A.18: Average rate of fuel consumption for road vehicles by vehicle and fuel type

Vehicle Type	Fuel Type		
	Automotive Gasoline (L/km)	ADO (L/km)	LPG / NG (L/km)
Passenger cars	a	a	a
Light commercial vehicles	a	a	a
Medium duty trucks	a	a	a
Heavy duty trucks	a	a	a
Buses	a	a	a
Motor Cycles	0.059	NA	NA

Source: ABS 2013a. (a) Refer to Table 3.A.15 - 3.A.17.

Table 3.A.19: Evaporative emission factors for road vehicles using automotive gasoline

Vehicle Type	Emission Factor (g/km)	
	Hot Soak and Diurnal Emissions (FH_{ij}) [a]	Running Losses (FR_{ij}) [b]
Passenger Cars[c]		
Post 1985	0.38	0.9
1976–1985	0.96	0.9
Pre-1976	1.92	0.9
Light Commercial Vehicles	1.13	0.19
Medium Trucks	2.24	0.26
Heavy Trucks	2.75	0.29
Buses	2.24	0.20
Motorcycles	0.76	0.0

Sources: (a) Carnovale *et al.* (1991);
(b) OECD (1991);
(c) Calculated with an RVP (Reid Vapor Pressure) of 11.0 psi (pound-force per square inch)

Table 3.A.20: Average Trip Length by State and Territory, by vehicle type, 2011

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Passenger Cars	12.53	12.17	15.98	15.27	11.77	11.69	11.95	12.98
Light Commercial Vehicles	16.55	14.90	25.45	18.59	16.37	13.22	15.43	17.10
Medium Trucks	26.00	23.06	32.53	23.90	19.13	14.87	17.88	21.30
Heavy Trucks	123.57	80.55	131.03	101.46	74.17	69.94	69.91	71.42
Buses	24.95	29.45	46.00	30.59	33.46	20.14	18.40	23.71

Sources: Pekol Traffic and Transport 2013

Table 3.A.21: Urban and Non-Urban VKT proportion by State and Territory, by vehicle type, 2011

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Passenger Cars	0.78	0.79	0.60	0.75	0.67	0.72	0.80	0.78
Light Commercial Vehicles	0.80	0.69	0.46	0.70	0.45	0.58	0.65	0.63
Medium Trucks	0.74	0.68	0.46	0.69	0.61	0.61	0.76	0.66
Heavy Trucks	0.14	0.40	0.15	0.26	0.14	0.39	0.25	0.25
Buses	0.89	0.67	0.30	0.79	0.75	0.75	0.74	0.56

Source: Pekol Traffic and Transport 2013

Table 3.A.22: CO_2 emission factor for coke

Year	Emission Factor (Gg/ PJ)
1990	105.9
1991	105.9
1992	106
1993	106
1994	105.9
1995	106
1996	105.9
1997	106
1998	106
1999	106
2000	106
2001	105.9
2002	106.6
2003	106.3
2004	107.5
2005	108.6
2006	108.8
2007	109.2
2008	109.2
2009	108.4
2010	108.9
2011	107.7
2012	107.7

Source: Determined using a carbon balance of the coke oven process.

Table 3.A.23: NMVOC emission factors for service station storage and transfer operations

Region	Population (million)[(a)]	Emission factor (kg per kl distributed)[(b)]
Sydney Statistical Region[(c)]	3.67	0.16
Port Phillip Control Region[(d)]	3.39	0.16
Other	10.22	1.00
Australia[(e)]	17.28	0.66

Sources: *(a)* Australian Bureau of Statistics, Census (ABS 1991b).

(b) Filling losses and underground-tank breathing.

(c) Environment Protection Authority NSW (EPA 1995).

(d) Melbourne, Geelong and Westernport Regions, Environment Protection Authority Victoria (EPA 1991).

(e) Population weighted average, all years 1988-1994.

Table 3.A.24: NMVOC emission factors for bulk fuel storage facilities

Region	Population (million)[(a)]	Emission factor (kg per kl distributed)[(b)]
Melbourne/Sydney Region[(c)]	7.06	0.48
Other[(d)]	10.22	1.49
Australia[(e)]	17.28	1.08

Sources: *(a)* Australian Bureau of Statistics, Census (ABS 1991b).

(b) Storage and working losses

(c) Assume emission factors in Melbourne (Environment Protection Authority Victoria, (EPA 1991) and Sydney are similar because control regulations are identical

(d) From Australian Environment Council (AEC 1988) data for regions outside Melbourne and Sydney.

(e) Population weighted average, all years 1988-1994.

4. Industrial Processes

4.1 Overview

Total net emissions estimated from industrial processes were 31.2 Mt CO_2-e in 2012, or 5.8% of net national emissions (excluding *LULUCF*) (Table 4.1).

Table 4.1: Industrial processes sector CO_2-e emissions, 2012

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	HFC/PFC/SF_6	Total
2 INDUSTRIAL PROCESSES	20,288	63	2,522	8,333	31,206
A Mineral products	6,588	NA	NA	NA	6,588
B Chemical industry	3,145	12	2,504	NA	5,661
C Metal production	10,337	51	17	254	10,659
D Other production	218	NA	NA	NA	218
E Production of halocarbons and sulphur hexafluoride	NO	NO	NO	NO	NO
F Consumption of halocarbons and sulphur hexafluoride	NA	NA	NA	8,079	8,079

Metal production contributed 34.2% (10.7 Mt CO_2-e) of the sector's emissions, *mineral products* contributed 21.1% (6.6 Mt CO_2-e), *chemical industries* contributed 18.1% (5.7 Mt CO_2-e), the *consumption of HFCs and SF_6* contributed 25.9% (8.1 Mt CO_2-e) and food and drink contributed 0.7% (0.2 Mt CO_2-e).

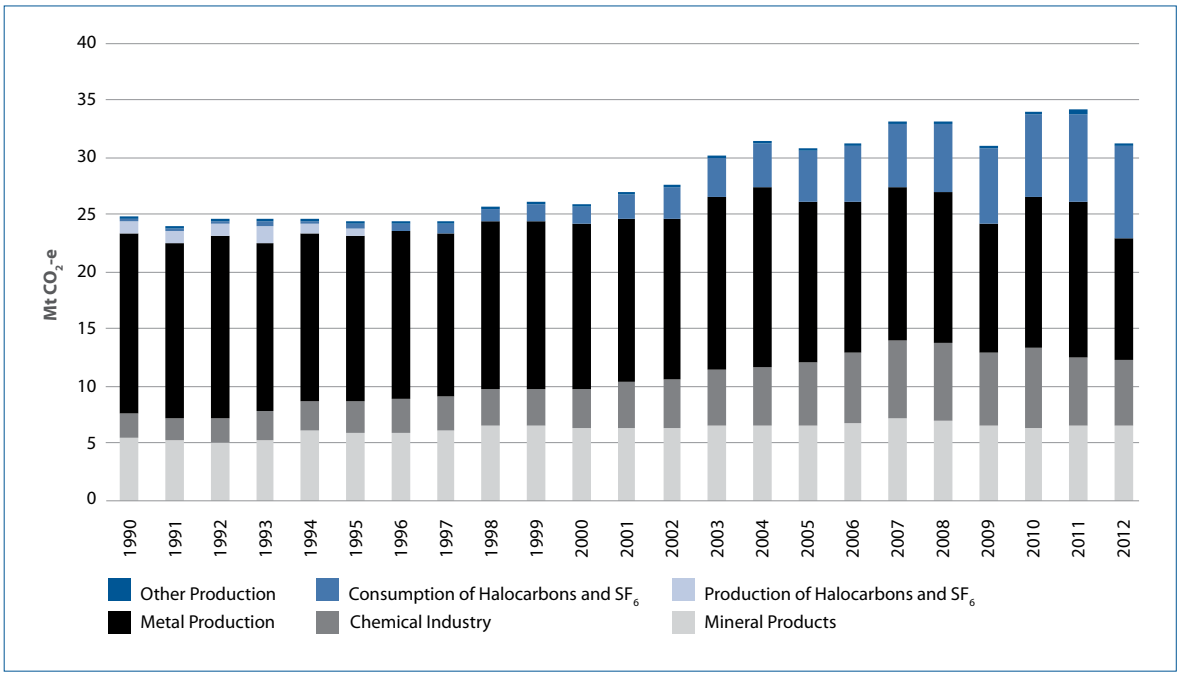
The main gas emitted by *industrial processes* is CO_2, contributing 65.0% (20.3 Mt) of the sector's emissions in 2012. PFCs contributed 0.8% (0.3 Mt CO_2-e), HFCs contributed 25.5% (7.9 Mt CO_2-e), SF_6 contributed 0.4% (0.1 Mt CO_2-e), N_2O contributed 8.1% (2.5 Mt CO_2-e), and CH_4 0.2% (0.1 Mt CO_2-e).

Trends

Net emissions from *industrial processes* increased by 26.5% (6.5 Mt CO_2-e) from 1990 to 2012, and decreased by 8.5% (2.9 Mt CO_2-e) between 2011 and 2012 (Figure 4.1). The increases in sectoral emissions observed over the longer term are principally due to growth in emissions associated with the manufacture of chemical products. The decrease in emissions from 2010 to 2011 predominantly reflects declines in metal production associated with the closure of a blast furnace in late 2011.

Each source category's contribution to total emissions and to sectoral trends within the Industrial Processes sector between 1990 and 2012 is shown in Figure 4.1.

Figure 4.1: Emissions from industrial processes by subsector, 1990–2012



Clinker Production

Emissions of CO_2 for this source category are dependent on the quantity of clinker produced and this in turn is closely tied to annual growth in the Australian economy. Emissions of CO_2 from clinker production in 2012 were 3,518 kt CO_2-e, a 1.6% increase from 1990, while production has increased by 3.5% over the same period. Improvements in industry practices such as the recycling of cement kiln dust have resulted in lower emissions per unit production.

From 2011 to 2012, total CO_2 emissions increased by 0.6%. This increase reflects an increase in production of 0.8% from 2011 to 2012. Year on year fluctuations in emissions from clinker production is variable and matches fluctuations in clinker production very closely.

Lime Production

Emissions of CO_2 from the production of lime vary year to year according to the quantities of commercial and in-house lime produced. The quantities of lime produced are dependent on the demand for lime within the Australian economy. Total lime production in 2012 was 1,593 kt compared with 1,634 kt in 2011 representing a decrease in production of 2.5%. Lime production levels are sensitive to levels of demand in the resources sector as evidenced by the decline in lime production of 16.7% observed in 2000 and a similar decline in 2009. The decline in 2000 is attributed to the fall in demand for minerals processing particularly in the gold sector while the 2009 decline is associated with the general economic downturn also affecting other industrial processes.

Limestone and Dolomite Use

The total CO_2 emissions reported in this source category include emissions from the consumption of carbonates in (calcite, magnesite, dolomite, sodium bicarbonate, potassium carbonate, barium carbonate, lithium carbonate and strontium carbonate), magnesia production, zinc production, ferroalloys production, iron and steel production, ceramics (including clay bricks) and glass production, soda ash use and production and miscellaneous uses of carbonates. The trend in emissions is heavily influenced by the consumption of limestone which is consumed in greater quantities than any other carbonate. In 2012 limestone consumption had increased by 8.3%

from 1990. The year on year growth in limestone consumption, however, has varied from positive to negative throughout the time series with the decrease of 8.0% observed between 2011 and 2012 predominantly reflecting a downturn in consumption in the production of iron and steel and other metals.

Soda Ash Production and Use

Soda ash is produced in Australia by only one company, Penrice Soda Products. Soda ash is also imported into Australia in significant quantities. More than half the soda ash produced is consumed by glass manufacturers. Other important users of soda ash are manufacturers of detergents, soaps and chemicals and the metals and mining industries. Production of soda ash has remained relatively constant while imports of soda ash have experienced large fluctuations and an overall increase in quantities. Emissions for this source category are confidential and are reported under 2.A.3 limestone and dolomite use.

Road Paving with Asphalt

NMVOC emissions from road paving with asphalt were 16.8 kt in 2012 and are increasing over the long term with a rise of 11.8% from 1990 and no change from 2011.

Chemical Production

In 2009, there was a scaling back of chemical products manufacture reflecting in combination the effects of the international economic downturn and a gas explosion in Western Australia in October 2008 which affected natural gas supplies for ammonia production in that part of the country. Since these events and the resultant decline in emissions, emissions in 2012 have returned to generally normal levels. However a decline of 6.2% from 2011 has been observed in 2012 reflecting a similar decline in ammonia production associated with temporary plant shut downs and improvements in nitric acid emissions control.

Iron and Steel Production

Emissions per tonne of Iron and Steel produced vary according to changing quantities of reductants used. Emissions from iron and steel production in 2012 were 29.8% lower than in 2011. This decrease in emissions in 2012 reflects a decrease in the coke consumption in iron and steel production reported under the NGER System. This decline is associated with the closure of the No.6 blast furnace at the Port Kembla steelworks in October 2011.

The down-turn in emissions during 2005 occurred due to the blast-furnace re-lining activities at the Whyalla steel works. There has been a general declining trend in the Iron and Steel CO_2-e IEF due to the increased use of pulverised coal injection in lieu of coke. Pulverised coal used in iron and steel production has been reallocated from 1.A.2 *Manufacturing Industries and Construction* to 2.C.1 *Iron and Steel* in this inventory.

Aluminium Production

Emissions from the production of aluminium were slightly lower in 2012 than 2011 owing to a decrease in production levels and the associated consumption of coal tar, petroleum coke and other inputs to the anode production process.

The downward trend in CO_2-e emissions per tonne of aluminium produced since 1990 has occurred as a result of improvements in process control and the resultant reduction in PFC emissions. Any fluctuations in IEFs occurring in the latter part of the time series are the result of small fluctuations in the number of anode effects in the production process occurring due to electricity supply disruptions and potline maintenance. The fall in the PFC IEF between 2005 and 2007 occurred as a result of a smelter upgrade at Hydro Kurri Kurri (conversion of Potline No 1 from side-work to centre-work) and an enhanced emissions performance at the Tomago smelter (AAC 2007).

Consumption of halocarbons and SF_6

Emissions from the consumption of halocarbons and SF_6 are increasing steadily on 1990 levels with a growing stock of gas and low levels of destruction and recycling. HFC refrigerants were first used in Australia in 1994 and have been increasing in use since that time as ozone depleting refrigerants are phased out under the Montreal Protocol. SF_6 has been in use in electricity supply and distribution and miscellaneous uses throughout the time series.

4.2 Overview of Source Category Description and Methodology – Industrial Processes

The *industrial processes* sector includes emissions generated from a range of production processes involving *inter alia* the use of carbonates (i.e. limestone, dolomite, magnesite, etc.); carbon when used as a chemical reductant (e.g. iron and steel or aluminium production); chemical industry processes (e.g. ammonia and nitric acid production) and the production and use of synthetic gases such as halocarbons. Key categories for Australia include emissions from cement production, iron and steel production, aluminium production and the consumption of halocarbons.

For some industries, for example the iron and steel industry, reported emissions are split between the *industrial processes* sector and the *energy* sector depending on the type of process within the industry that generated the emissions.

The Australian methodology for *industrial processes* contains both country specific and IPCC default methodologies and EFs (Table 4.2). The use of tier 2 methods indicates a higher level of complexity, data requirements and in-principle accuracy than a tier 1 method.

In certain sub sectors within *industrial processes*, activity data are commercial-in-confidence and, due to the direct relationship between activity and emissions, emissions estimates by gas species are also confidential. Where this is the case, it is necessary to aggregate sub-sectoral emission estimates in order to preserve confidentiality.

Emissions of CO_2 from soda ash production and use (2.A.4) (including sodium bicarbonate production), and magnesia production (2.A.5) have been aggregated with CO_2 from limestone and dolomite use (2.A.3). CO_2 emissions from the use of acetylene (2.B.5) and the production of synthetic rutile and titanium dioxide (2.B.5) have been aggregated with CO_2 from the production of ammonia (2.B.1). This aggregate is reported at the chemical industry sectoral level (2.B.5 – confidential chemical industry emissions). Emissions of N_2O from the use of N_2O in anaesthesia and aerosols (3.D.3) have been aggregated with N_2O from nitric acid production (2.B.2). This aggregate is reported at the chemical industry sectoral level (2.B.5 – confidential chemical industry emissions).

Table 4.2: Summary of methods and emission factors: Industrial Processes

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
2. Industrial Processes												
A. Mineral Products	**T2**	**CS, D**	**NA**	**NA**	**NA**	**NA**						
1. Cement Production	T2	CS	NA	NA	NA	NA						
2. Lime Production	T2	CS	NA	NA	NA	NA						
3. Limestone and Dolomite Use	T2	CS	NA	NA	NA	NA						
4. Soda Ash Production and Use[(a)]	T2/3	CS, D	NA	NA	NA	NA						
6. Road Paving with Asphalt	NA	NA	NA	NA	NA	NA						
7. Other *(please specify)*												
B. Chemical Industry	**CS,T1b, T2**	**CS,D**	**T2**	**D**	**T3,CS**	**CS**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
1. Ammonia Production[(b)]	T1b	CS,D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2. Nitric Acid Production[(b)]	NA	NA	NA	NA	T3	CS	NA	NA	NA	NA	NA	NA
5. Other *(please specify)*												
Polymers and other chemicals	NA	NA	T2	D	NA	NA	NA	NA	NA	NA	NA	NA
Synthetic Rutile[(b)]	T2	CS	NA	NA	NA	NA			NA	NA	NA	NA
Confidential emissions[(c)]	CS	CS			CS	CS						
C. Metal Production	**T2,T1b**	**CS**	**T2**	**CS**	**T2**	**CS**			**T1c**	**CS**	**T2**	**CS**
1. Iron and Steel Production	T1b	CS	T2	CS	T2	CS			NA	NA	NA	NA
3. Aluminium Production	T1b	CS	NA	NA	NA	NA			T1c	CS	NA	NA
4. SF_6 Used in Aluminium and Magnesium Foundries	NA	NA	NA	NA	NA	NA			NA	NA	T2	CS
5. Other *(please specify)*												
Other Metals	T2	CS	NA	NA	NA	NA			NA	NA	NA	NA

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
D. Other Production	**CS**	**CS**										
E. Production of Halocarbons and SF_6							**T1**	**D**	**NA**	**NA**	**NA**	**NA**
1. By-product Emissions							NA	NA	NA	NA	NA	NA
Production of HCFC-22							T1	D	NA	NA	NA	NA
Other							NA	NA	NA	NA	NA	NA
F. Consumption of Halocarbons and SF_6							**M**	**D**	**NA**	**NA**	**T1,T2**	**CS**
1. Refrigeration and Air Conditioning Equipment							M	CS/D	NA	NA	NA	NA
2. Foam Blowing							M	CS/D	NA	NA	NA	NA
3. Fire Extinguishers							M	D	NA	NA	NA	NA
4. Aerosols/ MDIs							M	D	NA	NA	NA	NA
5. Solvents							M	D	NA	NA	NA	NA
6. Semiconductor Manufacture							NA	NA	NA	NA	NA	NA
7. Electrical Equipment							NA	NA	NA	NA	T2	CS
8. Other *(please specify) (d)*							NA	NA	NA	NA	T1	CS
G. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: EF = Emission Factor, T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific, D= IPCC default, NE = not estimated, NA= not available, NO = not occurring, IE = included elsewhere.

(a) Emissions reported under 2.A.3 *limestone and dolomite use*;

(b) Emissions reported under 2.B.5 *confidential chemical industry emissions*;

(c) Methods for acetylene use and from use of N_2O (3D), methods for other components identified separately;

(d) Other uses of SF_6

Data Sources

The inventory for the *industrial processes* sector relies primarily on data collected under the National Greenhouse and Energy Reporting System. The following table summarises the data sources used in compiling the inventory for industrial processes.

Table 4.3: Summary of principal data sources for Industrial Processes 2012

Industrial Processes Sector	Method of data collection	Activity data
2.A.1. Cement clinker	NGER	Cement Australia, Boral, Adelaide Brighton
2.A.2. Lime	NGER	Boral, Adelaide Brighton, Cement Australia, Unimin, Alcan and Queensland Alumina
2.A.3. Limestone and dolomite and other carbonates	NGER	Owens-Illinois, CSR, Amcor, Qmag, Causmag, OneSteel, BlueScope Steel, Rio-tinto, Billiton Manganese, Bradken, Sun Metals, BHP Billiton, Xstrata, Nyrstar, Incitec Pivot, Minara Resources, Fletcher Insulation, Thales Australia, Penrice, Think Brick, Alcoa, Kalgoorlie Consolidated Gold, Bass Metals and Heathgate
2.A.4. Soda ash	NGER	Penrice Soda Products
2.A.6. Bitumen	Published statistics	ABARES Commodity Statistics
2.B.1. Ammonia	NGER	Incitec, Orica, Wesfarmers CSBP, BHP Billiton, Queensland Nitrates, Burrup Fertlisers
2.B.2. Nitric acid	NGER	Orica, Wesfarmers CSBP, Queensland Nitrates
2.B.5. Other chemicals	Company Census	Dynea W.A, Borden Chemicals, Orica, BP, Shell, Huntsman Chemicals, Dow Chemicals, Qenos, ExxonMobil, Continental Carbon, Cabot Australia, Australian Vinyl, BOC Gases, Airliquide, Caltex, Coogee Chemicals
2.B.5 Synthetic Rutile and Titanium Dioxide	NGER	Tiwest, Iluka Resources, Milenium Chemicals
2.C.1. Iron and steel	NGER	BlueScope Steel, OneSteel
2.C.3. Aluminium	NGER	Alcoa, Rio Tinto, Hydro Kurri Kurri, Tomago Aluminium
2.C.4. SF_6 used in metal production		CSIRO, Brisbane
2.C.5. Other metals	NGER and published statistics	Billiton Manganese, BHP Billiton, Simcoa ABARES Commodity Statistics for various metals
2.D.2. Food and drink	NGER and published statistics	ABS apparent consumption data, Penrice Soda Products, Air Liquide, BOC, Hunstman Chemicals, Incitec, Orica.
2.F Consumption of Halocarbons and SF_6	Import licence reporting	Bulk import and pre-charged equipment data reported to the former Department of Sustainability, Environment, Water, Population, Arts and Community (now DE) under the regulations applying under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 2003* *SF_6 stock data and EFs obtained from NGER reporting entities.*

4.3 Source Category 2.A Mineral Products

4.3.1 Cement Production

Source Category Description

Cement clinker production is a key category for Australia. CO_2 is produced during the manufacture of portland clinker, which is an intermediate product in the production of cement. CO_2 emissions are essentially proportional to the lime content of the clinker. On exit from the cement kiln, and after cooling, the clinker is ground to a fine powder and up to 5% (by weight) of gypsum or natural anhydrite (that is, forms of calcium sulphate) added to control the setting time of the cement. The finished product is referred to as 'portland' cement.

There are three clinker producers in Australia; Adelaide Brighton, Blue Circle Southern Cement (Boral) and Cement Australia. The production of blended cements, incorporating waste materials from other industries (e.g. slag, fly ash and silica fume), represents a significant portion (approximately 20%) of the total cement manufacturing market in Australia. According to the Cement Industry Federation (CIF 2003), the proportion of waste materials added to cement varies significantly and may range from 10% to 80% (by weight). Blending waste materials with cement significantly reduces the CO_2 emissions per unit of cement produced. According to the CIF 2009 sustainability report, the industry aims to increase the use of supplementary cementitious materials in cement and concrete to at least 29% by 2012.

Methodology

Calcium carbonate ($CaCO_3$) from calcium rich raw materials such as limestone, chalk and natural cement rock is heated at temperatures of approximately 1500° C in cement kilns to form lime (CaO) and CO_2 in a process known as calcination.

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

Emissions from clinker production are estimated using a tier 2 method.

$$E_{cl} = [EF_{cl} \cdot A_{cl} + EF_{cl} \cdot F_{ckd} \cdot A_{ckd} + EF_{toc} \cdot (A_{cl} + A_{ckd})] \cdot 10^{-6}$$

CO_2 emissions from clinker manufacture are estimated by the application of a country – specific emission factor EF_{cl}, in kilograms of CO_2 released per tonne of clinker produced, to the annual national clinker production A_{cl}.

The country - specific EF is the product of the fraction of lime used in the clinker and a constant reflecting the mass of CO_2 released per unit of lime produced. This factor was derived using the World Business Council for Sustainable Development (WBCSD 2005) methodology. Assuming CaO and MgO proportions of 0.66 and 0.015 respectively, based on Ryan and Samarin 1992, leads to an EF of 534 kg CO_2 per tonne of clinker.

In addition to the emissions associated with the lime used in the clinker, the methodology accounts for emissions associated with the calcination of cement kiln dust (A_{ckd}) and the quantity of total organic carbon expressed as a proportion of total clinker produced (TOC). F_{ckd} is the degree of calcination of cement kiln dust (ranging from 0% to 100%) and is assumed to be 100% in Australia such that $F_{ckd} = 1$ (following WBCSD 2005). A_{ckd} is the quantity of cement kiln dust (CKD) produced annually. The EF for TOC is taken from WBCSD 2005 (equivalent to 10kg CO_2 per tonne of clinker).

Choice of emission factor

No facility-specific data on EFs were obtained under the NGER System. The country–specific CO_2 EF was applied for all facilities and for all years.

Activity data

Data for clinker production for individual facilities were obtained from the NGER System for 2009 onwards and the reporting mechanisms of the former Emissions Intensive, Trade Exposed Industries assistance program (EITEIs - now known as the Jobs and Competitiveness Program) for 2007 and 2008. Data for the period 1990-2006 were obtained by industry survey undertaken by the Cement Industry Federation (CIF). In all cases, all producers of clinker have been captured throughout the time-series.

Table 4.4: Australian cement clinker production and emissions 1990, 2000–2012

Year	Clinker production (kt)	Cement Kiln Dust (kt)	Emissions (Gg CO_2)
1990	6,205	160	3,463
2000	6,557	99	3,621
2001	6,425	84	3,541
2002	6,354	58	3,488
2003	6,566	22	3,584
2004	6,492	42	3,555
2005	6,657	79	3,664
2006	7,076	72	3,888
2007	7,254	47	3,972
2008	7,053	48	3, 863
2009	6,986	52	3,829
2010	6,470	53	3,549
2011	6,374	55	3,496
2012	6,425	45	3,518

Source: GHD 2009c, DCCEE EITEIs Program 2009, NGER System 2009 to date

4.3.2 Lime Production (2.A.2)

Source Category Description

Lime is an important chemical having major uses in metallurgy (steel, copper, gold, aluminium and silver), other industrial applications (water softening, pH control, sewage sludge stabilisation), and construction (soil stabilisation, asphalt additive and masonry lime). The producers of commercial lime in Australia include Cement Australia, Blue Circle Southern Cement (Boral), Adelaide Brighton Cement, Unimin, and Queensland Alumina. Rio Tinto Alcan also produces in-house lime for alumina production.

Methodology

CO_2 is produced when either high calcium lime (CaO) or dolomitic lime (CaO.MgO) are manufactured by the calcination of calcium rich raw materials (limestone or dolomite) in a kiln.

$CaCO_3$ (limestone) + heat → CaO (high calcium lime) + CO_2

$CaCO_3.MgCO_3$ (dolomite) + heat → CaO.MgO (dolomitic lime) + 2 CO_2

Emissions from lime production are estimated using a tier 2 method.

Total CO_2 emissions E_q associated with lime production A_q are estimated as the sum of emissions by facility according to:

$$E_q = \Sigma A_q \,.\, EF_q$$

The EF for lime produced is estimated for each facility from a consideration of the molecular weights (56 for CaO, 44 for CO_2) and the composition of the lime products.

Choice of emission factor

Selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

Information important to the derivation of lime production emission factors as been obtained under the former EITIEs program and the NGER (2009–2012) System from 2007 onwards where available. Emission factors are derived under 2 different scenarios:

a) where facility-specific lime product composition information is available:

Where lime producers have information on the specifications of their product, they are able to derive facility-specific emission factors on the basis of pure calcium carbonate (CaO) and magnesium carbonate (MgO) content of their product. The pure carbonate emission factors used to derive facility-specific emission factors are as follows:

- 0.785 t CO_2 x the fraction of pure CaO in the lime
- 1.092 t CO_2 x the fraction of pure MgO in the lime

The following equation is applied to derive a facility-specific emission factor:

EF = 0.785 t CO_2 x the fraction of pure CaO in the lime + 1.092 t CO_2 x the fraction of pure MgO in the lime

It follows therefore that where lime producers manufacture lime with a high MgO content, their facility-specific emission factor will be higher than the default case.

From 2007 onwards, facility-specific emission factor information related to commercial lime production became available. The weighted average of these emission factors for all facilities producing commercial lime (including those who did not provide facility-specific emission factors) was 0.751 in 2007 – based on the relative contributions to total production of all commercial lime producers. This weighted value applies only to manufacturers of commercial lime and is higher than the commercial lime CS EF because it reflects the non-standard specifications of producers with commercial lime with a high MgO content. To date, no facility level information on in-house lime production has been available.

b) where facility-specific lime product composition information is not available:

Under this scenario, Australia provides country-specific emission factors for the use of lime manufacturers reporting under the NGER System. These are based upon assumed fractional purities of commercial and in-house lime and are calculated according to the equation:

$$EF = F \times (44.01/56.08)$$

Where F is the fractional purity of lime produced

44.01 is the molecular weight of CO_2

56.08 is the molecular weight of CaO

The CS emission factors are as follows:

- 0.675 t CO_2 / t commercial lime produced
  Based on a fractional purity of lime of 0.86

- 0.730 t CO_2 /t in-house lime produced
  Based on a fractional purity of lime of 0.93

As outlined above, facilities that do have product composition information, have reported facility-specific emission factors. The average emission factor for all facilities weighted on the basis of relative levels of production is 0.751 t CO_2/t lime.

Country-specific emission factors for commercial and in-house lime are applied to facilities which do not have information on the composition of their product:

- 0.675 t CO_2 / t commercial lime produced
- 0.730 t CO_2 /t in-house lime produced

The following timeline sets out the application of each of the emission factors:

	1990 → 2006	2007	20xx
Commercial lime	Weighted average EF 0.751 t CO_2/ t lime	Facility specific Efs	
		Default CS EF-0.675 t CO_2/t lime	
In-house lime	Default CS EF-0.675 t CO_2/t lime		

The fluctuation in the implied emission factor year on year reflects the relative proportions of commercial and in-house lime production as well as the relative proportions of production of individual lime producers from 2007 onwards where facility level emission factors are used.

Time series consistency is maintained through the use of a weighted average EF of 0.751 t CO_2/t lime produced for the years when individual facility data are not available (1990 – 2006). It is assumed for the years 1990-2006 that lime producers continued to produce lime in the same relative proportions as observed in 2007 when facility-level data first became available.

For in-house lime, as no producers have composition information, the CS emission factor is applied for all years where in-house lime production occurs.

Activity data

Data on lime production have been collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008.

Data for the period 1990-2006 were obtained by industry census undertaken by the National Lime Association up to 2000 and various consultants from 2001 to 2006 (For example, GHD 2009a). The census and NGER collection mechanisms have enabled complete coverage of lime producers throughout the time-series.

Table 4.5: Lime production emissions 1990, 2000–2012

Year	Total Lime production (kt)[a]	Emissions (Gg CO_2)
1990	1,035	775
2000	1,277	957
2001	1,533	1,150
2002	1,569	1,176
2003	1,593	1,194
2004	1,624	1,217
2005	1,617	1,213
2006	1,467	1,102
2007	1,632	1,225
2008	1,758	1,320
2009	1,530	1,152
2010	1,631	1,231
2011	1,634	1,244
2012	1,593	1,305

Source: GHD 2009c, DCCEE EITEIs Program 2009, NGER System 2009 to date

(a) includes quantities of in-house lime production

4.3.3 Limestone And Dolomite Use (2.A.3)

Source Category Description

Apart from use in clinker and lime production, limestone ($CaCO_3$), magnesite ($MgCO_3$) and dolomite ($CaCO_3$. $MgCO_3$) are basic raw materials that have commercial applications in a number of industries including metallurgy (for example, iron and steel), glass manufacture, ceramics and clay bricks , agriculture, construction, magnesia production and environmental pollution control.

All CO_2 emissions associated with the consumption of carbonates, with the exception of the emissions reported under cement and lime production, are accounted for under Limestone and Dolomite Use. This includes emissions from the use of limestone by the iron and steel, ferroalloys, magnesia, zinc, glass, ceramics and clay brick production and soda ash production industries. Emissions from the use of limestone in cement and lime production are accounted for under 2.A.1 and 2.A.2 respectively.

Companies using carbonates in their production processes include Owens-Illinois, CSR, Amcor, Qmag, Causmag, OneSteel, BlueScope Steel, Rio-tinto, Billiton Manganese, Bradken, Sun Metals, BHP Billiton, Xstrata, Nyrstar, Incitec Pivot, Minara Resources, Fletcher Insulation, Thales Australia, and Penrice.

To protect confidentiality, the emissions from the production and use of soda ash (2.A.4) have been aggregated with this source category (2.A.3).

To improve the completeness of the inventory emissions from other carbonates known to be supplied to the Australian economy have also been included in this source category (2.A.3). These include sodium bicarbonate, potassium carbonate, barium carbonate, lithium carbonate and strontium carbonate.

Methodology

A tier 2 method is utilised for the Australian inventory. The mass of CO_2 emitted per unit of limestone EF_{ls}, dolomite EF_d and other carbonates use EF_o is estimated from a consideration of the purity of the raw materials and the stoichiometry of the chemical processes (44 for CO_2; 100 for limestone; 184 for dolomite, 84 for magnesite, 106 for soda ash and 114 for the remaining carbonates). Only the amount of carbonate material used in an application which generates CO_2 is used in the estimation of CO_2 emitted.

Total CO_2 emissions, E, are estimated by summing over each facility the quantity of limestone, $A_{ls,}$ dolomite, A_d, and other carbonate use, $A_{o,}$ multiplied by their respective country-specific fractional purities and EFs derived from stoichiometry:

$$E = A_{ls} . F_{ls}. EF_{ls} + A_d . F_d . E_{Fd} + A_o . F_o . E_{Fo}$$

The fractional purities are country specific and include limestone, F_{ls}, 0.90, dolomite $F_{d,}$ 0.95, and for all other carbonates, 1.00. The EFs are derived from stoichiometry and are 0.396 t CO_2/t limestone, 0.522 t CO_2/t magnesium carbonate, and 0.453 t CO_2/t dolomite.

Emissions from the manufacture of clay bricks

Emissions from carbonate consumption associated with the manufacture of clay bricks have been included for the first time in this submission. Emissions are based upon the quantities of clay bricks produced annually as recorded by the Australian Bureau of Statistics (ABS 1991a, 2000 and 2012) and a country-specific EF derived from data provided by the peak industry body representing Australian clay brick and paver manufacturers, Think Brick.

Choice of Emission Factor

No facility-specific data on EFs were obtained under NGER. Country–specific CO_2 fractional purities and stoichiometric EFs were applied for all facilities and for all years.

Activity data

Limestone and dolomite consumption data have been collected under the NGER System for 2009 and the reporting mechanisms of former EITEIs Program for 2007 and 2008.

Data for the period 1990-2006 were obtained by a combination of industry survey (for example GHD 2009c) and back casting of production based on NGER data.

The coverage of companies for this source was expanded in the 2011 submission due to the mandatory reporting by all companies with emissions above the NGER System reporting thresholds whereas previous voluntary surveys had not identified all consumers of limestone. Where data for a particular facility collected under the NGER System was not available in GHD 2009c, time series consistency was maintained by the interpolation of consumption rates reported under the NGER System for 2009 to the period between the commencement date for the facility and 2008. These facilities include Bradken, Incitec Pivot, Rio Tinto, Fletcher Insulation, Thales, Sun Metals and Minara Resources.

Table 4.6: Limestone and dolomite consumption and emissions 1990, 2000–2012

Year	Limestone Use (kt)	Dolomite and Other Carbonate Use[(a)] (kt)	Total emissions from the consumption of carbonates (Gg CO_2)[(b)]
1990	2,176	779	1,345
2000	2,800	1,183	1,776
2001	2,506	1,188	1,671
2002	2,577	1,237	1,751
2003	2,606	1,288	1,775
2004	2,557	1,253	1,742
2005	2,506	1,252	1,727
2006	2,641	1,305	1,806
2007	2,905	1,273	1,916
2008	2,736	1,300	1,839
2009	2,420	943	1,554
2010	2,548	1,072	1,653
2011	2,563	1,406	1,819
2012	2,357	1,332	1,765

Source: EnerGreen Consulting 2009, DCCEE EITEIs Program 2009, NGER System 2009 to date.

(a) Includes magnesite, soda ash, barium carbonate, lithium carbonate, potassium carbonate, strontium carbonate and sodium bicarbonate,

(b) Includes emissions from soda ash production and use

4.3.4 Soda Ash Production And Use (2.A.4)

Source Category Description

A tier 3 method is utilised for the Australian inventory. Soda ash (sodium carbonate, Na_2CO_3) is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper manufacture and water treatment. Soda ash is produced by one company, Penrice Soda Products, located in South Australia, using the Solvay process. Emissions of CO_2 are generated from both the consumption and production of soda ash. To protect confidentiality, these emissions are aggregated with emissions from limestone and dolomite use reported under 2.A.3.

Emissions from the production of soda ash include emissions from the coke used as a reductant. This quantity of coke is deducted from the energy sector as it is a non-energy use of coke and ensures there is no double-counting. Limestone is also consumed in the manufacture of soda ash and both the emissions from the calcination of limestone and the coke used as a reductant are accounted for under limestone and dolomite use (2.A.3).

Sodium bicarbonate ($NaHCO_3$) is also produced in the Solvay process for soda ash production. When heated or reacted with a weak acid, sodium bicarbonate generates CO_2. Emissions from the use of sodium bicarbonate in applications where CO_2 is generated have been included in the inventory under food and drink (2.D.2).

Methodology

Soda Ash Production

In the Solvay process, sodium chloride brine, limestone, coke and ammonia are the raw materials in a series of reactions leading to the production of soda ash, sodium bicarbonate and waste products containing calcium carbonate. Ammonia, however, is recycled and only a small amount is lost. The series of reactions involved in the Solvay process may be simply expressed as:

$$CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$$

The CO_2 generated in pyrolysis processes is captured, and directed to Solvay precipitating towers for consumption in a mixture of brine (aqueous NaCl) and ammonia. The Solvay process itself is in theory stoichiometrically neutral in relation to CO_2 gas (that is, generation equals uptake), however, in practice a greater amount of CO_2 is generated than can be absorbed in order to optimise the production process.

Emissions from soda ash production are estimated using a tier 2 method.

The estimation of the CO_2 emissions from a standalone soda ash plant should be based on an overall balance of CO_2 around the whole chemical process. To estimate the excess CO_2 generated during production the carbon in the products and waste materials is deducted from the carbon in the raw materials leaving the excess carbon which is assumed to be entirely converted to CO_2 gas.

$$E_s = [\ \Sigma_f CC_f \,.\, A_f + CC_l \,.\, A_l - \Sigma_p CC_p \,.\, A_p . - \Sigma_w CC_w \,.\, A_w\ ] \,.\, 3.664$$

Where: E_s is the emissions of CO_2 from the production of soda ash and sodium bicarbonate

CC_f is the carbon content of the fuel consumed

A_f is the mass of fuel consumed (coke)

CC_l is the carbon content of the limestone consumed

A_l is the mass of limestone consumed

CC_p is the carbon content of a product

A_p is the mass of product (soda ash and sodium bicarbonate)

CC_w is the carbon content of the waste products

A_w is the mass of waste product (brine mud)

In the first step of the Solvay process limestone is calcined to form lime which is then mixed with water to produce slaked lime for the ammonia recovery step. Any limestone that is not calcined is removed as waste (backstone and grits) from the process and this is deducted from the mass of limestone consumed A_l in the emissions estimate.

A relatively small amount of waste material containing carbon in the form of calcium carbonate is also deducted from the carbon in the raw materials. The calcium carbonate waste is produced during a brine purification process where calcium and magnesium salts are removed from the brine feedstock. The purification of the brine is achieved through a reaction of soda ash and sodium hydroxide with the calcium and magnesium salts in the brine forming the solids, calcium carbonate and magnesium hydroxide. Calcium carbonate is also formed in the manufacture of the sodium hydroxide used in these reactions.

Soda ash is taken from the product stream and diverted to the brine purification process where it reacts with the calcium salts (calcium sulphate) to form calcium carbonate and sodium sulphate:

$$Na_2CO_3 + CaSO_4 \rightarrow CaCO_3 + Na_2SO_4$$

Sodium hydroxide is manufactured using soda ash (also diverted from the product stream) and slaked lime with calcium carbonate as a waste by-product:

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2\ NaOH + CaCO_3$$

The sodium hydroxide manufactured is then fed into the brine purification process where it reacts with the magnesium salts (magnesium sulphate) to form magnesium hydroxide and sodium sulphate.

$$MgSO_4 + 2\ NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$$

In this way the CO_2 absorbed into the soda ash product is then diverted for use in the brine purification process and the manufacture of sodium hydroxide is converted into calcium carbonate. The carbon in the calcium carbonate formed in these reactions is deducted from the raw materials in the calculation of the emissions estimate. The soda ash product used in the brine purification process and manufacture of sodium hydroxide is essentially a non-emissive use of soda ash and the amount used is not included in the total soda ash produced for sale.

Soda Ash Consumption

A tier 2 method is utilised for the Australian inventory. CO_2 emissions are associated with the use of soda ash where it is assumed that for each mole of soda ash use, one mole of CO_2 is emitted. The mass of CO_2 emitted from the use of soda ash E_{sau} may be estimated from a consideration of the consumption data A_{sau} and the stoichiometry of the chemical process (where 44.01 is the molecular weight of CO_2 and 105.99 is the molecular weight of Na_2CO_3).

$$E_{sau} = 0.415\ \text{kg/tonne}\ Na_2CO_3 \,.\, \Sigma A_{sau}$$

Sodium Bicarbonate Consumption

Sodium bicarbonate ($NaHCO_3$) is also produced in the manufacture of soda ash using the Solvay process. Sodium bicarbonate has a wide range of applications some of which result in the release of CO_2. When sodium bicarbonate is heated or reacted with a weak acid CO_2 is released. Uses of sodium bicarbonate in which CO_2 is generated include leavening agents, pharmaceuticals, stock feed buffer and effervescent salts and beverages. Energreen Consulting 2009 indicates that the proportion of sodium bicarbonate consumption resulting in emissions of CO_2 is 80%. This proportion is used to estimate the amount of CO_2 emissions from consumption of sodium bicarbonate. It is assumed that the sodium bicarbonate thermally decomposes in the following reaction:

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

The mass of CO_2 emitted from the use of sodium bicarbonate E_{sbu} is estimated using consumption data A_{sbu}, the proportion resulting in emissions and the stoichiometry of the chemical process (where 44.01 is the molecular weight of CO_2 and 84.01 is the molecular weight of $NaHCO_3$).

$$E_{sbu} = 0.8 \,.\, A_{sbu} \,.\, 0.262\ \text{kg/tonne}\ NaHCO_3$$

Choice of emission factor

Soda Ash Production

The selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

The EFs for limestone consumption and coke consumption are facility-specific and obtained under NGER for 2009 onwards and under the former EITEIs Program for 2007 and 2008. As there is only one producer, complete coverage for the sector was achieved.

Time series consistency for the entire period 1990-2006 is maintained by the application of the facility-specific factors, obtained for the period 2007-2008, to years when no facility data are available.

Soda Ash Consumption

No data on EFs was obtained under NGER. The EF for soda ash consumption is given by stoichiometry considerations and is the same as the IPCC default.

Activity data

Soda Ash Production

Data on limestone and coke consumption for the purpose of soda ash production were collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008.

Data for limestone and coke consumption for the period 1990-2006 were derived from data for soda ash production obtained by industry survey (Energreen 2009). Time series consistency was maintained by the application of constant factors of limestone and coke consumption per unit of soda ash production estimated from data available for the period 2007-2009.

Soda Ash Consumption

Data on soda ash consumption were collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008. Data for soda ash consumption for the period 1990-2006 were obtained by industry survey (Energreen 2009) and data on soda ash imports taken from ABS 2014.

Table 4.7: Soda ash use and emissions

Year	Soda ash use (kt)	Emissions (Gg CO_2)
1990	450	186
2010	381	158
2011	358	151
2012	237	122

Source: EnerGreen Consulting 2009, NGER System 2009 to date.

4.3.5 Asphalt Roofing (2.A.5)

There is negligible use of asphalt for roofing purposes in Australia.

4.3.6 Road Paving With Asphalt (2.A.6)

Source Category Description

Cutback bitumen is the most common form of primer used in Australia to protect roads from excessive wear. Cutback bitumen primers and primer binders are manufactured from refined bitumen which are 'cutback' (i.e. blended) with petroleum solvents. NMVOC emissions occur during the mixing of bitumen batches, stockpiling, application and curing of the road surface.

Methodology

According to Treadrea (1995), for a system in equilibrium where the quantity of NMVOC used is constant each year and the average temperature conditions do not vary significantly from year to year, the quantity of flux and cutter lost to the atmosphere will be approximated by the quantity used each year.

It is assumed that the quantity of fluxed bitumen is negligible; the fraction of total bitumen consumption used in cutback bitumen is approximately 42% (Australian Asphalt Pavement Association, pers. comm., 1995); and, the quantity of cutter added to the bitumen used in cutback bitumen is equal to 5.4% (Treadrea 1995). Bitumen data are sourced from *Australian Energy Statistics* (BREE 2013a).

4.3.8 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Time series consistency for all sources has been maintained in accordance with the principles established in section 1.4.1

Activity data obtained under the NGER (2009–2012) System was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

Where facilities were newly identified from NGER (2009–2012) System data as emitting facilities, in category 2.A.3, activity data was interpolated to the facility's commencement date assuming that consumption of limestone and dolomite in previous years was equal to the consumption of limestone and dolomite in 2009 for the each of the new facilities.

Where facility-specific EFs were identified from NGER (2009–2012) System data for particular facilities, in category 2.A.2 and 2.A.4, the observed EFs were interpolated using a national weighted average EF for all years 1990-2006.

4.3.9 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Additional source specific quality control checks were undertaken to assess completeness and international comparability.

In order to maintain continuity in the compilation of industrial processes emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data, EFs and emissions estimates. This work is of particular importance in industrial processes where confidentiality of historical activity data poses some challenges for the assessment of time series consistency.

Reconciliation between sources of carbonate supply and use in the Australian economy are undertaken to ensure completeness (see Table 4.8). This reconciliation includes limestone used in soda ash production as well as consideration of dolomite, soda ash use, magnesite and other carbonates (barium, lithium, potassium, strontium and sodium bicarbonate).

Table 4.8: Reconciliation of limestone, dolomite, soda ash, magnesite and other carbonates supply and use in the Australian economy, 2012

	Raw material[(d)] (kt)	Emissions (Gg CO_2)	Carbon (kt)
Use			
2.A.1 Cement – clinker	8,319	3,518	960
2.A.2 Lime production	3,280	1,305	356
2.A.3 Limestone and Dolomite use	3,790	1,581	431
5.G. Agricultural Liming	3,792	1,419	387
Change in stocks, statistical discrepancy, and residual available for non-pyro processes	-1040	-	-
Total Use [(a)]	18,141	7,824	2,134
Supply			
Production	17,541		
Imports	707		
Exports	108		
Total supply [(b)]	18,141		

(a) DE;

(b) ABS 2014;

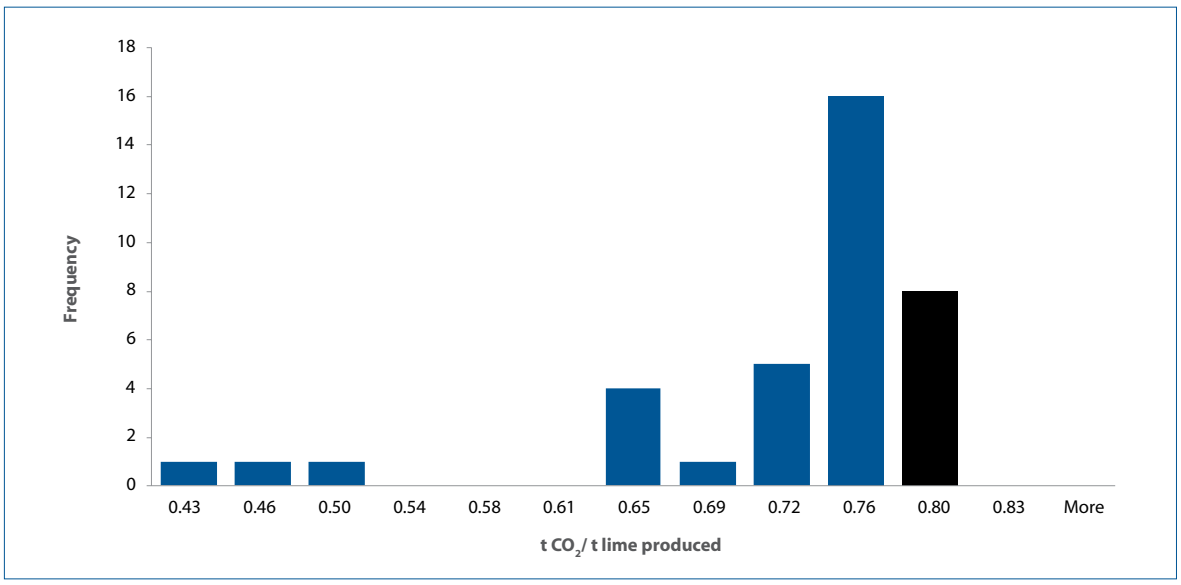
(c) Clinker emissions excluding those from the calcination of magnesium carbonates;

(d) Includes tonnes of limestone, dolomite, soda ash, magnesite and other carbonates.

Comparisons of IEFs and activity data with international data sources are conducted systematically for the Australian inventory.

As the EF for lime was subject to revision as a result of the application of facility- level data obtained under the former EITEIs Program, the IEF per unit of lime production is reported with the distribution of the IEFs of other Annex-1 parties. (Figure 4.2)

Figure 4.2: Lime production implied emission factors for Annex I countries (2011 Inventory) and Australia (2012 Inventory)



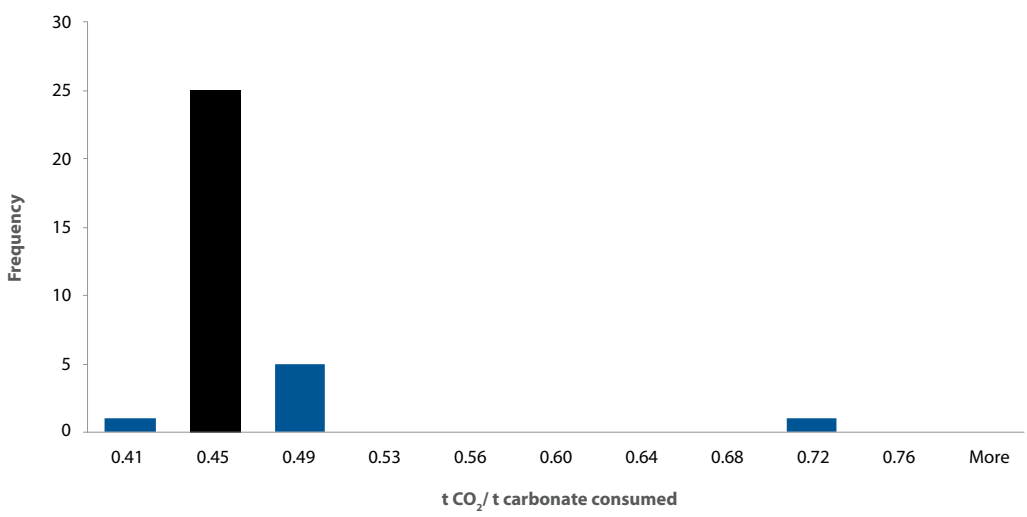
Note: In the figure above, Australia's IEF is located within the black range.

Australia's IEF for lime production at the national level ranges between 0.749 t CO_2/tonne of lime produced and 0.764 t CO_2/tonne of lime produced. The IEF fluctuates year on year according to the relative contributions of product from each facility with their own particular product specifications reflecting use of different types of carbonates as well as the relative proportions of commercial and in-house lime produced as well as lime kiln dust recirculation.

Statistical analysis indicates that the IEF for lime production for Australia (included in the light shaded column above) is not significantly different to the factors reported by other Annex I parties. Australia's IEF is slightly higher than the *Good Practice Guidance* default EF of 0.75 t CO_2/t high calcium quicklime produced. This is due to the production of lime with a high MgO content at a number of large production facilities in Australia.

The IEF for limestone and dolomite use (2.A.3) for Australia is also reported with the distribution of IEF values for other Annex I countries. Results are shown in Figure 4.3.

Figure 4.3: Limestone and dolomite implied emission factors for Annex I countries (2011 Inventory) and Australia (2012 Inventory)



Note: In the figure above, Australia's IEF is located within the black range.

Australia's limestone and dolomite IEF ranges between 0.410 t CO_2/t carbonate consumed and 0.430 t CO_2/t carbonate consumed. With the availability of facility level data, the national IEF fluctuates according to changes in the relative proportions of each carbonate consumed by individual facilities from year on year.

Statistical analysis indicates that the IEF for limestone and dolomite use for Australia (included in the light shaded column above) is not significantly different to the factors reported by other Annex I parties. Australia's IEF is below the IPCC default of 0.440 t CO_2/t limestone and 0.477 t CO_2 /t dolomite. The revised 1996 IPCC *Guidelines* suggest the use of a fractional purity of 1 in the absence of country-specific information. In Australia's case, fractional purities of 0.9 for limestone and 0.95 for dolomite are used.

International comparison of mineral products activity data is also undertaken. Reported clinker production is consistent with cement production for Australia reported by the United Nations given the high level of use of supplementary cementitious materials (fly ash and granulated blast furnace slag) in Australian cement.

The Mineral Products sector was reviewed independently by an international expert (Tsaranu) in 2007. The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. A number of minor refinements were made to the Mineral Products chapter in response to recommendations made in this review.

4.3.10 Recalculations Since the 2011 Inventory

There was a minor recalculation to the estimate of emissions from limestone and dolomite use in 2011 as a result of revisions to carbonates trade data. The magnitude of this revision is shown in table 4-11 below.

Table 4.9: 2.A.1 Clinker production: recalculation of CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.A.1 Clinker Production				
1990	3,463	3,463	0	0.0%
2000	3,621	3,621	0	0.0%
2001	3,541	3,541	0	0.0%
2002	3,488	3,488	0	0.0%
2003	3,584	3,584	0	0.0%
2004	3,555	3,555	0	0.0%
2005	3,664	3,664	0	0.0%
2006	3,888	3,888	0	0.0%
2007	3,972	3,972	0	0.0%
2008	3,863	3,863	0	0.0%
2009	3,829	3,829	0	0.0%
2010	3,549	3,549	0	0.0%
2011	3,496	3,496	0	0.0%

Table 4.10: 2.A.2 Lime production: recalculation of CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.A.2 Lime Production				
1990	775	775	0	0.0%
2000	957	957	0	0.0%
2001	1,150	1,150	0	0.0%
2002	1,176	1,176	0	0.0%
2003	1,194	1,194	0	0.0%
2004	1,217	1,217	0	0.0%
2005	1,213	1,213	0	0.0%
2006	1,102	1,102	0	0.0%
2007	1,225	1,225	0	0.0%
2008	1,320	1,320	0	0.0%
2009	1,152	1,152	0	0.0%
2010	1,231	1,231	0	0.0%
2011	1,244	1,244	0	0.0%

Table 4.11: 2.A.3 Limestone and dolomite use: recalculation of CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.A.3 Limestone and Dolomite Use				
1990	1,345	1,345	0	0.0%
2000	1,776	1,776	0	0.0%
2001	1,671	1,671	0	0.0%
2002	1,751	1,751	0	0.0%
2003	1,775	1,775	0	0.0%
2004	1,742	1,742	0	0.0%
2005	1,727	1,727	0	0.0%
2006	1,806	1,806	0	0.0%
2007	1,916	1,916	0	0.0%
2008	1,839	1,839	0	0.0%
2009	1,554	1,554	0	0.0%
2010	1,653	1,653	0	0.0%
2011	1,816	1,819	3.4	0.2%

4.3.11 Planned Improvements

The methodology and emission factors used for the estimation of emissions from mineral products will be kept under review.

4.4 Source Category 2.B Chemical Industry

4.4.1 Ammonia Production (2.B.1)

Source Category Description

The overall process of producing ammonia involves a series of stages to remove impurities such as sulphur, carbon monoxide, carbon dioxide and water from the natural gas feedstock and the generation and reaction of hydrogen and nitrogen. The multi stage process involved in ammonia production (from natural gas feedstock) results in the industrial process emissions of CO_2, NMVOC, and CO in addition to ammonia and sulphur compounds.

Carbon dioxide emissions from ammonia reflect the use of natural gas for both energy and feedstock uses. In Australia's inventory, only emissions from the use of natural gas as a feedstock are reported in the industrial processes sector. An appropriate deduction has been made in natural gas consumption in the *stationary energy* sector to remove the possibility of double-counting.

A portion of carbon dioxide emissions arising from the production of ammonia are principally recovered for use in the production of urea and food and drink products. Emissions from the production and use of urea are included with the emissions from ammonia in accordance with *good practice*. Emissions from the use of carbon dioxide derived from ammonia production in the food and drink industry are reported under 2.D.2 *food and drink*. The emissions from the ammonia category are aggregated with emissions from the use of acetylene and the production of synthetic rutile and titanium dioxide and included under *2.B.5 confidential chemical industry emissions.* In 2012, ammonia production contributed around two-thirds of total CO_2 emissions under 2.B Chemicals.

Ammonia is produced in seven plants operated by six producers in Australia; Incitec, Orica, Wesfarmers, BHP-Billiton, Queensland Nitrates and Burrup fertilisers. All companies provided natural gas consumption and CO_2 recovery data (where appropriate) for this Inventory under the NGER System. Historical ammonia production data are confidential.

Methodology

A tier 1b method is utilised for the Australian inventory. Ammonia is manufactured by the catalytic steam reforming of natural gas. Hydrogen from the reformed natural gas and nitrogen from air are compressed at reduced temperatures to form ammonia:

$$3H_2 + N_2 \rightarrow 2NH_3$$

The overall manufacturing process for ammonia production involves a series of stages to remove impurities such as sulphur, carbon monoxide, carbon dioxide and water from the natural gas feedstock and the generation and reaction of hydrogen and nitrogen.

The manufacture of ammonia from the catalytic steam reforming of natural gas is documented to result in emissions of CO_2, NMVOC and CO. While the CO_2 equivalent emissions associated with the use of natural gas are accounted for, data on emissions of NMVOC and CO are not currently available. It is assumed that carbon in natural gas feedstock is converted entirely to CO_2.

The general method for deriving emissions relates a country-specific emission factor EF_i (reported in Table 3.2) to plant specific natural gas consumption data A_i:

$$E_a = \Sigma A_i \,.\, EF_i - R_{food\ and\ drink}$$

$R_{food\ and\ drink}$ is CO_2 captured and sold for use in the food and drink industry. Carbon dioxide is captured and used in either the production of urea or the manufacture of food and drink products. The CO_2 recovered for use in urea production is not deducted from CO_2 emissions from ammonia production.

The quantity of CO_2 recovered for use in food and drink applications is derived from data reported under the NGER System. Ammonia producers are required to report the quantity of CO_2 recovered and used in urea production and it is assumed that CO_2 recovered and not used in urea production is sold to the food and drink industry.

Choice of emission factor

A facility-specific EF for one facility reported under the NGER System was used for 2009 onwards. This particular facility has reported a facility-specific natural gas EF throughout the time series.

For the remaining six facilities, no facility-specific EF information was available. Therefore the country-specific EF for the consumption of natural gas as listed in table 3.2 of the NIR was used.

Emissions estimates for ammonia production for all facilities (including the facility reporting a facility-specific emission factor) assume 100% oxidation of natural gas takes place in line with GPG recommendations.

Activity data

Data on fuel consumption, ammonia production and CO_2 capture were obtained under the NGER System for 2009 onwards. Data for consumption of fuels were derived from data on production for the period 1990-2008 provided by Energreen 2009 and constant consumption to production factors in order to ensure time series consistency. Complete coverage of all ammonia producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

4.4.2 Nitric Acid Production (2.B.2)

Source Category Description

The manufacture of nitric acid (HNO_3) generates N_2O as a by-product of the high temperature catalytic oxidation of ammonia (NH_3). Nitric acid is used as a raw material mainly in the manufacture of nitrogenous agricultural fertiliser.

Nitric acid is produced by three producers in Australia; Wesfarmers, Orica and Queensland Nitrates.

Emissions for the nitric acid category are reported as 'included elsewhere' where the estimates are aggregated with emissions from the use of N_2O in anaesthesia and aerosols and included under *2.B.5 confidential chemical industry emissions*.

Methodology

A tier 3 method is utilised for the Australian inventory. Nitric acid production involves three distinct chemical reactions. These are summarised as follows:

$$4\,NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

$$2NO + O_2 \rightarrow 2NO_2$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

Nitric oxide (NO), an intermediate in the manufacture of nitric acid, is documented to readily decompose to N_2O and nitrogen dioxide (NO_2) at high pressures for temperatures in the range of 30 to 50°C.

Facility-specific EFs for N_2O from nitric acid production EF_n are based on periodic measurements of the off-gas emitted at nitric acid production plants in the Australia. These EFs are confidential.

The emissions of N_2O, E_n, from the manufacture of nitric acid production A_n is calculated according to:

$$E_n = A_n \,.\, EF_n$$

Choice of emission factor

The selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

The EFs for nitric acid production are facility-specific and obtained under the NGER System for 2009 onwards. For earlier years, incomplete data on facility-specific EFs were available from Energreen 2009. Where facility-specific factors were not available, no information about the factors applicable to the remaining facilities were inferred from the Energreen data on the assumption that factors applicable to each facility are technology-specific and independent of each other. In these cases, IPCC good practice default factors were applied in accordance with information available on the applicable technologies (Energreen 2009).

Time series consistency is maintained by the interpolation of the available facility-specific EFs to the most recent year for which data were available.

Activity data

Data on nitric acid production for individual facilities were collected under the NGER System from 2009 onwards.

Data for nitric acid production for the period 1990-2008 were provided by Energreen 2009.

Complete coverage of all nitric acid producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

4.4.3 Adipic Acid Production (2.B.3)

There is no adipic acid production occurring in Australia.

4.4.4 Carbide Production (2.B.4)

Silicon carbide and calcium carbide are not produced in Australia. Minor quantities of acetylene are produced from imported calcium carbide and used in welding applications. Data are reported by one company, BOC. Emissions for this category are reported as 'included elsewhere' where the estimates have been aggregated with emissions from the production of ammonia and synthetic rutile and titanium dioxide and included in *2.B.5 confidential chemical industry emissions*.

4.4.5 Other (2.B.5) Synthetic Rutile and Titanium Dioxide

Source Category Description

Rutile (titanium dioxide) is naturally occurring in Australia. Synthetic rutile can be produced from naturally occurring ilmenite using coal reductant. The rutile is then refined using petroleum coke reductant to produce titanium dioxide (TiO_2).

Titanium dioxide is a white pigment which is used in paint manufacture, paper, plastics, rubber, ceramics, fabrics, floor covering, printing ink, and other miscellaneous uses). Titanium dioxide products are referred to generically as titanium dioxide unless there is a need to make a distinction between the products.

Synthetic rutile is produced in Australia by Iluka Resources and Tiwest whilst TiO_2 is produced by Tiwest and Millennium Chemicals.

The use of coal and petroleum coke as reductants in the synthetic rutile and TiO_2 production processes are accounted for in the industrial processes sectors. These reductant quantities have been removed from the stationary energy sector to eliminate the possibility of a double-count.

Emissions data for synthetic rutile are reported as 'included elsewhere' where the estimates are aggregated with emissions from the production of ammonia and the use of acetylene and included under *2.B.5 confidential chemical industry emissions*.

Methodology

A tier 2 method is utilised for the Australian inventory. The processes that are used in the production of TiO_2 in Australia that lead to process greenhouse gas emissions are synthetic rutile production using the Becher process, and rutile TiO_2 production via the chloride route.

The Becher process reduces the iron oxide in ilmenite to metallic iron and then reoxidises it to iron oxide, and in the process separates out the titanium dioxide as synthetic rutile of about 91% to 93% purity. Rutile TiO_2 is produced through the carbothermal chlorination of rutile ore or synthetic rutile to produce titanium tetrachloride ($TiCl_4$) and oxidation of the $TiCl_4$ vapours to TiO_2 according to the following reactions (Kirk-Othmer, 1999; p.2017):

$$2TiO_2 + 4Cl_2 + 3C \rightarrow 2TiCl_4 + 2CO + CO_2$$

$$TiCl_4 + O_2 \rightarrow TiO_2 + 2Cl_2$$

Based on stoichiometry and assuming complete conversion of the input C to CO_2 through further conversion of CO in excess air, the CO_2 EF cannot be less than 0.826 tonnes of CO_2 per tonne of TiO_2 (based on 1.5 moles of CO_2 per mole of TiO_2).

Emissions from rutile and TiO_2 respectively may be calculated by:

$$CO_2 \text{ Emissions} = \Sigma EF_i \,.\, A_i$$

Where EF_i is the EF for fuel type i and A_i is the quantity of fuel type i consumed as a reductant.

Choice of EF

No facility-specific information on EFs from the NGER System has been used in this inventory. Country-specific EFs are applied to the quantities of black coal and petroleum coke consumed in the synthetic rutile and titanium dioxide production processes.

Activity data

Data on synthetic rutile and TiO_2 production, black coal and petroleum coke consumption were obtained under the NGER System from the three manufacturers, Illuka, TiWest and Millenium Chemicals. For the inventory years 2007 and 2008, activity data collected under the former EITEIs Program has been used.

Data for consumption of coal and petroleum coke were derived from data on production for the period 1990-2006 provided by Energreen 2009 and constant consumption to production factors in order to ensure time series consistency.

Complete coverage of all synthetic rutile and titanium dioxide producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

4.4.6 Other (2.B.5) Polymers And Other Chemicals

Source Category Description

The manufacture of organic chemicals results in process emissions of NMVOC. Other gases such as CO_2, CH_4, N_2O, NO_x and CO may also be generated depending on the manufacturing process.

Complete time series of emissions of CH_4 and NMVOCs are included in the inventory for methanol, butadiene, carbon black, ethyl benzene, ethylene, ethylene oxide, formaldehyde, HDPE, LDPE, LLDPE, propylene, polypropylene, polystyrene, styrene, polyvinyl chloride, and styrene butadiene rubber. Disaggregated production and emissions data for these sources are confidential. Emissions estimates are aggregated at the polymers and other chemicals source category level.

There are approximately 15 companies producing a large range of polymers and other chemicals in Australia. Companies include Dynea W.A, Borden Chemicals, Orica, BP, Shell, Huntsman Chemicals, Dow Chemicals, Qenos, ExxonMobil, Continental Carbon, Koppers, Australian Vinyl, BOC Gases, Airliquide, Caltex, and Nuplex.

Methanol is produced by one plant owned by Coogee Chemicals which has been operating since 1994 with an annual production capacity of 80 kt (see Coogee Chemicals website http://www.coogee.com.au/op_meth.html).

Dichloroethylene is used to produce vinyl chloride monomer (VCM) which is used to produce polyvinyl chloride (PVC) resin. All PVC resin manufactured in Australia is produced from imported VCM. (http://www.vinyl.org.au/Manufacturingprocess). Dichloroethylene production does not occur in Australia.

Methodology

A tier 2 method is utilised for the Australian inventory. Emissions from miscellaneous organic chemical manufacture are dependent on the level of activity and extent of emission control and estimated according to equation:

$$E_{ij} = (A_j \times EF_{ij})/10^6$$

where: E_{ij} is the process emission (Gg per year) of gas i from industrial sub-sector j

A_j is the amount of activity (production or consumption) of material in industrial sector j (tonnes per year unless)

EF_{ij} is the EF associated with gas i per unit of activity in industrial sector j (kg per tonne) – see table 4.12

The divisor 10^6 is a factor for converting kg to Gg (kt) (1,000,000kg = 1 Gg)

Table 4.12: Emission factors for organic chemicals

Subsector	CO_2 (kg/tonne)	CH_4 (kg/tonne)	NMVOC (kg/tonne)
Acetylene [(a)]	3 384 kg CO_2 per tonne C_2H_2 used		
Butadiene			1.5
Carbon black		0.11	0.5
Ethyl benzene			0.03
Ethylene		0.03	0.25-1.5
Ethylene oxide			0.069
Formaldehyde			9.2
HDPE			1.5
LDPE and LLDPE			1.5
Methanol [(b)]		0.002	
Propylene			1.5
Polypropylene			1.5
Polystyrene [(b)]			0.1 - 5.4
Styrene [(b)]		4	18
Styrene butadiene rubber		1.5	1.5
Polyvinyl chloride		8.5	8.5

Source: EnerGreen 2009. (a) Based on stoichiometry. (b) IPCC 1997.

4.4.7 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Activity data obtained under NGER was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

No facilities were newly identified from NGER data as emitting facilities for this category.

Where facility-specific EFs were identified from NGER data for particular facilities, in category 2.B.2, the reported EFs for 2007, 2008 and 2009 were interpolated for each facility to the most recent year for which data were available.

4.4.8 Source Specific QA/QC

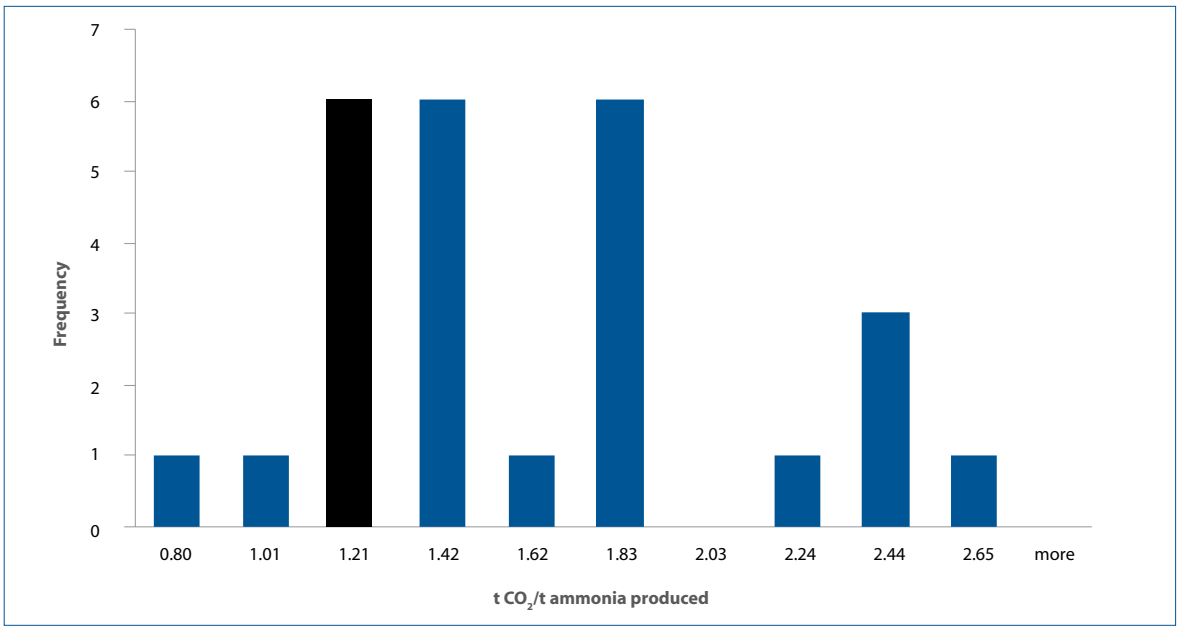
This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Additional source specific quality control checks were undertaken to assess international comparability.

In order to maintain continuity in the compilation of industrial processes emissions estimates during the transition to the use of NGERS data, the Department has engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data, EFs and emissions estimates. This work is of particular importance in industrial processes where confidentiality of historical activity data poses some challenges for the assessment of time series consistency.

The IEF per unit of production for Australia's inventory was compared with the IEFs for other Annex I parties in the cases of ammonia and nitric acid production. The factors for Australia were found to be not significantly different to the factors reported by other Annex I parties. The results of this comparison are presented below.

The quantity of CO_2 generated per tonne of ammonia produced has been compared with that of Annex I parties reporting emissions from ammonia production. The results of this comparison are shown in Figure 4.4.

Figure 4.4: Ammonia implied emission factors for Annex I countries (2011 Inventory) and Australia (2012 Inventory)



Note: In the figure above, Australia's IEF is located within the black range.

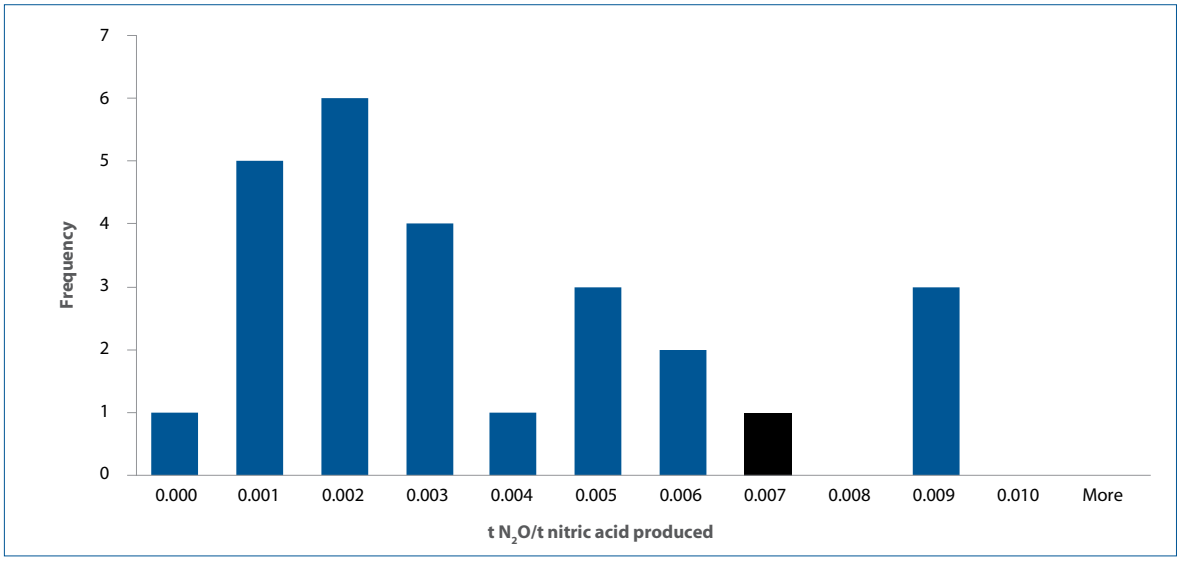
The IEF for ammonia production for Australia ranges between 1.187 t CO_2 per tonne of ammonia produced and 1.544 t CO_2 per tonne of ammonia produced. The IEF fluctuates year on year according to fluctuations in ammonia production levels of individual facilities.

In general, Australia's IEF is broadly consistent with the default values listed in the Revised 1996 IPCC *Guidelines* of 1.5 - 1.6. The *2006 IPCC Guidelines* lists a range of default "total fuel requirements" (including natural gas consumed for energy purposes) by production process whereas under the NGER System, facilities must report feedstock and fuel use separately. This specific IP / non-IP split in activity data partly explains the difference between Australia's IEF and the IPCC defaults. The specific ammonia production technology mix in Australia will also cause differences between parties and the default IPCC values.

Statistical analysis indicates that the IEF for ammonia production for Australia is not significantly different to the factors reported by other Annex I parties.

The quantity of N_2O emitted per tonne of nitric acid produced has also been compared with that for Annex I parties. The results of this comparison are shown in Figure 4.5.

Figure 4.5: Nitric acid implied emission factors for Annex I countries (2011 Inventory) and Australia (2012 Inventory)



Note: In the figure above, Australia's IEF is located within the black range.

The IEF for nitric acid production for Australia ranges between 0.006 t N_2O per tonne of nitric acid produced and 0.010 t N_2O per tonne of nitric acid produced. The IEF fluctuates year on year according to fluctuations in nitric acid production levels at individual facilities. Emissions at individual facilities are highly technology-specific with three main types of production plants and differing levels of abatement technology in place.

Statistical analysis indicates that the IEF for nitric acid production for Australia is not significantly different to the factors reported by other Annex I parties.

In 2011, the Department engaged a consultant to review N_2O emissions control in the nitric acid industry (EnerGreen Consulting 2011). This review found that a number of facilities were either trialling N_2O emissions reduction technology or monitoring developments domestically and internationally with a view to retrofitting existing plants or integrating abatement technology into future expansions.

Plant-level EFs have been declining since 1990 and more recent reductions have come about as a result of the

introduction of continuous monitoring of N_2O emissions and an associated improvement in management of process catalysts.

The *chemical products* category was reviewed independently by an international expert (Tsaranu) in 2007. The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. A number of minor refinements were made to the *chemical products* chapter in response to recommendations made in this review.

4.4.9 Recalculations Since The 2011 Inventory

In accordance with ERT recommendations the country specific emission factor used for 6 of the 7 ammonia production facilities inclusive of oxidation has been revised in this submission from 51.15 Gg CO_2/PJ Natural gas consumed to 51.41Gg CO_2/PJ Natural gas consumed. This revision amends the assumed oxidation factor of 99.5% to 100% in line with GPG. The facility-specific emission factor used for one facility obtained under the NGER System has also been increased by a commensurate amount. The impact of this revision is set out in table 4.13.

Table 4.13: 2.B Chemicals: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.B Chemicals				
1990	2,053	2,057	3	0.2%
2000	3,475	3,480	4	0.1%
2001	4,098	4,103	5	0.1%
2002	4,272	4,277	5	0.1%
2003	4,920	4,927	7	0.1%
2004	5,143	5,151	8	0.2%
2005	5,504	5,513	9	0.2%
2006	6,158	6,169	11	0.2%
2007	6,780	6,793	13	0.2%
2008	6,672	6,683	11	0.2%
2009	6,314	6,324	10	0.2%
2010	6,835	6,848	14	0.2%
2011	6,023	6,035	12	0.2%

4.4.10 Planned Improvements

Previous Expert Review Teams have encouraged Australia to explore the possibility of disaggregating emissions from ammonia production.

Confidentiality continues to be a concern in the chemicals sector where there are only a small number of companies in operation. The confidentiality provisions of the NGER Act under which chemical industry data are obtained are explicit and restrict publication of such confidential data. In recent years, Australia has invested effort in providing as much information as it can within the restrictions of the NGER Act, including provision of implied emission factor information and discussions of comparisons with other Annex 1 parties. Australia remains committed to enhancing the transparency of the chemicals sector estimates and will continue to explore additional options within the confidentiality restrictions of the NGER Act. It should be noted however, that most of these options have been implemented. Further options to report disaggregated data are limited.

4.5 Source Category 2.C Metal Production

4.5.1 Iron And Steel Production (2.C.1)

Source Category Description

Iron and Steel production is a key source in the Australian inventory. Emission sources relate to the in-house production of metallurgical coke and lime, the use of limestone and dolomite as flux in iron, steel and ferro-alloy production and fugitive gas leaks associated with the distribution of coke oven gas and other products within industrial premises. In-house lime production as well as limestone and dolomite use is accounted for under 2.A.2 and 2.A.3.

Metallurgical coke is an essential material in iron and steel production where it serves a number of major functions including the provision of a porous support for furnace ingredients, as a combustion ingredient producing the reducing atmosphere required for ore refinement and as a chemical reductant. Since 2003, pulverised coal has also been used in Australian iron and steel production to improve the performance of the blast furnace. Emissions from the use of coke and pulverised coal as a reductant are reported in this category. Emissions from the production of coke are reported under category1.A.1 while the emissions generated by the combustion of coke oven gas to produce energy are reported under the stationary energy category 1.A.2.

There are two major producers of iron and steel in Australia; Onesteel and Blue Scope. Integrated iron and steel production occurs primarily in New South Wales and South Australia. A hot briquetted iron (HBI) plant that used natural gas as a reductant in Western Australia between 2000 and 2005 is also included in the estimates from 2.C.1 *iron and steel production*.

Methodology

A tier 1b method is utilised for CO_2 and tier 2 for non-CO_2 in the Australian inventory. The manufacture of iron involves the high temperature reduction of iron-bearing materials in a blast furnace. The blast furnace is essentially a large chemical reactor charged with iron ore, coke and limestone/dolomite to produce hot metal or 'pig iron' which is converted into steel typically by injecting oxygen gas through a charge of scrap and the molten iron. During the process, lime is added to remove impurities and provide a slag of the desired basicity. The chemical reactions that occur in the blast furnace to produce molten iron (Fe as shown in the equations) may be summarised as follows:

$$2C\ (coke) + O_2 \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

$$FeyOz + zCO \rightarrow yFe + zCO_2$$

$$FeyOz + zH_2 \rightarrow yFe + zH_2O$$

$$CaCO_3\ (limestone) \rightarrow CaO + CO_2$$

$$CaCO_3.MgCO_3\ (dolomite) \rightarrow CaO.MgO + 2CO_2$$

Coke

The emissions from the use of coke as a reductant are estimated according to equations 3.1 and 3.2 reported in chapter 3.

The CO_2 EF used to compile the emission estimate for coke consumption (shown in table 4.14) is derived from a

carbon mass balance calculation conducted for the coke oven process. A full time series of coke emission factors is provided in Table 3.A.22 in the NIR.

A schematic diagram of the carbon balance used to derive the coke emission factor is provided in section 3.4.2 of the NIR. This balance is performed to ensure carbon inputs into the coke oven are balanced with all known outputs. In the case of coke ovens, the input is black coal and outputs are coke oven gas, coal tar and coke. All outputs are reported in Australia's energy statistics in the form of energy. With emission factors for black coal, coke oven gas and coal tar known, a balance is achieved through the derivation of an appropriate coke emission factor. This balance is performed each year with each new release of the *Australian Energy Statistics* (BREE 2013a).

Table 4.14: Carbon dioxide emission factors for iron and steel

Fuel Type	P Oxidation Factor (%)	F Emission Factor (Gg/PJ)
Coke	98[(a)]	107.7[(c)]
Natural Gas	99.5[(b)]	51.4[(c)]

(a) IPCC (1997) default value.

(b) IPCC (1997) default value.

(c) the CO_2 EF for coke is derived from a carbon balance calculation conducted for the coke oven process. The natural gas EF is provided by the Australian Gas Association.

Table 4.15: Non-carbon dioxide emission factors for iron and steel

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH_4	N_2O	CO	NO_x	NMVOC	SO_2
Coke	1.07	0.80	82.19	450.47	1.00	370
Natural Gas	0.94	0.09	68.20	914.60	1.10	2.3

The raw steel produced contains carbon, the ultimate source of which is fossil carbon from the coal input to coke ovens. Since steel is a long-lived product, this is a form of carbon sequestration. The carbon content of steel is reported directly by iron and steel producers under the NGER system. The reported carbon contents of steel range between 0.1% and 0.93%.

Fugitive Emissions

In addition to the estimation of emissions from the use of coke and gas as reductants, a process EF is established for CH_4 from integrated iron and steel production (0.44 kg CH_4/tonne of crude steel produced) to reflect mainly sources of fugitive emissions. The estimated CH_4 EF is based on experimental data and engineering calculations conducted at the plant owned by BlueScope Steel by BHP (pers. comm. 2000) for its major Australian integrated iron and steelworks. Process emission sources considered include the in-plant distribution of coke oven gas and natural gas, leakage from coke ovens and the bleeding of unflared blast furnace gas to the atmosphere. By comparison with fugitive emissions from the in-plant distribution of coke oven gas, emissions of CH_4 associated with leakage from coke ovens and the bleeding of unflared gas from blast furnaces are estimated to be of minor significance.

Activity data

Activity data for coke consumption in the production of iron and steel are obtained from BREE *Australian Energy Statistics* (BREE 2013a) for inventory years up to 2009 and the NGER 2009–2012 System from 2009 onwards. Crude steel production has been sourced directly from companies (Energreen 2009 and the NGER 2009–2012 System). Data on pulverised coal consumed in the blast furnace have been obtained from investor reports published by Bluescope Steel (Bluescope 2013). In 2009, NGER crude steel production reporting under the NGER 2009–2012 System was incomplete and was derived by indexing the crude steel production in 2008 to the changes in coke consumption in 2009. This is not the case in subsequent years where crude steel production reporting was complete.

Complete coverage of all iron and steel production has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Table 4.16: Australian steel production, coke consumption, pulverised coal consumption and emissions 1990: 2000–2012

Year	Steel production (kt)	Coke consumption (kt)	Hot Briquetted Iron production (kt)	Natural Gas consumption (PJ)	Pulverised coal consumption (kt)	Total emissions from iron and steel production (Gg CO_2-e)
1990	6,223	3,232	NO	NO	NO	9,099
2000	6,345	3,407	558	6	NO	9,883
2001	6,027	3,341	1,223	22	NO	9,144
2002	5,933	2,730	1,142	23	NO	8,911
2003	6,282	2,479	1,670	34	500	10,079
2004	6,312	2,683	1,592	32	600	10,662
2005	5,977	2,568	NO	NO	600	8,767
2006	6,560	2,531	NO	NO	600	8,949
2007	6,600	2,566	NO	NO	700	9,351
2008	6,597	2,605	NO	NO	600	9,193
2009	5,529	2,183	NO	NO	400	7,378
2010	6,867	2,562	NO	NO	700	9,317
2011	7,333	2,642	NO	NO	700	9,465
2012	5,357	1,942	NO	NO	400	6,644

Source: ABARES, NGER (2009–2012) and Bluescope Steel

4.5.2 Ferroalloys Production (2.C.2)

Source Category Description

Emissions from the consumption of fossil fuels when used as reductants, or when used to produce carbon anodes on-site, or as carbon anodes are estimated under this category.

There is one company producing ferroalloys in Australia consuming black coal, coking coal, coke oven coke, petroleum coke and limestone in the process.

The availability of NGER System data on reductant consumption in the production of ferroalloys has enabled reductant emissions from this source to be estimated for the first time in this submission. These emissions are reported under 2.C.4 'Other Metals' to protect confidentiality of data. An equivalent deduction has been made

in stationary energy to ensure there is no double counting or omission of emissions. The use of limestone in the production of ferroalloys is reported under 2.A.3 'Limestone and Dolomite Use'.

Methodology

Emissions from the consumption of reductants in the production of ferro-alloy metals have been estimated using a tier 2 method. Emissions from the use of reductants in the production of ferroalloys are estimated by the application of a country-specific EFs in Table 3.2 and the oxidation factors in Table 3.3 to the quantity of each reductant used.

Choice of emission factor

EFs have been selected in accordance with the decision tree in section 1.4.1. No information on facility-specific EFs were available under the NGER System. Time series consistency has been maintained by the application of values for EFs for 2009 for the period 1990-2008.

Activity data

Data on fuel consumed as reductants for the purpose of production of ferro-alloy metals have been collected under the under the NGER System from 2009 onwards. For the years 1990-2008, this level of fuel consumption has been assumed to be constant. While the approach to estimating pre-NGER activity data introduces a degree of uncertainty, there are presently no other data sources on which to base historical ferroalloy estimates.

4.5.3 Aluminium Production (2.C.3)

Source Category Description

Aluminium is a key source in the Australian inventory. Emissions from the consumption of fuels in the production of carbon anodes on-site, or as carbon anodes, are estimated for this source. Additional perfluorocarbon emissions resulting from process upsets are also reported under this category.

Aluminium is produced by the electrolysis of alumina in a series of complex electrode reactions. The overall reaction results in aluminium being produced at the cathode and carbon dioxide at the anode:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

The electrolysis process is conducted in carbon-lined steel pots containing high purity carbon anodes. The cell electrolyte consists of a molten bath of cryolite (Na_3AlF_6) to which varying proportions of aluminium fluoride, calcium fluoride or lithium fluoride may be added to lower the melting point, decrease the density of the electrolyte and improve energy efficiency.

Carbon dioxide is primarily formed by the chemical reaction of oxygen (produced in the electrolysis process) with the carbon anode. During the electrolysis of alumina to aluminium, some of the CO_2 formed at the anode may be reduced to CO by a secondary reaction involving particles of aluminium or sodium. Grjotheim and Welch (1980) report that for a typical 150kAmp pre-baked cell, the anode gas consists of 70–85% CO_2 with the balance (15–30%) as CO. Measurements conducted by the ADC at several Australian smelters indicate that approximately 10% of the anode gas (by weight) consists of CO. On contact with air, the majority of the CO in anode gas is burnt to CO_2 immediately above the electrolyte.

The perfluoronated carbon compounds (PFC), tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) are powerful greenhouse gases which are generated during the so-called anode effect in the production of aluminium. The anode effect is characterised by an increase in cell voltage as a result of the cryolite bath becoming deficient in alumina.

There are four companies operating aluminium smelters in Australia; Alcoa, Tomago Aluminium Rio Tinto and Hydro Kurri Kurri.

In Australia, bauxite is refined to alumina in Western Australia (WA), Queensland (Qld) and the Northern Territory (NT). The in-house production of lime at alumina refineries in Qld and NT represents an industrial process source of CO_2 emissions, which are accounted for under 2.A.2.

Methodology

CO_2 emitted during the consumption of carbon anodes is reported as if all the carbon is oxidised to CO_2. Emissions from the production of carbon anodes for use in aluminium production are estimated on the basis of the quantities of coal tar, petroleum coke and coke oven coke consumed in the production process and plant-specific EFs. CO_2 emissions are derived using the equation:

$$E_{al} = A_i \cdot EC_i \cdot EF_i$$

Where: A_i is the quantity of fuel type i consumed in the production of anodes

EC_i is the energy content of each fuel type i

EF_i is the CO_2 EF for each fuel type i

Facility specific PFC EFs have been estimated in accordance with accepted international measurement protocols (International Aluminium Institute (2006), *The Aluminium Sector Greenhouse Gas Protocol, Addendum to the WRI/WBCSD GHG Protoco*l, USEPA, International Aluminium Institute (2008), *Protocol for Measurement of Tetrafluoromethane (CF_4) and Hexafluoroethane (C_2F_6) Emissions from Primary Aluminium Production*).

Choice of emission factor

CO_2 EFs have been applied to the quantities of fuels used in the production of anodes. One NGER reporting facility has derived facility-specific CO_2 EFs for coal tar and petroleum coke. It was assumed that the fuel specifications measured at this facility were equally applicable to all facilities.

The facility-specific fuel consumption EFs for anode production are confidential, however, the implied total CO_2 EF per unit of aluminium produced is shown in table 4.17 and confirms that these values are within the historical range of IEFs and not significantly different to the mean of the values reported between 1990 and 2010.

In the case of emissions of perfluorocarbons, facility-specific EFs at all facilities have been estimated and sourced from the NGER System from 2009 onwards. National average factors for previous years have been supplied by the Australian Aluminium Council based on collected information on individual facility factors.

Activity data

Data on coke oven coke, petroleum coke and coal tar consumption for the purpose of production of aluminium have been collected under the NGER System from 2009 onwards. For the years 1990-2008 coal tar and petroleum coke consumption are derived from the carbon in the reported emissions and the typical composition of carbon anodes used in the aluminium production process.

Data on aluminium for the purposes of estimating emissions of PFCs has been obtained under the NGER System for 2009 onwards and ABARES *Commodity Statistics* (various years) for 1990-2008.

Complete coverage of all aluminium producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Table 4.17: Emission factors: kg per tonne of aluminium production 1990, 2000–2012

Year	CO_2 [(a)]	CF_4	C_2F_6
1990	1,636	0.416	0.054
2000	1,587	0.082	0.011
2001	1,603	0.112	0.015
2002	1,663	0.106	0.014
2003	1,638	0.101	0.013
2004	1,606	0.102	0.013
2005	1,611	0.106	0.014
2006	1,586	0.040	0.005
2007	1,608	0.033	0.004
2008	1,591	0.025	0.003
2009	1,584	0.020	0.002
2010	1,630	0.017	0.002
2011	1,651	0.018	0.002
2012	1,644	0.017	0.002

Source: NGER 2009–2012, Beyond Neutral 2008, GHD 2009c.

(a) IEF including production and consumption of anodes.

The carbon anode consumed in aluminium smelting is approximately 3% sulphur by weight. Based on the assumption that 413 kg of carbon from the carbon anode is oxidised (consumed) for each tonne of aluminium produced, this implies that approximately 12.77 kg of sulphur and 25.54 kg of sulphur dioxide are oxidised per tonne of aluminium produced.

Table 4.18: Aluminium: production and emissions 1990, 2000–2012

Year	Aluminium production (kt) [(a)]	Emissions [(b)] (Gg CO_2-e)
1990	1,235	5,971
2000	1,742	3,867
2001	1,788	4,411
2002	1,809	4,489
2003	1,855	4,482
2004	1,877	4,484
2005	1,890	4,581
2006	1,912	3,621
2007	1,954	3,641
2008	1,965	3,507
2009	1,980	3,444
2010	1,926	3,384
2011	1,943	3,468
2012	1,943	3,447

Source: (a) ABARES /NGER 2009–2012;

(b) Beyond Neutral 2008, GHD 2009c.

4.5.4 SF_6 Used In Aluminium And Magnesium Foundries (2.C.4)

The inventory includes experimental quantities of SF_6 used between 1996 and 2000 as a cover gas in magnesium foundries preparatory to the development of a commercial magnesium casting plant (which was not, ultimately, commercially viable). The data on SF_6 use for this experimental foundry was supplied by CSIRO.

4.5.5 Other Metals Production (2.C.5)

Source Category Description

In Australia the other metals source category includes emissions from the production of copper, lead, nickel, silver and zinc. There are 10 major companies involved in the production of other metals in Australia. In Australia, the major zinc refinery, in Hobart, uses an electrolytic process, which is non-emissive. The major lead refinery, at Port Pirie, which also refines a small amount of zinc, uses blast furnace technology.

CO_2 emissions from the use of fossil fuels as reductants, or in the production of carbon anodes on-site, or as carbon anodes in these refineries are reported under this category. An equivalent deduction has been made from fuel consumption in stationary energy to ensure there is no double-count of fuels in the inventory.

CO_2 emissions from the consumption of limestone in the production of other metals are reported under 2.A.3.

Australia's metal ores are predominantly sulphide ores leading to the generation of SO_2 as a by-product of metal production. SO_2 emissions from metal production are reported under this category.

Methodology

Emissions from the consumption of reductants in the production of other metals have been estimated using a tier 2 method. Emissions are estimated using country-specific energy contents and CO_2 EFs for relevant fuels or, in certain cases, based on facility-specific EFs.

Ore composition and stoichiometric relationships have been used to derive sulphur dioxide emission estimates for copper, lead, nickel, zinc, and silver. The general approach is illustrated using the example of zinc. Zinc occurs either as sulphide ores (ZnS) or carbonate ores ($ZnCO_3$). Australia's zinc production is predominantly from sulphide ores. The objective of the refining process to obtain primary refined zinc is to break the compound ore down by separating the sulphur from the zinc. Based on atomic and molecular weights, 0.980 tonnes of SO_2 will be released per tonne of primary refined zinc. EFs for other metals, based on stoichiometry relationships, are given in the Table 4.19.

Table 4.19: Sulphur dioxide emission factors for refined metals

Metal	Tonnes SO_2 per tonne of refined metal
Copper	2.0
Lead	0.3
Nickel	1.1
Silver	0.3
Zinc	1.0

Choice of emission factor

EFs have been selected in accordance with the decision tree in section 1.4.1.

In the case of one company, a facility-specific CO_2 EF has been used for the consumption of petroleum coke. This EF is confidential. In all other cases, the factors are taken from Table 3.2.

Time series consistency has been maintained by the application of values for EFs for 2009 for the period 1990-2008.

Activity data

Data on fuel consumed as reductants for the purpose of production of other metals have been collected under the NGER System from 2009 onwards. For the years 1990-2008, this level of fuel consumption has been assumed to be constant.

4.5.6 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Activity data obtained under the NGER System was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

Where facilities were newly identified from NGER data as emitting facilities for a category, estimates of fuel consumption were interpolated through the time period from the most recent year for which data was available to the year of commencement of the facility based on metal production estimates.

Where facility-specific EFs were identified from NGER data for particular facilities, in category 2.C.4, the reported EFs for 2007, 2008 and 2009 were interpolated for each facility between 2006 and the most recent year for which data were available.

4.5.7 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Additional source specific quality control checks were undertaken to assess international comparability.

The Metal Products sector was reviewed independently by an international expert (Tsaranu) in 2007. The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. Small refinements were made to the iron and steel non-CO_2 methodology and general refinements made to the metal products chapter in response to recommendations made in this review.

Iron and Steel

The consumption of coke as a reductant which is used as the basis of emissions from iron and steel can be compared between the primary data source under the NGER (2009–2012) system and the *Australian Energy Statistics* (BREE 2013a). A secondary source of trend comparison is the production of crude steel.

It is apparent from the figure that NGER coke consumption tracks very closely with crude steel production levels while BREE coke data appear not to reflect the increase in crude steel production observed in 2010-11. As a result of this QC measure, and in consultation with BREE, it was determined that NGER data were best to use for this particular source.

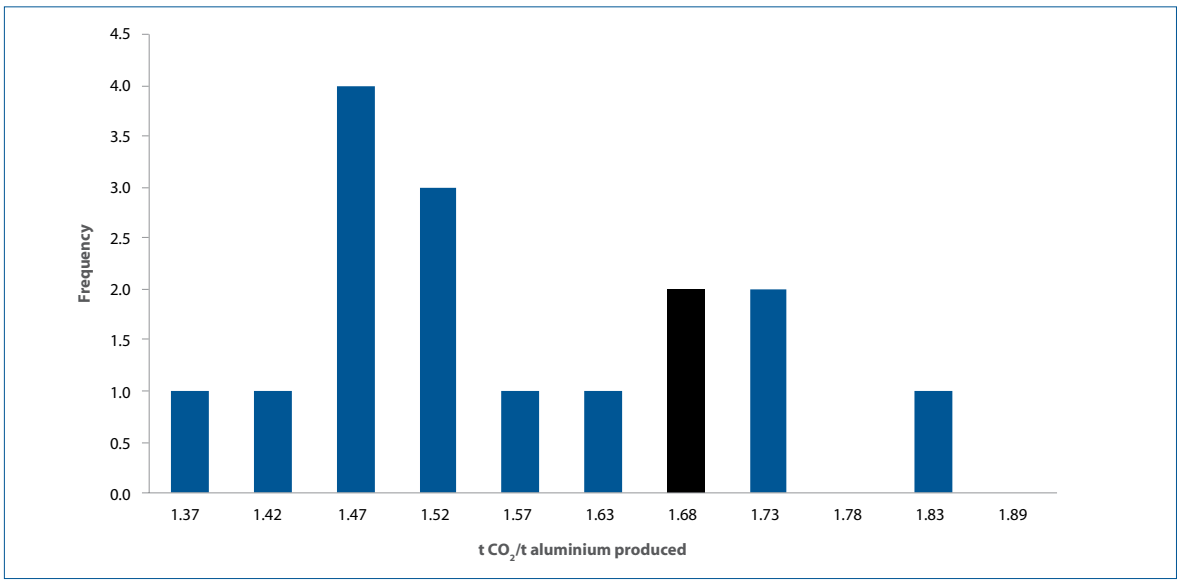
Aluminium

Emissions of PFCs by the Australian aluminium industry are a key category under both the level and trends analyses. Consequently, additional analysis has been performed to provide a comparison of Australian emission trends with those worldwide. The results of the comparison show that the trend in emissions per unit of production in Australia is very close to that observed worldwide. The decline in PFC emissions per unit of aluminium production in Australia since 1990 has mirrored the decline internationally (75%), whereas the International Aluminium Institute (2005) reports a decline of 73% between 1990 and 2003 worldwide. Emissions per unit of production reported by Australia are lower than the global averages, reflecting relatively modern plant and efficient operation, although this difference has narrowed slightly over time.

Monitoring of PFC concentrations occurs at the Cape Grim Baseline Air Pollution Station in Tasmania. Analysis of the observed atmospheric data has been undertaken by the CSIRO and compared to the emissions estimates in the inventory. Estimates of CF_4 and C_2F_6 emissions based on the measured data are in good agreement with inventory estimates for 2010 (CSIRO 2011).

The quantity of CO_2 per tonne of aluminium produced has been compared with that from other Annex I parties reporting emissions from this source. The results of this comparison are shown in Figure 4.6.

Figure 4.6: Aluminium production implied emission factors for Annex I countries (2011 Inventory) and Australia (2012 Inventory)



Note: In the figure above, Australia's IEF is located within the black range.

The CO_2 IEF for aluminium production for Australia ranges between 1.541 t CO_2/t aluminium produced and 1.746 t CO_2/ t aluminium produced. IEFs fluctuate observed year on year according to the quantities of carbon-based fuels used to produce anodes.

Statistical analysis indicates that the IEF for aluminium production for Australia (in the light shaded column above) is not significantly different to the factors reported by other Annex I parties.

In order to maintain continuity in the compilation of industrial processes emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data, EFs and emissions estimates. This work is of particular importance in industrial processes where confidentiality of historical activity data pose some challenges for the assessment of time series consistency.

4.5.8 Recalculations Since The 2011 Inventory

There have been 3 main sources of recalculations in the metal production time series in this submission:

1) The re-allocation of emissions from pulverised coal injection between 2003 and 2012 from 1.A.2 to 2.C.1. This revision has been undertaken in accordance with previous ERT recommendations.
2) The use of NGER coke consumption data in place of BREE estimates for the first time in this submission. In previous submissions, the NGER data had not been considered suitable for use in inventory compilation. For this submission, a comprehensive review and comparison between BREE coke consumption and that obtained under the NGER System was undertaken. This review of data confirmed that NGER coke consumption were suitable for use in the compilation of the inventory.
3) The inclusion of estimates of CH_4 and N_2O associated with carbon reductant consumption for all years for the first time in this submission. These estimates have previously not been included for reductant consumption in the metals industry.

The impact of these revisions is set out in table 4.20 below.

Table 4.20: 2.C Metal Production: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.C Metals				
1990	15,603	15,605	1	0.0%
2000	14,287	14,288	1	0.0%
2001	14,089	14,090	1	0.0%
2002	13,934	13,936	1	0.0%
2003	13,740	15,096	1355	9.9%
2004	14,328	15,683	1355	9.5%
2005	12,533	13,888	1355	10.8%
2006	11,484	13,110	1626	14.2%
2007	11,636	13,534	1897	16.3%
2008	11,615	13,241	1626	14.0%
2009	10,277	11,361	1085	10.6%
2010	11,402	13,306	1904	16.7%
2011	12,682	13,592	910	7.2%

4.5.9 Planned Improvements

Historical activity data for the consumption of reductants in the production of ferroalloys and other metals will be reviewed and updated where better information is available.

4.6 Source Category 2.D Other Production

4.6.1 Source Category Description

The supply of CO_2 gas for use in the food and drink industry is provided from three main sources in Australia. Three ammonia producers sell a proportion of the CO_2 generated as a by-product of the ammonia production process to the food and drink industry. Gas is also obtained from two natural CO_2 wells located at Caroline in South Australia (commissioned in 1967) and Boggy Creek in Victoria (commissioned in 1995). The third source is by product CO_2 from an ethylene oxide plant located in Botany in New South Wales.

In the case of the CO_2 wells and the ethylene oxide plant, some CO_2 sold is also used for medical and other purposes (such as use in fire extinguishers). However, all CO_2 sold by these operators is reported under 2.D.2 *Food and drink.*

A small source of CO_2 emissions also derives from the use of sodium bicarbonate in food production. These emissions are also reported under 2.D. Sodium bicarbonate is a by-product of the production of soda ash.

The manufacture of beer, wine, alcoholic spirits, and bread involve the use of fermentation processes. The IPCC (1997) indicate the fermentation of sugar by industry is not considered to be a net source of CO_2 emissions, consistent with the IPCC *Guidelines*, Australia does not estimate CO_2 emissions from this source. NMVOC emissions from food and drink production, however, are included in the inventory. Production data for meat and poultry, beer and wine are obtained from ABS. Production data for sugar are obtained from ABARE (2009b).

4.6.2 Methodology

Emissions of CO_2 from food and drink are derived based on the assumption that all CO_2 gas used is emitted in the year of production.

CO_2 generated in the production of ammonia and then captured for consumption in the food and drink industry is described in the method for the estimation of emissions from ammonia production (2.B.1). The quantity of CO_2 supplied from the two gas wells is derived based on published production capacity. The quantity of CO_2 supplied from the ethylene oxide plant is derived based on the production capacity of the plant and a CO_2 EF of 0.45 tonnes of CO_2 per tonne of ethylene oxide produced taken from the Netherlands National Inventory Report (no IPCC default factor is provided and the Netherlands is the only party to report emissions from this source). It is assumed that all CO_2 generated is sold for use in food and drink production.

The method for the calculation of emissions from the use of sodium bicarbonate is provided with the method for the estimation of emissions from soda ash (2.A.4).

Emissions of NMVOCs from food and drink production are based on tier 2 methods and IPCC default EFs. Generally the methods involve multiplying the product activity level data (the amount of material produced or consumed) by an associated EF per unit of production or consumption. The NMVOC EFs used are as follows:

- Beer 0.035 (kg NMVOC/hl beverage produced);
- Red Wine 0.08 (kg NMVOC/hl beverage produced);
- White Wine 0.035 (kg NMVOC/hl beverage produced);
- Bread 1.66 (kg NMVOC/t food produced);
- Sugar 10 (kg NMVOC/t food produced); and
- Meat and Poultry 0.3 (kg NMVOC/t food produced).

4.6.3 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

4.6.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6.

4.6.5 Recalculations Since The 2011 Inventory

No recalculations have occurred in 2.D in this inventory.

Table 4.21: 2.D Food and Drink: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013 Submission	2014 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
2.D Other Production				
1990	83	83	0	0.0%
2000	145	145	0	0.0%
2001	147	147	0	0.0%
2002	150	150	0	0.0%
2003	152	152	0	0.0%
2004	165	165	0	0.0%
2005	167	167	0	0.0%
2006	160	160	0	0.0%
2007	148	148	0	0.0%
2008	163	163	0	0.0%
2009	161	161	0	0.0%
2010	232	232	0	0.0%
2011	262	262	0	0.0%

4.6.6 Planned Improvements

Activity data and EFs will be kept under review.

4.7 Source Category 2.E Production of Halocarbons and SF_6

4.7.1 Source Category Description

HCFC-22 was produced in Australia from 1990 to 1995.

4.7.2 Methodology

For the production of HCFC-22, the IPCC tier 1 default methodology and an IPCC default EF of 0.04 t of HFC-23 per tonne of HCFC-22 has been used. This factor is at the upper limit of the default range and is considered appropriate given the age of the facility at the time of production.

4.8 Source Category 2.F Consumption of Halocarbons and SF_6

4.8.1 Source Category Description

This sub-sector comprises emissions of synthetic gases from the use of halocarbons in refrigeration and air conditioning, foam blowing, fire extinguishers, aerosols/metered dose inhalers, solvents and SF_6 in electrical equipment and other miscellaneous applications.

The methodology used for compiling emissions estimates from this range of sources relates emissions to the stock of halocarbon (HFC) gases in various equipment end-use categories. Where equipment stock data are available (in the case of domestic refrigeration and air conditioning, motor vehicle air conditioning and metered dose inhalers), information on the age and lifetimes of the capital stock of appliances have been used to estimate emissions on a bottom up basis. Where these stock data are not available, a top-down approach has been used.

The method relies primarily on inputs of data on HFC imports (an estimate of potential emissions – there is no export or local production of HFCs in Australia) reported to the Department of the Environment (DE) under the *Ozone Protection and Synthetic Greenhouse Gas Management Act, 2003*. As part of the licensing conditions specified in the *Act*, quantities of gas imported in bulk and in pre-charged equipment are reported to the Department of Environment and these data are used for emissions estimation.

4.8.2 Methodology

Consistent with IPCC good practice, the methodology uses specified equations to estimate HFC emissions for each equipment type for three separate processes a) initial losses that occur at the initial charging of the equipment; b) emissions from leakages during the life of the equipment and c) the emissions from the disposal of the equipment. Initial losses occur when an amount of bulk imported gas (Mb_{ijkt}) is allocated to a specific equipment type j. Emissions during the life of the equipment depend, in the first year, on the amount of imported bulk gas allocated to the equipment type j and the amount of gas in imports of precharged equipment of type j (Mpc_{ijkt}) and, for every year thereafter, on the opening stock of gas in the equipment type (S_{ijkt}) plus any replenishments of gas (R_{ijkt}) in the equipment type that may have occurred in that year. Emissions at disposal depend upon the closing stock of gas of vintage k in year t (S_{ijkt}), the proportion of the capital stock retiring in each year, αK_{jkt}, and the quantity of gas recovered for destruction, D_{ijkt}.

The following equations set out the general process for estimating emissions of HFCs:

$$E_{ijkt} = Mb_{ijkt} * IL_{ijkt} + (S_{ijkt-1} + Mb_{ijkt} + Mpc_{ijkt} + R_{ijkt}) * (EF_{ij}) + (\alpha K_{jkt} * S_{ijkt} - D_{ijkt})$$

$$S_{ijkt} = S_{ijkt-1} + Mb_{ijkt} + Mpc_{ijkt} + R_{ijkt} - E_{ijkt} - D_{ijkt}$$

$$R_{ijkt} = \Sigma_{t-1,\, t-z}\, E_{ijkt}$$

$$D_{ijktbase} = \alpha K_{jkt} * S_{ijkt} * DF_{ijk}$$

$$D_{ijkt} = D_{ijktbase} / \Sigma_j \Sigma_k D_{ijktbase} * DTOT_t$$

and

$$E_t = \Sigma_i \Sigma_j \Sigma_k E_{ijkt}$$

Where: E_t is the sum of emissions of all gases of type i from all equipment types j and vintages k in year t

E_{ijkt} is the emissions of gas i from equipment type j and vintage k in year t

S_{ijkt-1} is the opening stock of gas i from equipment type j and vintage k in year t

S_{ijkt} is the closing stock of gas i from equipment type j and vintage k in year t

Mb_{ijkt} is the quantity of bulk import of gas i allocated to equipment type j for vintage k if k = year t, else = 0;

Mpc_{ijkt} is the quantity of gas i in imports of pre-charged equipment type j for vintage k if k= year t, else =0;

R_{ijkt} is the amount of replenishment of the stock of gas i for equipment type j and vintage k in year t

EF_{ijkt} is leakage rate of gas i from equipment type j and vintage k in year t (in the first year of operation, EF is divided by 2 – assuming equipment is in operation for an average of 6 months)

IL_{ijkt} is the initial loss rate of gas i from equipment type j and vintage k in year t

αK_{jk} is the proportion of the capital stock of equipment type j and vintage k retired in year t

$\Sigma_{t-z\, t,} E_{ijkt}$ is the sum of initial and annual emissions from t-z to t where t is the current year and z is the number of years between replenishments

D_{ijkt} is the amount of gas i destroyed from equipment type j and vintage k in year t

DF_{ijkt} is the base destruction factor for gas i destroyed from equipment type j and vintage k in year t

$D_{ijktbase}$ is estimated base amount of gas i destroyed from equipment type j and vintage k in year t

$DTOT_t$ is the actual total gas destroyed reported by Refrigerant Reclaim Australia.

The initial loss rate (IL_{ijkt}) and the leakage rates of HFC gas during the life of the equipment (EF_{ijkt}) applied to each vintage of each equipment type are a mix of country-specific (Expert Group 2013) and IPCC 2006 defaults (the mid-point of specified ranges). Emission factors have been chosen that best reflect the most recently available knowledge on refrigerant losses from refrigeration and air conditioning equipment most commonly in use in Australia. Country-specific annual leakage rates for commercial air-conditioning and refrigeration, transport refrigeration and heavy vehicle air conditioning have been adopted for all years in this submission. These emission factors are sourced from Expert Group 2013 and represent a synthesis of the best available information on annual gas leakage from a range of equipment in use in Australia. The use of country-specific leakage rates from commercial equipment addresses a specific finding in Expert Group 2013 that default leakage rates for these equipment types were not reflective of economy-wide weighted leakage based on recorded gas consumption. This revision also forms Australia's initial response to previous ERT recommendations on the use of country-specific leakage rates.

The amount of gas allocated to the replenishment of the stock of HFC gas and for each equipment type and vintage during the year (R_{ijkt}) is equal to the amount of gas leaked over the life of the equipment to that point and the frequency of replenishment undertaken by the operators of the equipment. Little information is available on this use of bulk imports of gas. Nonetheless, it is assumed that all commercial refrigeration and air-conditioning and fire protection systems are well maintained and subject to regular gas replenishment every 2 years of operation. Light vehicles are assumed to undergo a single gas re-charge at the mid-point of each unit's life. Sensitivity testing of the impact of these assumptions on emissions is provided in the QA/QC section. Lifetime emissions are not affected by these assumptions, while the time profile of emissions is considered to be not significantly sensitive to these assumptions.

Average equipment lifetimes are IPCC defaults. A constant proportion of the equipment stock (αK_{jk}) is assumed to be disposed over a period of time, centred on the midpoint of the average equipment lifetime. For example, the disposal of the refrigerator and air conditioning stocks is assumed to occur over a period from age five to a final date that ensures that the midpoint is centred on the average age of equipment life.

Disposal losses reflect the residual charge or closing stock of gas in the equipment at the time of disposal (S_{ijkt}) and gas recovery for destruction undertaken at time of disposal. Data ($DTOT_t$) on recovery for destruction are supplied by Refrigerant Reclaim Australia (RRA), the sole entity responsible for the recovery and destruction of refrigerants in Australia. The RRA data are used to re-calibrate the recovery for individual equipment types estimated using base destruction factors or IPCC default disposal recovery rates (DF_{ijkt}). In effect, total recovery for destruction for the inventory as a whole is determined by data supplied by RRA, while the allocation of that total amount of destruction to the various equipment types is effectively determined by the relative IPCC default destruction rates.

Table 4.22: Halocarbons: key assumptions concerning average equipment life, initial and annual losses and replenishment rates, by equipment type

End Use Category	Average equipment life [a,b]	Loss on initial charge [a]	Annual loss [a]	Replenishment [c]
	Years	%	%	
Commercial refrigeration				
Stand-alone commercial applications	12.5	1.75	7.0 [d]	Full replenishment every 2 years
Medium and large commercial applications	11	1.75	12.0 [d]	Full replenishment every 2 years
Industrial commercial applications	22.5	1.75	17.5 [d]	Full replenishment every 2 years
Domestic refrigeration	15	0.6	0.3	No replenishment
Transport refrigeration	7.5	5.1	20.0 [d]	Full replenishment every 2 years
Light vehicle air conditioning	12	0.4	15.0	Full replenishment at 6 years
Heavy vehicle air conditioning	12.5	0.4	10.0 [d]	Full replenishment every 2 years
Domestic stationary air conditioning				
Refrigerated portable air conditioners	15	0.6	5.5	No replenishment
Split system air conditioners	15	0.6	5.5	No replenishment
Packaged air conditioners	15	0.6	5.5	No replenishment
Commercial air conditioners	22.5	5.1	6.0 [d]	Full replenishment every 2 years
Foams (closed cell)	20	10.0	4.5	No replenishment
Aerosols	2	0.0	50.0	No replenishment
Fire	10	0.4	5.0	Full replenishment every 2 years
Metered Dose Inhalers	2	0.0	50.0	No replenishment

(a) IPCC 2006,

(b) Burnbank 2002,

(c) DE,

(d) Expert Group 2013.

Bulk gas activity data allocation methods

Bulk imported HFC gas allocations to equipment types are undertaken in 3 ways depending on what information is available about equipment stocks and production levels. These are identified below as methods 1 to 3. Bulk gas demand is first estimated for classes of equipment where data on equipment stocks is available, then the residual bulk gas is allocated to the remainder of equipment types.

Method 1 covers the allocation of bulk gas to light vehicle air conditioning. Vehicle stocks by vintage in each inventory year are available from data underpinning the estimation of emissions from road transport. The following equation is used:

$$G_{demmv} = G_{dpmv} + G_{drmv}$$

$$G_{dpmv} = (New_{mv} - Imp_{mv}) \times Chg_{mv}$$

Where: G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

G_{dpmv} is gas demand for domestic production for motor vehicle air conditioners

G_{drmv} is the gas demand for replenishment for motor vehicle air conditioners – assumed to be total replacement of lost gas in the 5th year of operation.

New_{mv} is new additions to the motor vehicle stock – based on motor vehicle census data used for the estimation of emissions for the transport sector

Imp_{mv} is imports of pre-charged motor vehicle air conditioners

Chg_{mv} is the unit charge of motor vehicle air conditioners

Method 2 covers the allocation of bulk gas to domestic refrigeration and air conditioning. Total stocks of domestic refrigerators and air conditioners are tracked based on data available from the Australian Bureau of Statistics. To achieve mass balance, the method includes a 'stock in storage' factor, where a proportion of imported units are held over for installation in a following year. The following equation is used:

$$G_{demdrac} = G_{dpdrac} + G_{drdrac}$$

$$G_{dpdrac} = (Exp_{drac} - Imp_{domrac} + Ret_{drac} + \Delta S_{drac}) \times Shr_{hfc} \times Chg_{drac}$$

Where: $G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

G_{dpdrac} is gas demand for domestic production for domestic refrigerators and air conditioners

G_{drdrac} is the gas demand for replenishment for domestic refrigerators and air conditioners – no replenishment assumed

Exp_{drac} is the exports of domestic refrigerators and air conditioners

Ret_{drac} is the retirements of domestic refrigerators and air conditioners - based on assumptions about the operational life of each equipment type

ΔS_{drac} is the change in stock of domestic refrigerators and air conditioners calculated according to:

$CS_{drac} - OS_{drac}$

Where: CS_{drac} is the closing stock of domestic refrigerators and air conditioners

OS_{drac} is the opening stock of domestic refrigerators and air conditioners

Imp_{drac} is the imports of domestic refrigerators and air conditioners adjusted for stock in storage = $Imp_{pcedrac} \times P_{inst}$

Where: $Imp_{pcedrac}$ is total imports of pre-charged domestic refrigerators and air conditioners

P_{inst} is the proportion of pre-charged domestic refrigerators and air conditioners installed in the year of import.

Shr_{hfc} is the share of domestic production using HFCs

CHG_{drac} is the unit charge of domestic refrigerators and air conditioners

Bulk gas demand is summed for method 1 and 2 equipment types as follows:

$$G_{demtotal} = G_{demmv} + G_{demdrac}$$

Where: $G_{demtotal}$ is total demand for gas for production and replenishment for motor vehicle air conditioners and domestic refrigeration and air conditioners

G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

$G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

After bulk gas demand for method 1 and 2 equipment types is allocated, the residual gas is allocated to method 3 and 4 equipment types

Method 3 covers commercial refrigeration and air conditioning, metered dose inhalers, foams, aerosols and fire protection equipment. There is no equipment stock information available for these equipment types. Gas is allocated to these equipment types according to the following equation:

$$G_{res} = G_{bulk} - G_{demtotal}$$

$$G_{resi} = G_{res} \times Shr_{resi}$$

Where: G_{res} is the residual gas available to commercial refrigeration and air-conditioning, metered dose inhalers, foams, aerosols and fire protection equipment

G_{bulk} is total bulk gas imported available to all equipment

G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

$G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

G_{resi} is the residual gas available to equipment type i

Shr_{resi} is the share of residual gas used in equipment type i – this value is based upon end use data provided annually by the Department of the Environment

Activity data: HFC gas imported into Australia in 2012

Data on imports of HFC gases are reported to the Department under licensing arrangements operating under the *Ozone Protection and Synthetic Greenhouse Gas Management Act, 2003*. Imports of bulk gas are allocated initially to individual end uses on the basis of a consideration of the amount of gas required for domestic production and replenishment/servicing and retrofitting for the sources which are estimated on a bottom-up basis (gas demand in domestic refrigeration, packaged, split and refrigerated portable air-conditioning and light vehicle air conditioning). After this initial gas demand is satisfied, the residual bulk gas is allocated to the remaining end use categories in proportion to the information on use as reported by licensees under the Act. The sensitivity of these allocations on emissions estimates has been tested and the results are reported in the QA/QC section. The results show that lifetime emissions are not affected by these assumptions, and that the time profile of emissions – whilst impacted - is not considered sensitive to these assumptions.

Quantities of gas imported in bulk and contained in pre-charged equipment by end-use category are shown in Table 4.23.

Table 4.23: End-use allocation of imports of bulk and pre-charged HFC gas 2012

End Use Breakdown	Bulk Imports (Mt CO_2-e)	Pre-charged imports (Mt CO_2-e)	Total (Mt CO_2-e)
Refrigeration	**4.30**	**0.28**	**4.59**
Transport refrigeration	0.34	0.03	0.38
Commercial refrigeration	3.96	0.15	4.11
Domestic refrigeration and freezers	-	0.10	0.10
Stationary air-conditioning	**1.13**	**3.50**	**4.63**
Chillers	0.08	0.18	0.27
Refrigerated portable	-	0.05	0.05
Split systems	1.02	3.03	4.05
Packaged systems	0.03	0.23	0.25
Mobile air-conditioning	**0.79**	**0.72**	**1.52**
Cars	0.58	0.64	1.22
Trucks	0.21	0.08	0.30
Foam	0.06	-	0.06
Aerosols/solvents	0.07	-	0.07
Fire equipment	0.08	-	0.08
Metered dose inhalers	-	0.13	0.13
TOTAL	**6.43**	**4.63**	**11.06**

Source: DE

Backcasting

Collection of data on HFC imports under the *Act* commenced in the 2005 financial year. There are no data available on the import of HFCs for years prior to 2005. It is therefore necessary to backcast import data to enable an estimate of the bank of gas and associated emissions. For each of the end-use categories information on the transition from the use of CFC refrigerants to HFC refrigerants provided in Burnbank 2002 has been used to determine a time series of HFC imports up to 2005 when actual import data are available.

Breakdown of gas species (i)

The bulk gas import data collected under the *Act* are disaggregated into HFC 134a, 'Other HFCs' and 'Exotic HFCs'. The 'Other' gas category comprises a known group of gases but is reported as an aggregated CO_2-e value, whilst the constituent gases in the 'Exotic' gas category are not reported but are provided as an aggregated CO_2-e value. Gas imported in pre-charged equipment is disaggregated into the following equipment types:

Stationary air conditioners;

- Chillers - High pressure
- Chillers - Low pressure
- Air conditioner - Other
- Packaged - Air cooled
- Packaged - Water cooled
- Packaged - Window

- Refrigerated portable
- Split system - Multi head/ variable refrigerant flow
- Split system - Single head

Refrigeration; and

- Commercial refrigerated cabinets
- Domestic refrigerator and equipment
- Other commercial refrigeration
- Portable refrigerators (commercial)
- Self powered refrigerator (transport)
- Vehicle powered refrigerator

Mobile air conditioners.

- Vehicles weighing less than 3.5 tonnes Gross Vehicle Mass (cars and light commercial vehicles)
- Vehicles weighing more than 3.5 tonnes Gross Vehicle Mass (heavy vehicles)

The pre-charged equipment data are also disaggregated by the refrigerant they contain. The refrigerants that are reported are as follows: HFC-125; HFC-134a; HFC-404a; HFC-407a; HFC-407b; HFC-407c; HFC-410a; HFC-413a; HFC-417a; HFC-507a. The speciated gases in pre-charged equipment are used to disaggregate the final emissions estimates in each end use category into individual HFC species for reporting in the CRF tables.

Overview of the stocks of gas in operating equipment

The allocation of total gas imports to individual end use categories determines the relative sizes of gas stocks contained in equipment and the time profile of gas losses from the stock. Figure 4.7 shows the growth in the stock of synthetic gas in operating equipment. The chart shows significant growth in gas contained in commercial refrigeration systems, motor vehicle air conditioners and split system air conditioners. The general growth in the stock of gas in operating equipment reflects the transition from CFC to HFC refrigerant use associated with the Montreal Protocol controls on CFC use. In addition to the transitional trend, the recent strong growth in commercial refrigeration systems reflects similar growth in Australia's economy, whilst the growth in motor vehicle air conditioning and residential split systems reflects declines in relative prices of imported residential air conditioning systems as well as a transition in the vehicle fleet to more modern air conditioned vehicles.

The total stock and emissions from the consumption of halocarbons is shown in table 4.24.

Figure 4.7: Growth in the bank of HFC gas in operating equipment 1990–2012 (Mt CO_2-e)

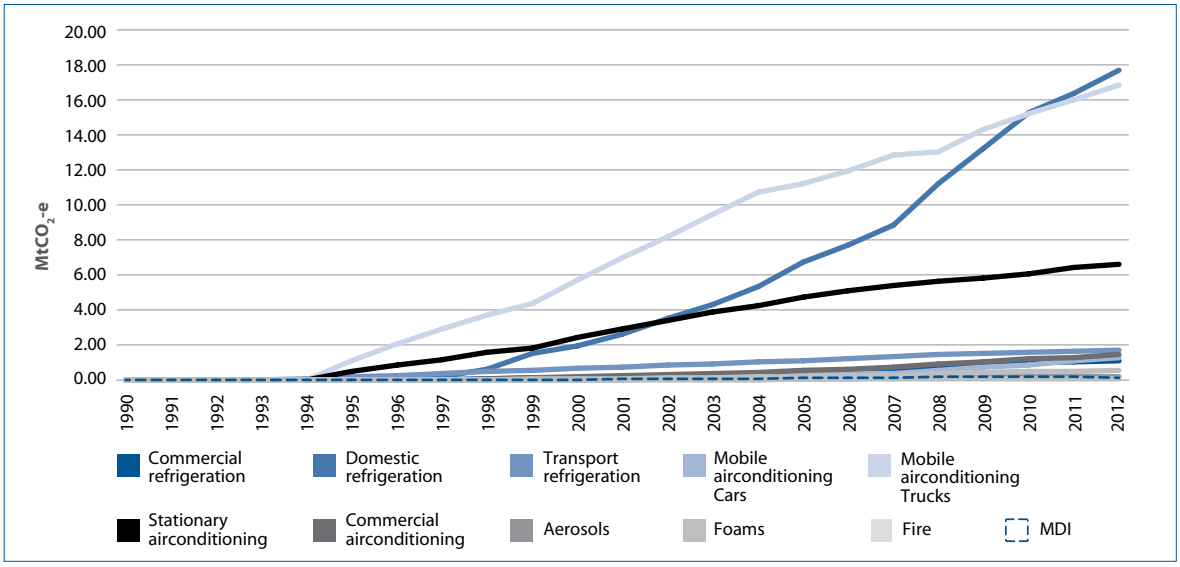


Table 4.24: Halocarbons: estimated stock and emissions: all equipment types

Year	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1990	-	-
1991	-	-
1992	-	-
1993	-	-
1994	0.09	0.00
1995	1.77	0.08
1996	3.24	0.35
1997	4.75	0.60
1998	6.61	0.85
1999	8.73	1.17
2000	11.34	1.37
2001	14.05	1.96
2002	16.86	2.49
2003	19.77	3.05
2004	22.77	3.63
2005	25.64	4.26
2006	28.08	4.65
2007	30.83	5.23
2008	34.36	5.81
2009	38.42	6.35
2010	42.16	6.94
2011	44.94	7.51
2012	47.68	7.95

Refrigeration and air conditioning (2.F.1)

The refrigeration and air-conditioning sector accounts for the majority of HFC consumption in Australia. Emissions from any piece of equipment include both the amount of chemical leaked during initial charging of equipment and the amount emitted during service life. Emissions also occur at equipment disposal. The disposal emission equation assumes that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment and the proportion of chemical released at disposal. The rate at which equipment is retired is based on IPCC default average service-lives for the various types of equipment.

Domestic Refrigeration and freezers

A bottom-up capital stock model has been used to determine a time series for the stock of gas contained in domestic refrigeration and freezers. The estimates are based on data on the number of households and the numbers of domestic fridge freezers found in each household in Australia (ABS 2008b and ABS 2008c) and pre-charged equipment import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act*.

Average charges per unit for domestic refrigerators are based on the pre-charged equipment data collected under the *Act* and were 0.144 kg in 2012. It is assumed that all new equipment and imports from 1994 onwards contain HFC refrigerants (Burnbank 2002). Service life emissions are derived using the IPCC default leakage rates.

Unit disposals are based on an average lifetime of 15 years with the first units in each vintage retiring after 5 years (Burnbank 2002). Under these assumptions the last units in each vintage are retired after 25 years.

The stock of HFCs in operating equipment is estimated to be 1.69 Mt CO_2-e in 2012. Domestic production of household refrigerators no longer takes place in Australia with the last producer Fisher and Paykel completing the relocation of their remaining production facility to Thailand in August 2009[6]. Gas imported in pre-charged equipment amounted to 0.10 Mt CO_2-e in 2012. It is assumed that no replenishment of gas losses from domestic refrigerators takes place as the units contain small well-sealed charges of gas. Upon disposal, a base assumption of 8% of retiring gas in each year is recovered for destruction. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.25 shows the capital stocks, HFC stock and emissions from domestic refrigeration from 1995 to 2012. Comparison of refrigerator stocks and household numbers shows that there has been a trend toward the use of more than one refrigerator in the home.

Unit disposals are based on an average lifetime of 15 years with 5% of units in each vintage retiring after 5 years (Burnbank 2002). Under these assumptions the last units in each vintage are retired after 25 years. The base assumption is made that 70% of each unit's residual charge is emitted upon disposal (although this is calibrated for actual data on total recovery for destruction).

6 http://www.fisherpaykel.com/global/investors/Investors-PDFs/Annual%20Reports/Annual%20Review%20Year%20Ended%2031%20March%202010.pdf

Table 4.25: Halocarbons: estimated stock and emissions: domestic refrigerator/freezers

Year	Domestic refrigerator stock[(a)]	Stock of gas(Mt CO_2-e)	Emissions (Mt CO_2-e)
1994	8,186,036	0.09	0.00
1995	8,382,254	0.19	0.00
1996	8,578,471	0.28	0.00
1997	8,774,688	0.38	0.00
1998	8,970,905	0.48	0.00
1999	9,167,123	0.57	0.01
2000	9,363,340	0.66	0.01
2001	9,538,827	0.74	0.01
2002	9,714,313	0.84	0.02
2003	9,937,512	0.94	0.02
2004	10,226,951	1.03	0.03
2005	10,518,356	1.13	0.03
2006	10,811,949	1.23	0.03
2007	11,045,172	1.36	0.04
2008	11,514,381	1.45	0.04
2009	11,850,689	1.53	0.04
2010	12,182,534	1.59	0.04
2011	12,283,818	1.65	0.05
2012	12,322,307	1.69	0.05

Sources: (a) ABS 2008b Includes stocks not containing HFC refrigerants;
(b) ABS 2011c ; (c) Projection

Domestic air conditioning

Stationary air conditioning comprises refrigerated portable, split and packaged systems. Emissions from this sub category are estimated on a bottom-up basis using equipment population estimates based on numbers of households and white-goods data provided in ABS 2008c, and pre-charged equipment import data. Tables 4.26, 4.27 and 4.28 show the capital stocks, HFC stocks and emissions from the three types of air conditioning equipment from 1995 to 2011.

The stock of HFCs in operating equipment is estimated to be 16.84 Mt CO_2-e in 2012. Imports of bulk gas for domestic production and servicing/replenishment were 1.05 Mt CO_2-e whilst 3.31 Mt CO_2-e arrived in pre-charged equipment in 2012.

IPCC default leakage rates are applied to each gas vintage. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 15 years. The first disposals of gas are assumed to occur after 5 years of operation continuing until the last units are retired after 25 years. Upon disposal, a base assumption of 5% of retiring gas in each year is recovered for destruction. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.26: Halocarbons: estimated stock and emissions: split system stationary airconditioners

Year	Split system air conditioner stocks [(a)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	664,300	0.65	0.02
1996	709,650	1.18	0.18
1997	755,000	1.61	0.31
1998	800,350	1.97	0.42
1999	845,700	2.28	0.51
2000	1,146,548	3.53	0.61
2001	1,447,395	4.70	0.92
2002	1,748,243	5.82	1.19
2003	2,075,944	7.00	1.45
2004	2,403,645	8.14	1.74
2005	2,731,346	8.76	1.98
2006	3,062,064	9.52	2.11
2007	3,549,559	10.37	2.31
2008	3,723,500	10.52	2.47
2009	4,106,477	11.48	2.50
2010	4,437,195	12.19	2.68
2011	4,767,913	12.77	2.86
2012	5,098,631	13.55	3.01

Sources: (a) ABS 2008c; Includes stocks not containing HFC refrigerants

Table 4.27: Halocarbons: estimated stock and emissions: packaged air conditioners

Year	Packaged air conditioner stocks [(a)]	Stock of gas(Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	1,582,177	0.44	0.02
1996	1,643,545	0.89	0.04
1997	1,704,215	1.31	0.07
1998	1,764,251	1.71	0.09
1999	1,823,714	2.09	0.11
2000	1,807,716	2.17	0.12
2001	1,791,754	2.25	0.15
2002	1,775,404	2.31	0.17
2003	1,767,740	2.40	0.19
2004	1,759,693	2.47	0.21
2005	1,746,587	2.34	0.22
2006	1,703,566	2.31	0.21
2007	1,660,699	2.27	0.21
2008	1,618,530	2.29	0.21
2009	1,674,441	2.50	0.22
2010	1,730,352	2.57	0.23
2011	1,786,263	2.76	0.23
2012	1,842,174	2.77	0.23

Sources: (a) ABS 2008c; Includes stocks not containing HFC refrigerants

Table 4.28: Halocarbons: estimated stock and emissions: refrigerated portable air conditioners

Year	Refrigerated portable system stocks [(a)]	Stock of gas(Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	160,971	0.00	0.00
1996	155,350	0.00	0.00
1997	149,730	0.01	0.00
1998	144,109	0.01	0.00
1999	138,488	0.01	0.00
2000	141,998	0.02	0.00
2001	145,508	0.03	0.00
2002	149,019	0.04	0.00
2003	177,029	0.07	0.00
2004	205,040	0.10	0.01
2005	233,050	0.12	0.01
2006	215,967	0.12	0.01
2007	198,883	0.21	0.01
2008	181,800	0.25	0.02
2009	270,000	0.32	0.02
2010	358,200	0.43	0.03
2011	446,400	0.49	0.03
2012	446,400	0.51	0.03

Sources: (a) ABS 2008c ; Includes stocks not containing HFC refrigerants

Mobile air-conditioning (Passenger Cars)

Emissions from the use of air conditioners in passenger cars and light commercial vehicles (vehicles under 3.5 tonnes gross vehicle mass) are also estimated on a bottom-up basis. Data on the stock of motor vehicles obtained from the ABS *Motor Vehicle Census* (ABS 2009a) have been used to construct a capital stock model. In Table 4.29 the stock of light vehicles, the stock of HFC gas contained in motor vehicle air-conditioners and the associated emissions are reported. It is assumed that all new units manufactured from 1995 onwards contain HFC-134a.

Table 4.29: Halocarbons: estimated stock and emissions: light vehicle air conditioners

Year	Light vehicle stocks [(a)]	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	9,710,640	0.47	0.04
1996	10,106,055	0.83	0.12
1997	10,249,706	1.18	0.19
1998	10,438,519	1.59	0.23
1999	10,735,002	1.83	0.29
2000	11,103,805	2.44	0.28
2001	11,441,871	2.92	0.40
2002	11,722,502	3.38	0.49
2003	12,017,165	3.88	0.57
2004	12,367,727	4.28	0.64
2005	12,701,059	4.75	0.69
2006	13,168,195	5.13	0.76
2007	13,453,049	5.39	0.86
2008	13,803,497	5.64	0.89
2009	14,121,275	5.82	0.93
2010	12,783,027	6.08	0.95
2011	14,776,260	6.46	0.99
2012	14,912,407	6.62	1.05

Source: (a) ABS 2009a; Includes stocks not containing HFC refrigerants

The stock of gas has been compiled using the ABS data on light vehicle stocks, assumptions about proportions of each vintage with air-conditioning and an average charge per unit of 1.04 kg of HFC-134a (derived from import data). Assumptions needed on the percentage of pre-1995 vehicles retrofitted with HFC-134a units to estimate an addition to the stock of gas have been taken from Burnbank 2002.

Equipment disposals are based on the IPCC default average life-span of 12 years with the first units of each vintage retiring after 5 years of operation. Under these assumptions, the last units of each vintage would be retired after 19 years. It is assumed that between 1995 and 2000, an initial base assumption that 40% of the remaining charge contained in disposed units is recovered for destruction. From 2000 onwards, the assumed base rate of recovery is assumed to grow at 1% per year. The quantity of gas not recovered is emitted to the atmosphere at disposal. These assumptions are consistent with Burnbank 2002. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Mobile air conditioning (heavy vehicles)

This source category comprises emissions from air conditioning units in vehicles over 3.5 tonnes gross vehicle mass.

The quantities of imported gas are allocated to heavy vehicle air conditioning on the basis of pre-charged equipment as reported under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

The bank of HFCs in operating equipment is estimated to be 1.44 Mt CO_2-e in 2012. Imports of bulk gas for domestic production and servicing/replenishment were 0.21 Mt CO_2-e whilst 0.08 Mt CO_2-e arrived in pre-charged equipment.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 12.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 20 years. Upon disposal, a base calculation of 8% of retiring gas in each year is recovered for destruction. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.30: Halocarbons: estimated stock and emissions: heavy vehicle air conditioners

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	-	0.00	0.00
1996	0.00	0.01	0.00
1997	0.01	0.03	0.00
1998	0.02	0.07	0.00
1999	0.04	0.13	0.01
2000	0.02	0.17	0.01
2001	0.04	0.23	0.02
2002	0.04	0.30	0.03
2003	0.04	0.37	0.04
2004	0.05	0.45	0.04
2005	0.08	0.56	0.06
2006	0.05	0.64	0.07
2007	0.07	0.75	0.08
2008	0.12	0.92	0.10
2009	0.12	1.06	0.12
2010	0.11	1.20	0.13
2011	0.08	1.31	0.15
2012	0.08	1.44	0.17

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Transport refrigeration

Transport refrigeration comprises vehicle and self-powered refrigeration units used in commercial vehicles.

Quantities of imported gas are allocated to transport refrigeration on the basis of pre-charged equipment as reported under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas demand for loss replenishment is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

The stock of HFCs in operating equipment is estimated to be 1.12 Mt CO_2-e in 2012. Imports of bulk gas for domestic production and servicing/replenishment were 0.34 Mt CO_2-e whilst 0.03 Mt CO_2-e arrived in pre-charged equipment in 2012.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 7.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life up to the year of disposal. It is assumed that the first disposals of gas occur after 5 years of operation and continue until the last units are retired after 10 years. Upon disposal, a base assumption of 9% of retiring gas is assumed to be recovered for destruction.

Table 4.31: Halocarbons: estimated stock and emissions: transport refrigeration

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	0.00	0.00	0.00
1996	0.00	0.00	0.00
1997	0.01	0.01	0.00
1998	0.04	0.05	0.01
1999	0.09	0.12	0.02
2000	0.06	0.15	0.03
2001	0.09	0.20	0.04
2002	0.12	0.27	0.05
2003	0.12	0.31	0.07
2004	0.16	0.38	0.09
2005	0.22	0.48	0.12
2006	0.20	0.54	0.13
2007	0.23	0.61	0.16
2008	0.36	0.77	0.19
2009	0.35	0.89	0.23
2010	0.39	1.01	0.26
2011	0.34	1.06	0.28
2012	0.38	1.12	0.30

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Commercial refrigeration

Commercial refrigeration comprises stand-alone, medium and large and industrial refrigeration units and is the most significant user of synthetic gases in Australia.

The quantities of imported gas are allocated to commercial refrigeration on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

The stock of HFCs in operating equipment is estimated to be 17.71 Mt CO_2-e in 2012. Imports of bulk gas allocated for domestic production and servicing/replenishment were 3.96 Mt CO_2-e whilst 0.15 Mt CO_2-e arrived in pre-charged equipment in 2012.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage from 1995 onwards. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 12.5 years for stand-alone units, 11 years for medium and large applications and 22.5 years for industrial systems and the Department's assumption that gas losses are replenished after every 2 years of a unit's life. It is assumed that the first disposals of gas occur after 5 years of operation and continue until the last units are retired after 20 years for stand-alone units, 17 years for medium and large applications and 40 years for industrial systems. Upon disposal, a base assumption of 10% of retiring gas is recovered for destruction.

Table 4.32: Halocarbons: estimated stock and emissions: commercial refrigeration

Year	Imports of gas (Mt CO_2-e)	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	0.01	0.01	0.00
1996	0.02	0.03	0.00
1997	0.17	0.18	0.02
1998	0.52	0.64	0.07
1999	1.05	1.52	0.17
2000	0.68	1.96	0.25
2001	1.02	2.65	0.34
2002	1.29	3.50	0.44
2003	1.38	4.30	0.57
2004	1.74	5.32	0.71
2005	2.37	6.73	0.95
2006	2.10	7.72	1.10
2007	2.49	8.88	1.31
2008	3.93	11.20	1.58
2009	3.97	13.21	1.93
2010	4.32	15.26	2.22
2011	3.68	16.36	2.51
2012	4.11	17.71	2.69

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Commercial air conditioning

Commercial air conditioning covers the use of chiller units used in commercial buildings.

Quantities of imported gas are allocated to commercial refrigeration on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas demand for loss replenishment is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

The bank of HFCs in operating equipment is estimated to be 1.28 Mt CO_2-e in 2012. Imports of bulk gas allocated for domestic production and servicing/replenishment were 0.08 Mt CO_2-e whilst 0.18 Mt CO_2-e arrived in pre-charged equipment in 2012.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 22.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life up to the year of disposal. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 40 years. Upon disposal, a base assumption of 16% of retiring gas is recovered for destruction.

Table 4.33: Halocarbons: estimated stock and emissions: commercial air conditioners

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	0.00	0.00	0.00
1996	0.01	0.01	0.00
1997	0.01	0.02	0.00
1998	0.02	0.04	0.00
1999	0.03	0.06	0.00
2000	0.03	0.09	0.00
2001	0.04	0.12	0.01
2002	0.04	0.15	0.01
2003	0.05	0.19	0.01
2004	0.06	0.23	0.01
2005	0.09	0.30	0.02
2006	0.07	0.35	0.02
2007	0.08	0.40	0.03
2008	0.19	0.56	0.03
2009	0.23	0.75	0.05
2010	0.18	0.87	0.06
2011	0.29	1.09	0.07
2012	0.27	1.28	0.08

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Foam Blowing (2.F.2)

The quantities of imported gas are allocated to foam on the basis of a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning.

The bank of HFCs contained in foams is estimated to be 0.22 Mt CO_2-e in 2012. Imports of bulk gas for domestic production were 0.06 Mt CO_2-e.

IPCC default leakage rates are applied to each gas vintage. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 20 years. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 35 years. There is no recovery or replenishment assumed in foams.

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100% emissive in the year of manufacture. Closed cell foams are assumed to emit a portion of their total HFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, and a portion at disposal.

Table 4.34: Halocarbons: estimated stock and emissions: foam

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	-	-	-
1996	0.00	0.00	0.00
1997	0.00	0.00	0.00
1998	0.02	0.01	0.01
1999	0.03	0.02	0.02
2000	0.01	0.02	0.01
2001	0.03	0.03	0.02
2002	0.03	0.04	0.02
2003	0.03	0.05	0.02
2004	0.03	0.07	0.02
2005	0.06	0.09	0.04
2006	0.03	0.10	0.02
2007	0.05	0.11	0.03
2008	0.08	0.14	0.06
2009	0.08	0.17	0.06
2010	0.08	0.19	0.05
2011	0.05	0.21	0.04
2012	0.06	0.22	0.04

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Fire Extinguishers (2.F.3)

The quantities of imported gas are allocated to fire extinguishers on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

The bank of HFCs contained in fire protection equipment is estimated to be 0.54 Mt CO_2-e in 2012. Imports of bulk gas for domestic production were 0.08 Mt CO_2-e.

IPCC default leakage rates are applied to each gas vintage from 1995 onwards. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 10 years and the assumption that gas losses are replenished after every 2 years of a unit's life. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 15 years. Upon disposal, approximately 26% of retiring gas in each year is recovered for destruction.

The UNFCCC expert review of Australia's 2008 submission recommended that the completeness of the *industrial processes* estimates be improved by inclusion of estimates of emissions from PFC use in fire extinguishers. In response, the Australian Fire Protection Association (FPA) was consulted and they confirmed that the ozone depleting or synthetic greenhouse fire fighting gases most common in Australia are: FE 227 (HFC 227ea), FM 200 (HFC 227ea), NAF-S-III (HCFC Blend A) and NAF-P-III (HCFC Blend C). The use of other gases is considered quite rare. On this basis, PFC use in fire extinguishers is considered to be 'Not Occurring'.

Table 4.35: Halocarbons: estimated stock and emissions: fire protection equipment

	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	-	-	-
1996	0.00	0.00	0.00
1997	0.00	0.00	0.00
1998	0.02	0.02	0.00
1999	0.03	0.05	0.00
2000	0.02	0.06	0.00
2001	0.03	0.09	0.00
2002	0.03	0.11	0.01
2003	0.03	0.14	0.01
2004	0.04	0.17	0.01
2005	0.06	0.22	0.01
2006	0.05	0.24	0.02
2007	0.06	0.28	0.02
2008	0.10	0.35	0.02
2009	0.10	0.42	0.03
2010	0.10	0.47	0.03
2011	0.08	0.51	0.03
2012	0.08	0.54	0.04

Source: DE - HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Aerosols/Metered Dose Inhalers and Solvents (2.F.4 and 2.F.5)

Emissions from these sectors come from two sources: product use and fugitive emissions associated with product manufacture. Emissions from solvent and aerosol product use can be assumed to be 100% of the charge size (e.g. 100% of consumption).

The quantities of bulk gas imported into Australia and allocated for use in aerosols is based on the proportion of reported end use adjusted for gas requirements in domestic refrigerator and air conditioning and mobile air conditioning. There are no imports of pre-charged equipment in Australia and no replenishment is assumed to occur. Therefore all gas imported in bulk goes into charging domestically produced stock.

The complete charge of gas from an aerosol application is assumed to be lost over 3 years with any residual charge being completely emitted upon disposal.

There is no domestic production of metered dose inhalers (MDIs) in Australia. Imports of metered dose inhalers containing HFCs are not covered by the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003) so that data on HFC consumption of metered dose inhalers cannot be derived from this source. Consequently, emissions of HFCs from the use of metered dose inhalers are estimated on a bottom up basis. Estimates of the imports of gas contained in metered dose inhalers is based on information supplied by SEWPaC on the number of MDIs imported into Australia in 2009 and a per-capita based estimation of imports up to that year. Assumptions about the penetration of HFC propellants in imported MDIs are based on information in Burnbank 2002. It is assumed that each imported unit is pre-charged with 18 grams of HFC-134a based on information supplied from SEWPaC (Annie Gabriel, pers. comm.).

Emissions from MDIs are estimated according to the same assumptions used for aerosols.

The bank of HFCs contained in metered dose inhalers is estimated to be 0.16 Mt CO_2-e in 2012. Imports of gas in pre-charged equipment were 0.13 Mt CO_2-e. Table 4.36 shows the growth in imports and the bank of HFC in metered dose inhalers along with the associated emissions from this bank.

Table 4.36: Halocarbons: estimated stock and emissions: metered dose inhalers

	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1998	0.01	0.01	0.00
1999	0.02	0.02	0.01
2000	0.04	0.04	0.02
2001	0.05	0.05	0.04
2002	0.06	0.07	0.05
2003	0.08	0.08	0.06
2004	0.09	0.10	0.08
2005	0.11	0.12	0.09
2006	0.12	0.13	0.11
2007	0.14	0.15	0.12
2008	0.16	0.17	0.14
2009	0.18	0.19	0.16
2010	0.18	0.20	0.17
2011	0.18	0.20	0.18
2012	0.13	0.16	0.17

Source: DE

Semiconductor Manufacture (2.F.6)

There is no semiconductor manufacture activity occurring in Australia.

Electrical Equipment (2.F.7)

Australia has implemented the IPCC tier 2a method to estimate emissions of SF_6 from the electricity supply and distribution network.

Equation 3.16

Total Emissions = Manufacturing Emissions + Installation Emissions
+ Use Emissions + Disposal Emissions

Australia has chosen this method in accordance with the IPCC *good practice guidance* decision tree because:

1. SF_6 is used in electrical equipment in Australia;
2. This is not a key source for Australia; and
3. Activity data and EFs are available from data reported under the NGER System.

Country specific emission factor (use of equipment)

With the availability of facility-level leakage rates from 2010 onwards under the NGER System, Australia has estimated a country-specific EF for the operation of electricity supply and distribution equipment.

The country-specific EF has been estimated using data obtained from over 300 facilities reporting under the NGER System estimated consistent with the IPCC tier 3b method (IPCC GPG 3.56).

Since the 2009 reporting year, amendments have been made to the *National Greenhouse and Energy Reporting Measurement Determination 2008* (Cwlth), which provide for utilities to estimate their emissions from their own data using mass-balance and 'top-up' approaches.

Under these approaches, surveyed utilities track their total consumption of SF_6 for refilling of equipment, the total nameplate capacity of their equipment, the quantity of SF_6 recovered from retiring equipment, and the nameplate capacity of their retiring equipment in the principle method. The approaches are consistent with those set out in the *Electricity Networks Association Industry Guideline for SF_6 Management,* ENA Doc 022-2008.

For the reporting year 2010, 15 companies, with stocks of 5.2 Mt of SF_6 as CO_2-e, elected to utilise one of the new EF methods to estimate losses, including the two largest users of SF_6 in Australia.

The weighted average emission rate derived from these 15 NGER reports is estimated at 0.0078 tonnes of SF_6 per tonne of stock of SF_6 per year.

In 2011, the average emission rate derived from these 15 NGER reporters (with stocks of 5.2 Mt in 2011) is estimated at 0.01 tonnes of SF_6 per tonne of stock of SF_6 per year.

The fluctuation in leakage rates between to two reporting years is attributed to differing service intervals and equipment retirement and replacement schedules. This fluctuation has been smoothed by taking a weighted average of the two years leakage rates to derive a leakage rate of 0.0089 tonnes of SF_6 per tonne of stock of SF_6 per year.

Around 40% of the national SF_6 stock is contained in equipment operated by companies that elected to utilise their own data on emission rates to estimate their SF_6 emissions.

The reported EF obtained from facilities under the NGER System incorporates emissions from the operation of equipment and also emissions from disposal. A separate estimate of emissions from disposal is not available. Nonetheless, emissions from disposal are included with the EF from operation or use of the equipment - refer to *Energy Networks Australia, ENA Industry Guidelines for SF_6 Management*, ENA Doc 022-2008.

Australia has applied this factor to the total stock of SF_6 gas in the electricity supply and distribution network in accordance with the decision tree at section 1.4.

Stock of SF_6 held by electrical equipment users

Data on SF_6 stocks held by users of electrical equipment for 2009 onwards in the National Inventory Report are taken from data gas stock data reported under the NGER System.

Historical stocks of gas have been derived based on a consideration of equipment stock changes between 1972 and 2008. Critical to this process is a consideration of equipment lifetimes in Australia.

There is no comprehensive data available to the Department on the retirement of equipment using SF_6 in Australia. However, evidence on the retirements of circuit breaker stock that utilise SF_6 can be obtained from data published by Transgrid - the major network in the largest State, New South Wales in *Transgrid, Network Management Plan 2011*, February 2011. The characteristics of Trangrid's operations are likely to be similar to those of other large utilities in Australia and mainly reflect the operation of high voltage transmission lines

Figure 4.8: Illustration of Transgrid's network

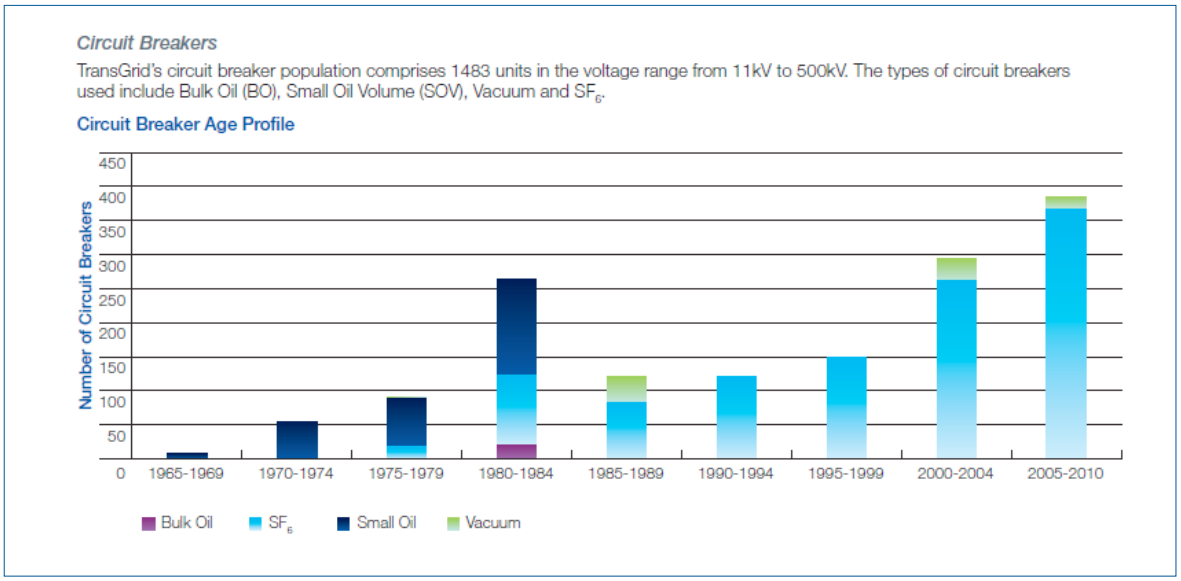
Source: Transgrid Network Management Plan 2011-2016

Confirmation of the general age profile of Transgrid's circuit breaker assets is provided in the Transgrid *Network Management Plan 2011, page 45.*

According to Transgrid 2011 the first time SF_6 was used in equipment in Australia was in the period 1975-79.

Analysis of the change in the age profile of the stock of circuit breakers using SF_6 based on changes in the asset register between 2002 and 2010 provides a basis for an estimated retirement rate of around 0.4% of the stock each year since 2003 (i.e. after equipment reached approximately 28 years). Transgrid also identifies plans to phase out certain classes of circuit breakers using SF_6 over the next decade. Based on Transgrid's announced plans (Transgrid 2011, page 59), the retirement rate will increase to around 1% of stock by 2019.

Figure 4.9: Age profile of Transgrid's circuit breaker assets, by type of equipment

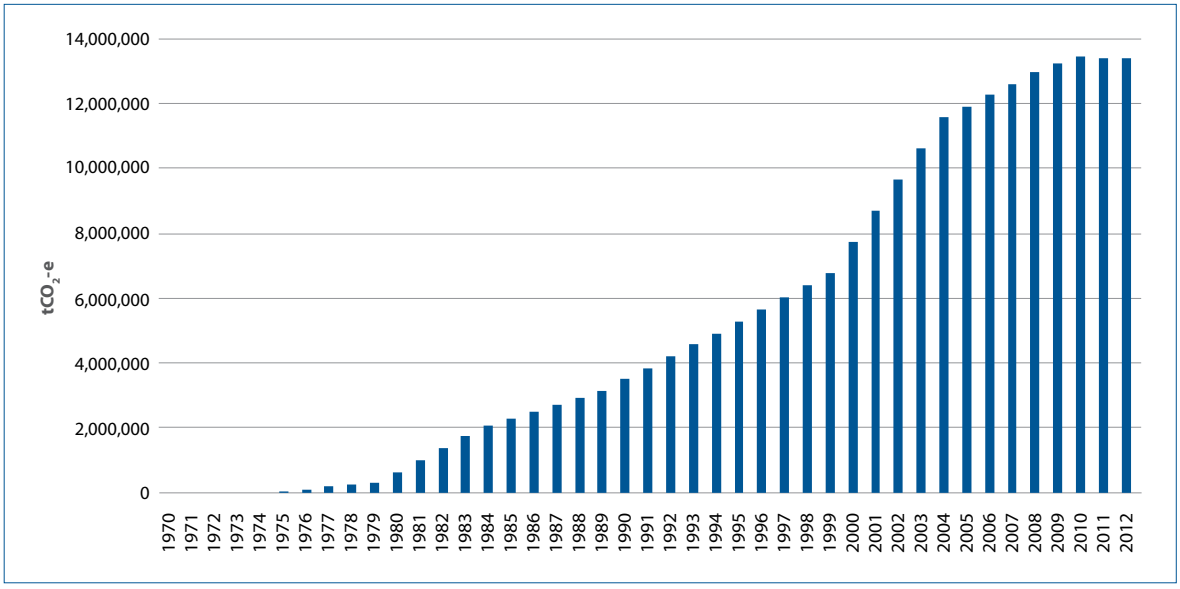


Source: Transgrid Network Management Plan 2011–2016?

The 2006 IPCC *Guidelines* provide additional relevant information in relation to typical equipment lifetimes. In particular, the 2006 IPCC *Guidelines* indicate that equipment lifetimes containing SF_6 are 'more than 30 to 40 years'. Providing a default factor of >35 years, the range of likely outcomes reported by the IPCC is -10% - +40% (2006 IPCC Volume 3, chapter 8, page 8.21) – i.e. retirement is most likely to occur within the range of 31 years to 49 years.

Taking into account the above information, the oldest equipment containing SF_6 in the Transgrid stock in 2020 is expected to be 40 years old.

Figure 4.10: Estimated stock of SF_6 in Australia 1970-2012 (tonnes of CO_2-e)



Estimation of emissions of SF_6 from the manufacture of switchgear and circuit breakers in Australia.

In addition to emissions from the operation and disposal of electricity supply and distribution equipment, Australia also estimates emissions associated with the manufacture of electricity supply and distribution equipment.

Many major international suppliers of electrical equipment operate in Australia - ABB, Siemens, Mitsubishi etc. Currently no data are collected under the NGER System from the manufacturers of electrical equipment in Australia about their use of SF_6 or their emissions of SF_6. In addition, no information is available at this time to indicate the quantities of gas imported to fill new equipment in Australia prior to sale relative to the quantities of gas imported in pre-charged equipment.

To prepare an estimate of emissions from this source requires an assumption in relation to the proportion of pre-charged imported equipment relative to equipment charged with gas domestically using imported gas.

For these estimates it is assumed that half of all equipment used in Australia was either manufactured in Australia or that, if imported, the equipment was charged with SF_6 in Australia. To proxy this outcome, the amount of SF_6 required for charging of new equipment in Australia was assumed to be equal to half of the sum of the change in stock of SF_6 in use recorded during the year and estimated emissions from use in stock.

The IPCC GPG does not report a default emission rate for global manufacturing. It does report factors taken from studies in Europe, which put leakage rates up until 1996 at 15%, and subsequent to 1996, at 6%. Much higher rates are assumed for Japan (29%).

On the other hand, New Zealand reports a leakage rate associated with charging of units during manufacturing in 2009 of 0.79%. The major manufacturer of this equipment in New Zealand, ABB, is also a significant supplier in Australia and, as Australian and New Zealand economies are highly integrated and reflect related political and cultural histories, it could be appropriate to consider the country-specific data from New Zealand.

Given the range of factors available, Australia has assumed that the IPCC GPG rates identified for Europe, which lie around the mid-point of the range, are applicable in Australia.

For the last 2 inventory years, NGER SF_6 stocks have declined. This results in no assumed manufacturing losses in 2011 and 2012. While manufacturing emissions estimates are only a small proportion of total emissions from electricity supply and distribution, it is important to ensure that Australia's estimate of emissions is complete.

Time series consistency

The construction of a time series of emissions estimates requires:

a) estimates of stocks of SF_6 over time;

b) EFs over time; and

c) emissions from disposals of equipment containing SF_6.

Time series of stocks of SF_6 *1972-2012*

Data on stocks of SF_6 are not available prior to 2009. To fill the gap, a time series of the stock of SF_6 was derived from:

i) Data on the age profile of equipment

Data on the age profile of the circuit breaker stock using SF_6 was constructed from data on circuit breakers used by Transgrid - the major network in the largest State, New South Wales (*Transgrid, Network Management Plan 2011*, February 2011). Information is available by manufacturer, type of unit (SF_6 or oil), marquee and date of installation. SF_6 was used in equipment in Australia for the first time in the period 1975-79.

ii) Retirements

Retirements of circuit breaker stock using SF_6 were calculated from the change in the age profile of the stock based on changes in the asset register between 2002 and 2010. Retirements are estimated at around 0.4% of the stock for each year since 2003 (after equipment reached approximately 28 years) with the retirement rate reaching 1% of stock by 2020.

iii) additions of new electrical equipment containing SF_6

Estimates of the additions to the stock of circuit breakers using SF_6 were determined from the change in the stock of circuit breakers and estimated retirements.

New equipment NC = observed (i.e., net) increase in the total equipment NC
+ decreases in the equipment NC due to retirements.

iv) extrapolation of Transgrid age profile and management regime to the rest of Australia

The time profile of the stock of Transgrid's circuit breakers was used to derive an estimate of the stock of SF_6 held by Transgrid using the application of a constant assumed charge per circuit breaker unit. Estimates of a time series of stock of SF_6 for Australia for 1990-2008 were derived by splicing the stock of SF_6 held by Transgrid to the national stock of SF_6 held in electrical equipment in 2009 according to data obtained from the NGER System. This approach is consistent with the approaches described in the IPCC GPG for extrapolation of data to ensure time series consistency.

Emission factors 1972-2012

The IPCC GPG notes that it is not good practice to apply recently calculated EFs to leakages from earlier periods (IPCC GPG 3.60), (2006 IPCC volume 3, 8.20). In the absence of country specific information, Australia has developed a time series of EFs for use of electrical equipment derived from the following assumptions:

a) application of the IPCC GPG global default factor for 1990-1995 of 5% (IPCC GPG 3.58);

b) application of IPCC GPG global default factor for the year 2000 of 2% (IPCC GPG 3.58);

c) country-specific factor for 2009 onwards - 0.89%;

d) interpolation of EFs between the above point estimates;

e) the above emission rates include disposal emissions.

In the absence of country specific information, Australia has developed a time series of EFs for manufacture or on-site filling of imported electrical equipment derived from the following assumptions:

f) application of the IPCC GPG global default factor for 1990-1995 of 15% (IPCC GPG 3.58);

g) application of IPCC GPG global default factor for the year 2000 of 6% (IPCC GPG 3.58);

The decline in leakage rates over time reflects improved awareness and training of personnel in the handling of SF_6 as reflected in industry initiatives both globally, through CIGRE, or nationally – for example as reflected in the development of an Australian Standard AS2791/1996, *Use and handling of SF_6 in high voltage switchgear and control gear* (1996) and industry guidelines as in the Energy Networks of Australia, *Industry Guideline for SF_6 Management* (2008).

Emissions 1972-2012

The stock of SF_6 and SF_6 emissions between 1972 and 2012 are presented in table 4.37.

Table 4.37: Stocks and emissions of SF_6: Australia: 1972-2012

	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			TOTAL
	National stock		Emission factor	Emissions	Quantity	Leakage rate	Emissions	Emissions
	t CO_2-e	% growth	t/t	t CO_2-e	t CO_2-e	t/t	t CO_2-e	t CO_2-e
1972	-		0.0500	-		0.1500		
1973	-		0.0500	-		0.1500		
1974	-		0.0500	-		0.1500		
1975	57,675		0.0500	2,884	30,279	0.1500	4,542	7,426
1976	115,349	100.0	0.0500	5,767	31,721	0.1500	4,758	10,526
1977	173,024	50.0	0.0500	8,651	33,163	0.1500	4,974	13,626
1978	230,698	33.3	0.0500	11,535	34,605	0.1500	5,191	16,726
1979	288,373	25.0	0.0500	14,419	36,047	0.1500	5,407	19,826
1980	634,420	120.0	0.0500	31,721	188,884	0.1500	28,333	60,054
1981	980,467	54.5	0.0500	49,023	197,535	0.1500	29,630	78,654
1982	1,326,514	35.3	0.0500	66,326	206,186	0.1500	30,928	97,254
1983	1,672,561	26.1	0.0500	83,628	214,838	0.1500	32,226	115,854
1984	2,018,608	20.7	0.0500	100,930	223,489	0.1500	33,523	134,454
1985	2,220,469	10.0	0.0500	111,023	156,442	0.1500	23,466	134,490
1986	2,422,330	9.1	0.0500	121,117	161,489	0.1500	24,223	145,340
1987	2,624,191	8.3	0.0500	131,210	166,535	0.1500	24,980	156,190
1988	2,826,052	7.7	0.0500	141,303	171,582	0.1500	25,737	167,040
1989	3,027,913	7.1	0.0500	151,396	176,628	0.1500	26,494	177,890
1990	3,373,960	11.4	0.0500	168,698	257,373	0.1500	38,606	207,304
1991	3,720,007	10.3	0.0500	186,000	266,024	0.1500	39,904	225,904
1992	4,066,054	9.3	0.0500	203,303	274,675	0.1500	41,201	244,504
1993	4,412,101	8.5	0.0500	220,605	283,326	0.1500	42,499	263,104
1994	4,758,149	7.8	0.0500	237,907	291,977	0.1500	43,797	281,704
1995	5,118,614	7.6	0.0500	255,931	308,198	0.1500	46,230	302,160
1996	5,479,080	7.0	0.0440	241,080	300,773	0.0600	18,046	259,126
1997	5,839,546	6.6	0.0380	221,903	291,184	0.0600	17,471	239,374

	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			TOTAL
	National stock		Emission factor	Emissions	Quantity	Leakage rate	Emissions	Emissions
	t CO_2-e	% growth	t/t	t CO_2-e	t CO_2-e	t/t	t CO_2-e	t CO_2-e
1998	6,200,012	6.2	0.0320	198,400	279,433	0.0600	16,766	215,166
1999	6,560,478	5.8	0.0260	170,572	265,519	0.0600	15,931	186,504
2000	7,483,270	14.1	0.0200	149,665	536,229	0.0600	32,174	181,839
2001	8,406,063	12.3	0.0188	157,786	540,289	0.0600	32,417	190,203
2002	9,328,855	11.0	0.0175	163,637	543,215	0.0600	32,593	196,230
2003	10,251,647	9.9	0.0163	167,220	545,006	0.0600	32,700	199,920
2004	11,174,440	9.0	0.0151	168,533	545,663	0.0600	32,740	201,272
2005	11,506,068	3.0	0.0139	159,387	245,508	0.0600	14,730	174,118
2006	11,837,697	2.9	0.0126	149,427	240,528	0.0600	14,432	163,858
2007	12,169,326	2.8	0.0114	138,651	235,140	0.0600	14,108	152,759
2008	12,500,954	2.7	0.0102	127,059	229,344	0.0600	13,761	140,820
2009	12,760,489	2.1	0.0089	114,008	186,772	0.0600	11,206	125,214
2010	13,001,364	1.9	0.0089	116,160	178,517	0.0600	10,711	126,871
2011	12,963,500	-0.3	0.0089	115,822	-	0.0600	-	115,822
2012	12,925,636	-0.3	0.0089	115,483	-	0.0600	-	115,483

Other uses of SF_6

An estimate of SF_6 emissions from other applications including eye surgery, tracer gas studies, magnesium casting, plumbing services, tyre manufacture and industrial machinery equipment has been made on the basis of a per-capita emissions value derived from the National Inventory of New Zealand. An average per-capita emission rate of 0.001 tonne of SF_6 per person per year has been applied to Australia's total population to derive a time series of emissions from this source.

Australia commenced procurement of a number of Boeing E7A Wedgetail airborne early warning and control (AEWC) aircraft in 2010 with the sixth and final unit delivered in June 2012. The Wedgetail aircraft is one of the most advanced aircraft of its kind in operation. The IPCC Guidelines note that AEWC aircraft are a potential user and emitter of SF_6 gas where this gas is used as an insulating medium in high voltage radar units. The IPCC guidelines cite an emission factor referenced in Schwarz 2005. This emission factor is based upon the Boeing E-3A aircraft operating a large rotating radar unit. Importantly, it is noted that the radar units on these aircraft operate at voltages larger than 135kv. It is this high voltage operation that necessitates the use of SF_6 to prevent flashovers in antenna conductors. It is also noted in the reference that "All other radar systems for aircraft, be it ground or aircraft radar, primary or passive, are operated at lower voltages (up to 30 kV), so that no SF_6 is necessary, oil (silicone oil) sufficing".

The Boeing E-3A aircraft first entered service in the late 1970's. By contrast, Australia's E-7A wedgetail aircraft are a new advanced design and operate the modern Multi-Role Electronically Scanned Array (MESA) surveillance radars. These types of radar systems operate at lower voltages than the older type radar systems employed in the E-3A - http://www.ausairpower.net/aesa-intro.html.

Enquiries with Boeing, the manufacturer of the 737 airframe; Northrop Grumman, the manufacturer of the MESA radar and the Royal Australian Air Force who operate the aircraft have all confirmed that no SF_6 gas is used in any capacity in the Wedgetail aircraft.

4.8.3 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

4.8.4 Source Specific QA/QC

Source specific QA/QC focuses on a range of measures undertaken to ensure methods, EFs and activity data are selected and applied appropriately. Section 4.8.4.1 deals with the QA/QC measures associated with the consumption of halocarbons such as independent review, mass balance, sensitivity testing and independent verification. Section 4.8.4.2 focuses on specific QA/QC measures associated with SF_6 use in electricity supply and distribution.

This source category is also covered by the general QA/QC of the greenhouse gas inventory in Section 1.6.

4.8.4.1 Source Specific QA/QC: Consumption of Halocarbons

Data are obtained by the Department from companies under licensing arrangements established under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003) and is subject to verification against known published sources (the Australian Bureau of Statistics data on imports of HFC-134a).

The Consumption of Halocarbons and SF_6 sector has been reviewed independently by an international expert (Tsaranu 2007). The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. The emissions model was reviewed previously by Burnbank consulting. The outputs of the domestic refrigeration and mobile air-conditioning components of the model have been cross-checked against those reported in Burnbank 2002 with close agreement between the two sets of estimates.

Mass balances

An additional comprehensive review of this source was undertaken during 2009 in which HFC balances were completed to ensure that:

- all imported gas in bulk and pre-charged equipment is assigned to an appropriate end-use category, and
- stock changes and emissions and gas destruction were fully tracked and accounted for.

The results of these allocation and stock balances are presented in tables 4.38 and 4.39.

Australia has introduced an additional QC check for this submission. Checks are undertaken to ensure that the sum of bulk gas demand for domestic production and replenishment of leaked gas equals total bulk imports. This check revealed an issue with the bulk gas allocation process in the previous submission which resulted in some bulk gas not being accounted for in charging domestically produced units or replenishing lost stock. Table 4.40 shows this new gas balance check.

Table 4.38: Halocarbons: balance sheet - allocations of imported gas (Mt CO_2-e)

	Backcast import data												Import data reported by SEWPaC						
Gas Imported	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Bulk gas imported	0.06	1.62	1.64	1.86	2.38	2.90	3.42	3.94	4.46	4.98	5.50	6.02	5.40	5.14	6.08	7.09	6.71	6.22	6.43
Gas imported in pre-charged equipment	0.04	0.14	0.19	0.25	0.32	0.40	0.57	0.75	0.89	1.06	1.24	1.24	1.85	3.04	3.49	3.62	4.34	4.44	4.63
Total gas imported	**0.09**	**1.76**	**1.82**	**2.11**	**2.70**	**3.30**	**3.99**	**4.69**	**5.35**	**6.04**	**6.73**	**7.26**	**7.26**	**8.18**	**9.56**	**10.72**	**11.05**	**10.66**	**11.06**
Allocations to end use																			
Transport refrigeration	-	0.00	0.00	0.01	0.04	0.09	0.06	0.09	0.12	0.12	0.16	0.22	0.20	0.23	0.36	0.35	0.39	0.34	0.38
Commercial refrigeration	-	0.01	0.02	0.17	0.52	1.05	0.68	1.02	1.29	1.38	1.74	2.37	2.10	2.49	3.93	3.97	4.32	3.68	4.11
Domestic refrigeration and freezers	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.12	0.13	0.13	0.13	0.17	0.14	0.13	0.12	0.11	0.10
Chillers	-	0.00	0.01	0.01	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.09	0.07	0.08	0.19	0.23	0.18	0.29	0.27
Refrigerated portable	-	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.03	0.02	0.02	0.09	0.06	0.09	0.13	0.10	0.05
Split systems	-	0.67	0.71	0.75	0.78	0.82	1.87	2.11	2.35	2.70	2.96	2.71	3.02	3.29	2.79	3.66	3.66	3.69	4.05
Packaged systems	-	0.46	0.49	0.49	0.49	0.49	0.21	0.22	0.23	0.28	0.29	0.10	0.18	0.18	0.23	0.44	0.31	0.43	0.25
Cars	-	0.51	0.49	0.54	0.64	0.53	0.88	0.88	0.94	1.07	1.04	1.16	1.13	1.13	1.15	1.13	1.22	1.37	1.22
Trucks	-	0.00	0.01	0.02	0.04	0.07	0.06	0.08	0.10	0.11	0.13	0.17	0.15	0.19	0.27	0.26	0.28	0.27	0.30
Foam	-	-	0.00	0.00	0.02	0.03	0.01	0.03	0.03	0.03	0.03	0.06	0.03	0.05	0.08	0.08	0.08	0.05	0.06
Aerosols/Solvents	-	-	0.00	0.01	0.03	0.06	0.05	0.08	0.10	0.11	0.13	0.18	0.16	0.20	0.26	0.27	0.27	0.24	0.19
Fire equipment	-	-	0.00	0.00	0.02	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.05	0.06	0.10	0.10	0.10	0.08	0.08
Total gas allocated	**0.09**	**1.76**	**1.82**	**2.11**	**2.70**	**3.30**	**3.99**	**4.69**	**5.35**	**6.04**	**6.73**	**7.26**	**7.26**	**8.18**	**9.56**	**10.72**	**11.05**	**10.66**	**11.06**
Balance against total gas imported	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.39: Halocarbons: Supply – use balance sheet (Mt CO_2-e)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Gas supply	**0.09**	**1.76**	**1.82**	**2.11**	**2.70**	**3.30**	**3.99**	**4.69**	**5.35**	**6.04**	**6.73**	**7.26**	**7.26**	**8.18**	**9.56**	**10.72**	**11.05**	**10.66**	**11.06**
Pre-charged Imports	0.04	0.14	0.19	0.25	0.32	0.40	0.57	0.75	0.89	1.06	1.24	1.24	1.85	3.04	3.49	3.62	4.34	4.44	4.63
Bulk gas used in production & retrofit	0.06	1.62	1.63	1.85	2.34	2.78	2.87	3.40	3.62	4.11	4.35	4.87	3.82	3.70	4.01	4.98	3.96	3.43	3.26
Bulk gas used in replenishment	-	-	0.00	0.01	0.04	0.12	0.55	0.54	0.84	0.86	1.15	1.14	1.58	1.44	2.06	2.11	2.75	2.79	3.17
Gas use/losses	**0.09**	**1.76**	**1.82**	**2.11**	**2.70**	**3.30**	**3.99**	**4.69**	**5.35**	**6.04**	**6.73**	**7.26**	**7.26**	**8.18**	**9.56**	**10.72**	**11.05**	**10.66**	**11.06**
Emissions	0.00	0.08	0.35	0.60	0.85	1.17	1.37	1.96	2.49	3.05	3.63	4.26	4.65	5.23	5.81	6.35	6.94	7.51	7.95
Recovery for destruction	-	-	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.10	0.13	0.18	0.20	0.23	0.30	0.36	0.37	0.38
Stock change	0.09	1.68	1.47	1.51	1.85	2.12	2.61	2.71	2.81	2.91	3.00	2.87	2.44	2.75	3.53	4.06	3.74	2.78	2.74
Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table 4.40: Halocarbons: Imports – demand balance sheet (Mt CO_2-e)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Total bulk imports	0.30	1.62	1.64	1.86	2.38	2.90	3.42	3.94	4.46	4.98	5.50	6.02	5.40	5.14	6.08	7.09	6.71	6.22	6.43
Bulk gas demand for production	0.30	1.62	1.63	1.85	2.34	2.78	2.87	3.40	3.62	4.11	4.35	4.87	3.82	3.70	4.01	4.98	3.96	3.43	3.26
Bulk gas demand for replenishment	-	-	0.00	0.01	0.04	0.12	0.55	0.54	0.84	0.86	1.15	1.14	1.58	1.44	2.06	2.11	2.75	2.79	3.17
Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sensitivity testing

In addition to the HFC balances documented above, sensitivity analysis was undertaken to assess the impacts of changes to the allocation of bulk gas to end use as well as changes to the assumptions about replenishment rates in equipment. These two elements of the HFC model are where critical assumptions are made about the areas of consumption of imported gas and the servicing/replenishment habits of the consumers of this gas.

The effect of end use allocation on total emissions was tested by altering the percentage of bulk gas allocated to domestic, commercial and transport refrigeration (which is the biggest user of imported bulk gas) by 1%, 5%,10% and 20% in all years with the residual gas allocated equally among the other end-use categories. In addition to this change in allocation, all gas imports are ceased after 2009.

Table 4.41: Halocarbons: results of sensitivity testing of allocation assumptions (Mt CO_2-e)

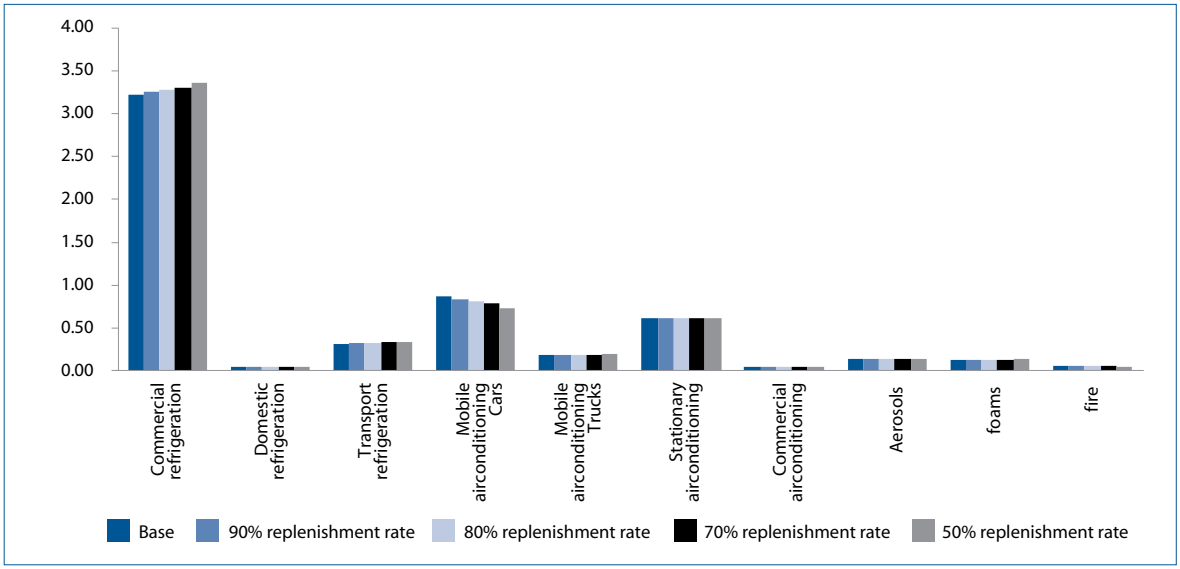
	Allocation assumptions (% of total bulk imports)				
End use allocation	**Base**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Aerosols/solvents	2%	2%	3%	4%	5%
Domestic/Commercial/ Transport refrigeration	60%	59%	55%	50%	40%
Fire	2%	2%	3%	4%	5%
Foam	2%	2%	3%	4%	6%
Mobile air conditioning	25%	25%	26%	27%	28%
Mobile OEM	1%	1%	2%	3%	5%
Stationary air conditioning	8%	8%	8%	9%	11%
Emissions in 2008 (Mt CO2-e)					
Commercial refrigeration	3.23	3.19	3.06	2.89	2.50
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.31	0.30	0.28	0.24
Mobile air conditioning cars	0.86	0.86	0.87	0.87	0.87
Mobile air conditioning trucks	0.19	0.19	0.20	0.22	0.25
Stationary air conditioning	0.62	0.62	0.62	0.62	0.62
Commercial air conditioning	0.06	0.06	0.06	0.06	0.07
Aerosols	0.13	0.15	0.20	0.27	0.43
Foams	0.13	0.14	0.18	0.24	0.37
Fire	0.05	0.06	0.08	0.11	0.18
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.75**	**5.74**	**5.73**	**5.70**
% change in total emissions compared with emissions in the base case		**-0.04%**	**-0.19%**	**-0.40%**	**-0.86%**

The results show that even with a 33% change in bulk gas allocation from domestic, transport and commercial refrigeration to other end use categories, total emissions in 2008 are changed by only 0.9%. This suggests that the estimate of emissions in any given year is relatively insensitive to changes in the allocation of bulk gas.

Figure 4.11 shows gas imports under the base end use assumption and each of the re-allocation assumptions. It can be seen that the gas diverted from domestic, commercial and transport refrigeration is re-allocated primarily to aerosols, foams, and fire protection. In total however, gas imports are unchanged as a result of the re-allocation.

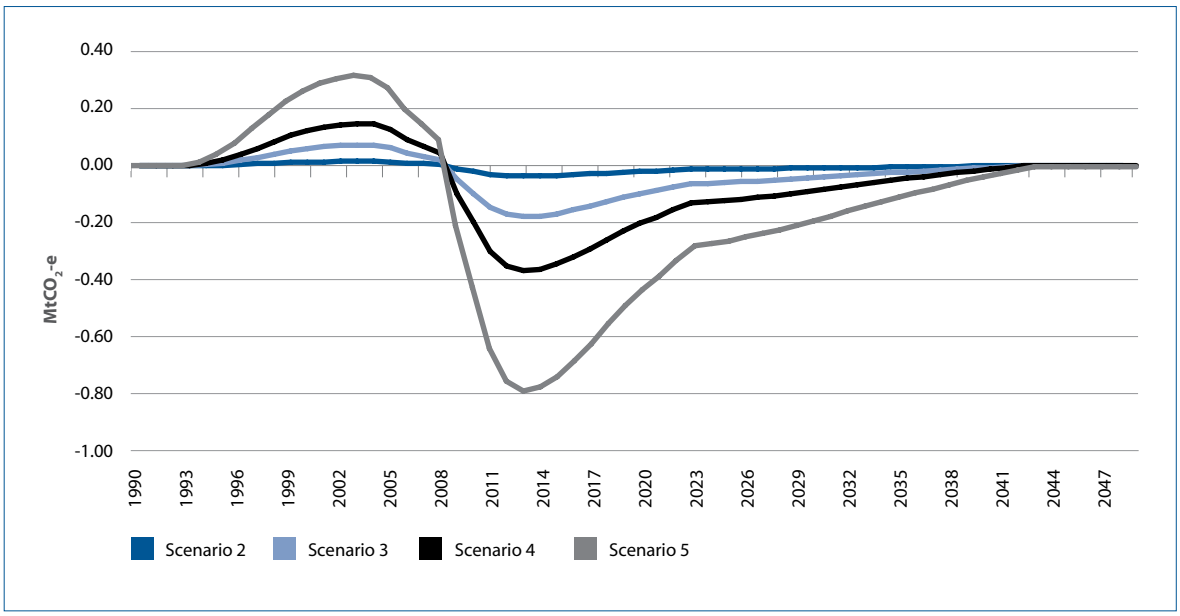
Under scenario 5 (a 33% re-allocation from domestic, commercial and transport refrigeration), approximately 1 million tonnes is re-directed in equal proportions towards aerosols, foam and fire protection. This results in a reduction in emissions of 0.79 million tonnes CO_2-e in domestic, commercial and transport refrigeration and a corresponding increase of 0.66 million tonnes in aerosols, foams and fire protection. The residual gas is accounted for as gas recovered and destroyed and stock change in the bank of gas in operating equipment.

Figure 4.11: Halocarbons: results of sensitivity testing of allocation assumptions: 2008 (Mt CO_2-e)



Total cumulative differences in emissions and destruction under each allocation scenario between 1990 and 2050 (where the last of the current stock of operating equipment is retired) are shown in Figure 4.12. The chart shows that while differences occur in emissions in individual years the total gas either emitted or destroyed is unchanged over the life of each equipment type. The gas end-use re-allocation results in an increase in emissions for years where imports are occurring (up to 2009 in the case of this test), followed by a decrease in emissions relative to the base assumption from 2009 onwards

Figure 4.12: Halocarbons: results of sensitivity testing of allocation assumptions: 1990–2050 (Mt CO_2-e)



As information about servicing and replenishment practices is limited, the replenishment assumptions have been devised by Department.

The effect of assumptions about gas replenishment was tested by reducing the replenishment rates for all sources where replenishment occurs by 10%, 20%, 30% and 50%.

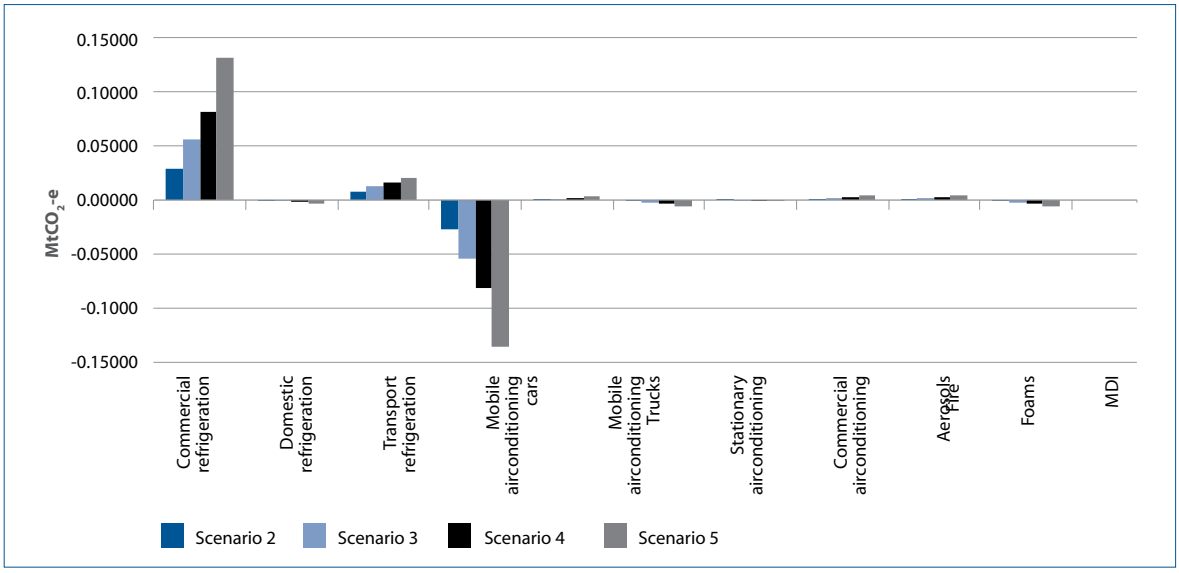
As with bulk gas allocation, the total emissions estimate was found to be insensitive to changes in assumed replenishment rates with a 50% reduction in replenishment resulting in only a 0.25% change in total emissions in 2008. The effects of changes to the replenishment assumptions on total emissions within the model, while minimal, are complex. The total gas allocated to equipment is unchanged under these scenarios such that when less gas is allocated to replenishment, more is available to be allocated to new equipment.

Figure 4.13 shows that emissions from commercial refrigeration increase as a result of a reduction in the general rates of replenishment as more gas is allocated to new equipment for this category. However, for domestic refrigeration, mobile air conditioning in cars and domestic stationary air conditioning the gas stocks are affected by the quantity of gas being replenished and thus, as a result of less gas being replenished, the gas bank and therefore emissions are lower for these categories.

Table 4.42: Halocarbons: results of sensitivity testing of replenishment assumptions (Mt CO_2-e)

	Replenishment assumptions				
	Base	Case 1	Case 2	Case 3	Case 4
Replenishment rate	**100%**	**90%**	**80%**	**70%**	**50%**
Emissions in 2008 (Mt CO2-e)					
Commercial refrigeration	3.23	3.26	3.28	3.31	3.36
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.32	0.32	0.33	0.33
Mobile air conditioning cars	0.86	0.84	0.81	0.78	0.73
Mobile air conditioning trucks	0.19	0.19	0.19	0.19	0.19
Stationary air conditioning	0.62	0.61	0.61	0.61	0.61
Commercial air conditioning	0.06	0.06	0.06	0.06	0.06
Aerosols	0.13	0.14	0.14	0.14	0.14
Foams	0.13	0.13	0.13	0.13	0.13
Fire	0.05	0.05	0.05	0.05	0.05
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.76**	**5.77**	**5.77**	**5.77**
% change on base case		**0.17%**	**0.24%**	**0.25%**	**0.25%**

Figure 4.13: Halocarbons: results of sensitivity testing of replenishment assumptions – change in emissions 2008 (Mt CO_2-e)

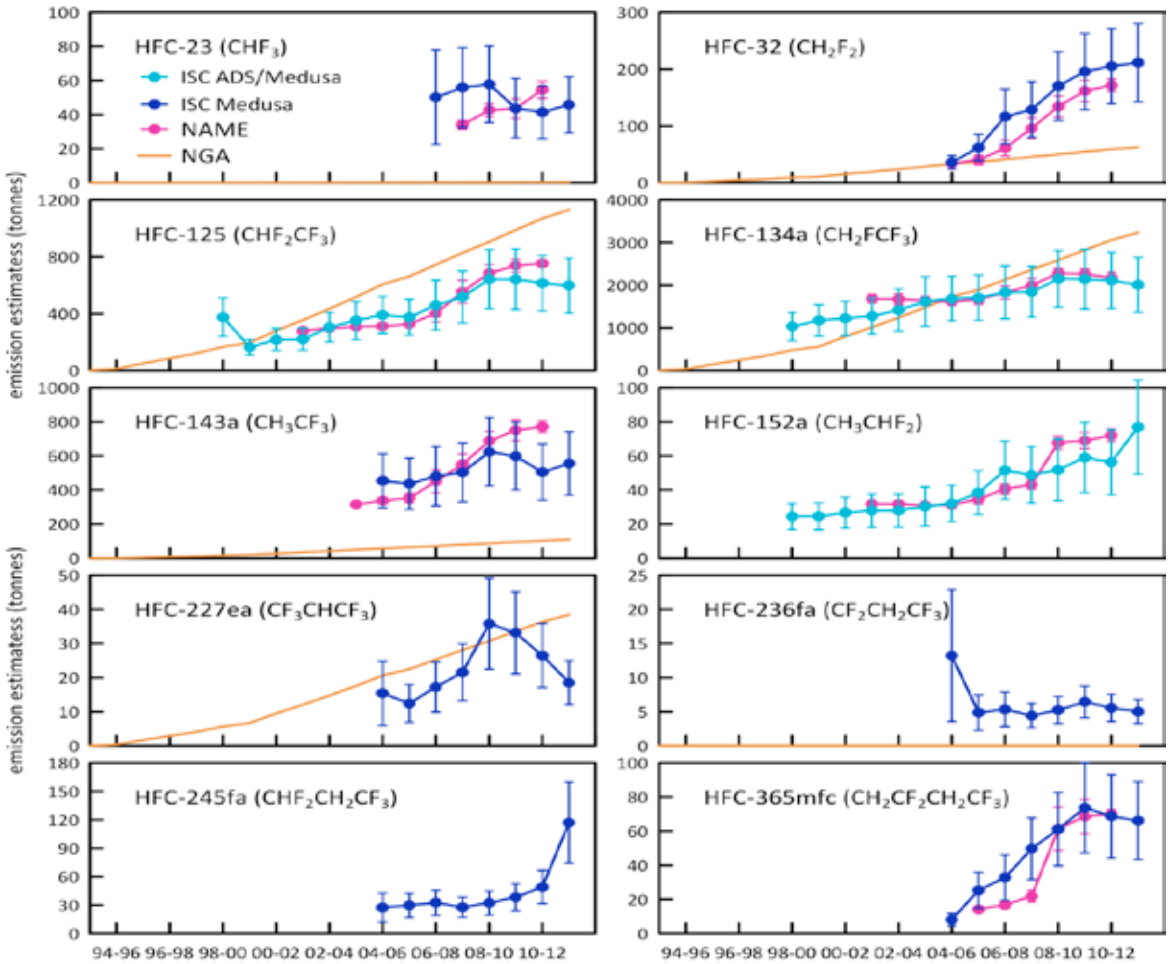


External verification through atmospheric testing

Monitoring of atmospheric HFC concentrations has been undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) at the Cape Grim Baseline Air Pollution Station in Tasmania since the mid 1990's. The department has commissioned CSIRO to verify its annual estimates of HFC emissions in the Inventory.

The verification process confirmed that total HFC, SF_6 and PFC emissions in the Inventory are in 1% higher than estimates based on Cape Grim data over the period 2005 to 2012 (CSIRO 2014). Verification of individual HFC species produced varying results and suggests that further work is required to better determine the relative levels of gas species. Figures 4.14 shows the comparisons of estimates based on Cape Grim measurements with inventory estimates by HFC species.

Figure 4.14: Comparison of various HFC Inventory estimates (NGGI 2014) with estimates derived from Cape Grim measurement data (ISC and NAME) (tonnes CO_2-e)



Source: CSIRO 2014

Industrial Processes

4.8.4.2 Source Specific QA/QC: SF_6 use in electricity supply and distribution

Australia applies six tests to consider the reasonableness of its estimates of SF_6 emissions from the electricity supply and distribution industry:

1) *Comparison of the country specific emission factor with the IPCC default.*

The IPCC GPG provides a global default factor of 2% (IPCC GPG 3.57). Australia has applied this factor for 1995, while noting that the IPCC itself is somewhat cautious about the validity of these estimates presenting an uncertainty range of ±30% indicating an IPCC range of 1.33% - 2.6%.

The *2006 IPCC Guidelines*, page 8.17, indicates that it would be good practice to select factors from countries with similar equipment designs and handling practices. In Australia, and based on the purchasing patterns of Transgrid, the dominant source of equipment are European manufacturers, although with an increasing supply from Japanese manufacturers in recent years.

Table 4.43: 2006 IPCC Guidelines default factors for Europe and Japan

	Default	Uncertainty	Range (higher)	Range (lower)
	Tonnes of SF_6 emissions per tonne (nameplate)	%	Tonnes of SF_6 emissions per tonne (nameplate)	Tonnes of SF_6 emissions per tonne (nameplate)
euro closed pressure	0.026	±30%	0.0338	0.0182
Japan closed pressure	0.007	±30%	0.0091	0.0049
euro sealed pressure	0.002	±20%	0.0024	0.0016
Japan sealed pressure	0.007	±30%	0.0091	0.0049

The IPCC notes that the defaults are those documented for 1995 – before any special industry actions for emission reduction were implemented (IPCC 2006, page 8.15). This makes validity of comparison for any year after 1995 difficult.

However, it can be noted that the national factor estimated for Australia for 2010 (0.0089) – which is an average factor applied across the full range of equipment types in use in Australia (and typically sourced from Europe or Japan) - falls within the range presented in the 2006 IPCC *Guidelines* (0.0016 to 0.0338) - that should be applied for the year 1995 (and before any emission reduction actions were undertaken by industry).

Since 1995, Australia has had active programs in place to reduce emissions from this source typified by the industry action documented in Electricity Networks Association, *Electricity Networks Association Industry Guideline for SF_6 Management*, ENA Doc 022-2008. From 2013, SF_6 will be covered by Australia's carbon price mechanism, and from that data all importers of SF_6 will be levied a carbon price on import. While this is a future action, it underlines the comprehensive approach to mitigation action undertaken by the Australian government.

Australia has assessed the consistency of the emission estimates presented in this document with those of other countries – see below. The time profile of Australia's emission estimates is consistent with the time profiles of the major economies in Annex I.

Consequently, Australia's assessment is that the country specific EF, 0.0089 tonnes of SF_6 emission per tonne of SF_6 stock, is consistent with the information presented by the IPCC.

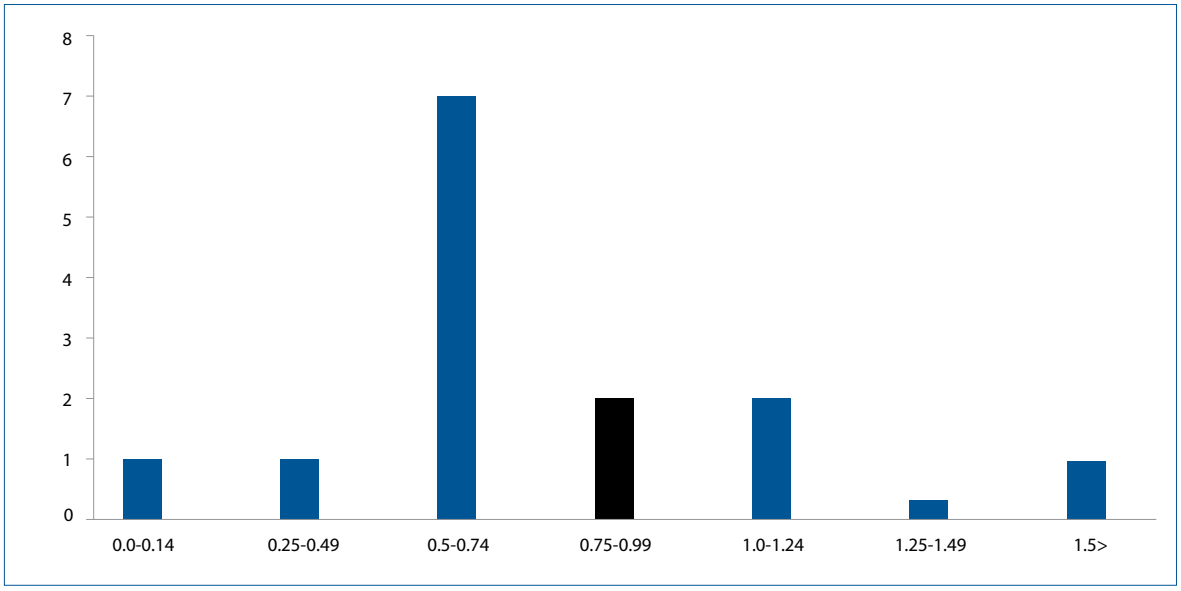
2) *Comparison of the country specific emission factor with the factors of similar countries.*

The estimated country specific EF for Australia has been compared with factors developed by the IPCC and factors used by a control group of Western European and other OECD countries. Australia's new EF is higher than the factors used in most Annex I parties. One other country shares a factor in the range 0.75-0.99 reported

in the histogram plot and only three other parties have higher EFs in the group. Nine parties have EFs below Australia's country specific factor.

Consequently, Australia's national EF is considered to be consistent with those appplied by other countries, with a tendency to the high side of reported EF estimates.

Figure 4.15: Histogram of reported product life factors (%) by Annex I parties (Western Europe and other OECD) (Australia in black)



Data available for Transgrid on equipment retirements are also consistent with the retirement information of other Annex I parties of similar circumstances and recent history. Of the group of major Annex I parties from Western Europe and other OECD countries (20 countries), around seven parties have identified an estimate for emissions from disposal; five indicate that disposal is 'not occurring' while the balance do not report.

3) *Assessment of the time series consistency of Australia's estimates*

Australia's emission estimates are considered to be time series consistent. Checks have been made in relation to the time series of both emission estimates and the time series of stocks.

4) *Assessment of the time series consistency of Australia's estimates with IPCC default growth rates*

Trend data were tested for consistency with IPCC GPG expectations for growth based on global growth data. The time series of the stock of SF_6 was checked against the increase in stocks cited as a *good practice* default growth rate for the period 1990-1996 of 6% (IPCC GPG 3.60).

The calculated time series shows the stock of SF_6 in Australia grew by 7% in 1996 and is comparable with IPCC default data.

5) *Assessment of the time series consistency of Australia's estimates with the time series profile of other countries*

The time profile of Australia's emission estimates presented in this document may be compared with the time profiles of emissions estimates presented by major economies within Annex I.

From this data, it can be observed that the time profile of emissions for Australia is similar to the time profile for of the parties, but has a slower rate of emission reduction than three of the parties. From this data, it can be concluded that the time profile of Australia's emissions are broadly consistent with the time profiles of major Annex I parties.

6) *Comparison of NGER facility level emission factors with the NGERdefault emission factor*

Overall, the weighted average emission rate of NGER reporters using their own data is 79% higher than the NGER default factor of 0.005 tonnes of SF_6 per tonne of stock of SF_6 On average, then, reporters that choose to use their own data do so even though the factor to be utilized is higher than the national NGER default factor. Consequently, there is no evidence from the available data that selection bias has been an issue.

4.8.5 Recalculations Since The 2011 Inventory

There have been a number of refinements to the HFC emission model used for this submission:

Australia has used country-specific annual leakage rates for commercial refrigeration and air-conditioning, transport refrigeration and heavy vehicle air conditioning based on Expert Group 2013. The use of country-specific leakage rates from commercial equipment addresses a specific finding in Expert Group 2013 that default leakage rates for these equipment types were not reflective of economy-wide weighted leakage based on recorded gas consumption. This revision also forms Australia's initial response to previous ERT recommendations on the use of country-specific leakage rates.

As a result of questions from the ERT, Australia implemented an additional QC check on bulk import data to ensure that the sum of gas demand for domestic production and replenishment of annual leakage equals total bulk imports. This additional check confirmed that the model used in the previous submission was not allocating 100% of bulk gas imports to domestic production or replenishment. This was leading to a minor systematic under-estimation of emissions from all equipment types in the previous submission. This has been corrected for this submission;

The correction identified above has also resulted in a revision to the quantities of bulk gas allocated to foams, aerosols and fire protection equipment; and,

A minor revision to the calculation of emissions from initial charging of new equipment has been undertaken. The previous model used the sum of pre-charged and bulk imported gas as the basis for estimating initial charging losses. This has been revised to use only gas consumed for domestic production.

The total impact of these revisions is outlined in table 4.44 below.

Revisions have also been made to stocks of SF_6 in operating equipment for 2011 following a review of NGER data.

Table 4.44: 2.F Consumption of halocarbons and SF_6: recalculation of total CO_2-e emissions (Gg), 1990-2011

	2013Submission	2014 Submission	Change	Change
	Gg CO2-e	Gg CO_2-e	Gg CO_2-e	%
2.F Consumption of halocarbons and SF_6				
1990	221	221	0	0%
2000	1,554	1,572	-18	1%
2001	2,142	2,169	-27	1%
2002	2,659	2,702	-43	2%
2003	3,194	3,262	-68	2%
2004	3,745	3,850	-105	3%
2005	4,289	4,450	-161	4%
2006	4,685	4,827	-142	3%
2007	5,238	5,398	-160	3%
2008	5,852	5,969	-117	2%
2009	6,422	6,497	-75	1%
2010	7,166	7,088	-78	-1%
2011	7,791	7,646	-145	-2%

4.8.6 Planned Improvements

Refinements to the *NGER Measurement Determination 2008 (Cwlth)* have been made to allow reporting facilities to estimate their emissions on the basis of gas stock balance and 'top-up' models. It is anticipated that the NGER System will provide country specific information on annual leakage rates from commercial and industrial refrigeration and air conditioning applications as well as gas insulated switch gear and circuit-breaker applications. Some of this information was used in this submission in the estimation of SF_6 emissions. Further use of facility-level leakage rates will be considered for future submissions following a review of NGER facility data. In the interim, Australia has adopted country-specific annual leakage rates cited in Expert Group 2013. In the first instance, Australia limited the use of these leakage rates to commercial equipment types (such as commercial refrigeration and air-conditioners) to address specific findings on weighted economy-wide refrigerant leakage from commercial equipment. Pending further analysis of the Expert Group findings, Australia will examine the possibility of expanding the use of country-specific leakage rates to other equipment types.

CSIRO verification of Inventory HFC estimates showed that total emissions are in excellent agreement with estimates based on independently measured atmospheric HFC concentrations. However further work is required in order to better estimate individual gas species. The department will continue its ongoing efforts to improve speciation of its HFC estimates in general and will also undertake further analysis in order to develop gas speciation data for emissions estimates from foam blowing, fire extinguishers, aerosols and solvents.

Amendments to the Australian Government's *Ozone Protection Act 1989* are have recently been approved by the Australian Parliament. Under these amendments, importers of SF_6 will be required for the first time to report data on quantities of SF_6 imported in Australia from 2013. As these data become available the aggregate import data will be assessed for their implications for Australia's SF_6 emissions estimates in the National Inventory.

The country-specific leakage rate of 0.0089 tonnes of SF_6 per tonne of stock is based on 2 years worth of facility-specific measurement. This factor will be reviewed as new data become available in subsequent NGER reporting years.

Australia also intends to implement a mixed tier 3 and tier 2 method for future reporting years. For the 15 facilities representing 40% of the stock of SF_6, future emission rates will be determined by data reported each year by those facilities.

The quantity of electrical equipment filled with SF_6 in Australia will also be examined. The current assumption, of 50% domestic manufacture or of equipment that are filled in Australia, will need to be tested with actual data where this is available.

5. Solvent and Other Product Use

5.1 Overview

Activities in the *solvent and other product use* source category results in emissions of N_2O and NMVOCs. Total net emissions estimated from *solvents and other products* were 161 Gg NMVOC in 2012 (Table 5.1). The main determinant of *solvent and other product use* emissions from year to year is the quantity of the relevant product that is produced or used.

Table 5.1: Solvent and other product use NMVOC emissions 2012

Greenhouse Gas Source and Sink Categories	N_2O Emissions (Gg)	NMVOC emissions (Gg)
3 SOLVENT AND OTHER PRODUCT USE	**IE**	161
A Paint application	NA	65
B Degreasing and dry cleaning	NA	41
C Chemical products manufacture and processing	NA	1
D Other	IE	55

Note: Confidential N_2O emissions are reported in the industrial processes sector – 2.B Chemical Industry

Paint application was the main source of NMVOCs contributing 40.2 % (64.7 Gg NMVOC) of the sector's emissions. The next largest source was *other* (33.8 %), followed by *degreasing and dry cleaning* (25.5 %). *Chemical products manufacture and processing* contributed only 0.6%.

Emissions from *solvent and other products use* increased by 7.1Gg (4.6 %) between 1990 and 2012. Reductions in emissions from paint application have been offset by increases in emissions from degreasing and dry cleaning and other.

5.2 Source Category Description

Surface coating operations involve the application of paint, varnish, lacquer or paint primer for decorative or protective purposes. Thinning solvents are normally used to dilute surface coating formulations or for cleaning purposes. Surface cleaning or degreasing operations involve the removal of materials such as oils, grease, waxes and moisture from surfaces. Chemical products manufacture and processing covers paint and ink manufacturing. General solvent use and consumer cleaning by the domestic and commercial sectors covers a large range of products including Domestic and Commercial Aerosol Products; Other Domestic and Commercial Products; and Consumer Cleaning Products.

5.3 Methodology

5.3.1 Paint Application (3.A)

Surface coating operations involve the application of paint, varnish, lacquer or paint primer for decorative or protective purposes. Thinning solvents are normally used to dilute surface coating formulations or for cleaning purposes. Collectively, surface coatings and thinners represent the most significant solvent use category.

Surface coatings have differing solvent content. Average densities and EFs are given in Table 5.2.

Table 5.2: Properties of surface coatings and thinners

Category	Average Density (kg/l)	EF kg NMVOC /kg Product
Architectural/Decorative	1.33	0.11
Industrial	1.24	0.44
Thinners	0.77	1.00

Source: Australian Paint Manufacturers Federation (pers. comm., 1995)

5.3.2 Degreasing And Dry Cleaning (3.B)

Surface cleaning or degreasing operations involve the removal of materials such as oils, grease, waxes and moisture from surfaces. In the commercial/industrial sectors, surface cleaning/degreasing is normally conducted in preparation for other treatment such as painting and electroplating.

There are three basic types of surface cleaning operations, which are used by commerce and industry. These operations are referred to as cold cleaning, vapour cleaning and in-line or conveyorised cleaning. EFs for surface cleaning/degreasing and dry cleaning are presented in Table 5.3. Population figures are mean populations for the relevant financial year.

Table 5.3: Surface cleaning/degreasing and dry cleaning emission factors

Category	Emission Factor kg NMVOC/capita/yr
Cold Cleaning, Automobile Repair	1.14[(a)]
Cold Cleaning, Manufacturing	0.50[(a)]
Dry Cleaning	0.17[(b)]
Total	1.81

(a) USEPA (1991b)

(b) ICI (pers. comm., 1994)

5.3.3 Chemical Products Manufacture And Processing (3.C)

Chemical products manufacture and processing covers paint and ink manufacturing. EFs for chemical products manufacture and processing are presented in Table 5.4.

Table 5.4: Emission factors for chemical products manufacture and processing

Category	EF_i kg NMVOC/tonne Product
Paint Manufacturing	3[(a)]
Printing Ink Production	9[(b)]

(a) Dulux (pers. comm., 1995)

(b) Mid-range value reported for USA facilities, Buonicore and Davis (1992)

5.3.4 Other (3.D)

General solvent use and consumer cleaning by the domestic and commercial sectors covers a large range of products. These products include aerosol spray products such as insect sprays, hairsprays and household carpet cleaners, and non-aerosol spray products such as adhesives, waxes and general household solvents. Also included in this source category is the use of N_2O in aerosol products and for medical use.

N_2O emissions from Aerosol Products and Anaesthesia

Emissions of N_2O from aerosol products and anaesthesia are based on production data provided by the industrial gas manufacturers (BOC and Air Liquide). These data and the resultant emissions estimates are confidential and are included in the 2.B.5 *confidential chemical industry emissions* in the *industrial processes* sector.

NMVOC Emissions from General Solvent use and Consumer Cleaning

Per-capita EFs provided by the Aerosol Association of Australia (AAA, pers. comm. 1994) have been used for Domestic/Commercial Aerosol Products and US data for aerosol spray products and miscellaneous non-aerosol spray products (USEPA 1997) have been adopted for estimating NMVOC emissions from Other Domestic/Commercial products and Consumer Cleaning Products.

EFs for general solvent use and consumer cleaning products are presented in Table 5.5.

Table 5.5: Emission factors for general solvent use and consumer cleaning products

Product	Emission Factor kg NMVOC/capita/yr
Domestic/Commercial Aerosol Products [(a)]	
Insect/Garden Sprays	0.33
Hair Sprays	0.26
Personal Deodorants	0.17
Air Fresheners	0.14
Miscellaneous Automotive/Industrial	0.17
General Household	0.13
Other	0.10
Sub Total	1.30
Other Domestic/Commercial Products [(b)]	
Adhesives and Sealants	0.21
Coatings and Related Products	0.35
Sub Total	0.56
Consumer Cleaning Products [(b)]	
Automotive Products	0.51
Miscellaneous Products	0.03
Sub Total	0.54
Total	**2.40**

(a) Aerosol Association of Australia (pers. comm., 1994)

(b) USEPA (1997)

NMVOC emissions from general solvent use and consumer cleaning products are reported in table 5.5. The mean population for the financial year is multiplied by the EF and the result is expressed in gigagrams (Gg). EFs are expressed in terms of per capita use per year.

5.3.5 Uncertainties And Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates.

5.3.6 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6.

5.3.7 Recalculations Since The 2011 Inventory

There have been no recalculations in this sector.

5.3.8 Planned Improvements

All activity data, methodologies and EFs are kept under review.

6. Agriculture

Overview

Agriculture produced an estimated 87.4 Mt CO_2-e emissions or 16.1% of net national emissions (excluding LULUCF) in 2012 (Table 6.1).

Enteric fermentation was the main source of *agriculture* emissions contributing 64.3% (56.2 Mt CO_2-e) of the sector's emissions. The next largest source was *agricultural soils* (17.5%), followed by *prescribed burning of savannas* (13.4%) and *manure management* (3.7%). *Rice cultivation* and *field burning of agricultural residues* contributed 1% of the sector's emissions.

The *agriculture* sector is the dominant national source of both methane and nitrous oxide - accounting for 60.1% and 78.6% respectively of the net national emissions (excluding LULUCF) for these two gases.

Table 6.1: Agriculture sector CO_2-e emissions, 2012

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
4 AGRICULTURE	**NA**	**67,123**	**20,238**	**87,361**
A Enteric fermentation	NA	56,216	NA	56,216
B Manure management	NA	1,676	1,545	3,221
C Rice cultivation	NA	478	NA	478
D Agricultural soils	NA	NA	15,295	15,295
E Prescribed burning of savannas	NA	8,454	3,261	11,715
F Field burning of agricultural residues	NA	298	137	435

Trends

Emissions from *agriculture* decreased by 1.0% (0.9 Mt CO_2-e) between 1990 and 2012 and had increased by 3.3% (2.8 Mt CO_2-e) between 2011 and 2012 (Figure 6.1).

Enteric fermentation emissions declined by 12.1% (7.7 Mt CO_2-e) between 1990 and 2012. The decline in emissions in the early 1990s was principally driven by a fall in sheep numbers, however by the late 1990s the emissions had begun to increase as the numbers of beef cattle began to rise, reflecting changing relative returns to each industry. From 2002 until 2010 livestock populations declined in response to the prolonged drought conditions which occurred over extensive areas of southern and eastern Australia. Since late 2010 better seasonal conditions have seen farmers begin to rebuild their herds. Between 2011 and 2012, emissions from *enteric fermentation* increased by 2.0% (1.1 Mt CO_2-e).

Figure 6.1: CO_2-e emissions from agriculture, 1990–2012

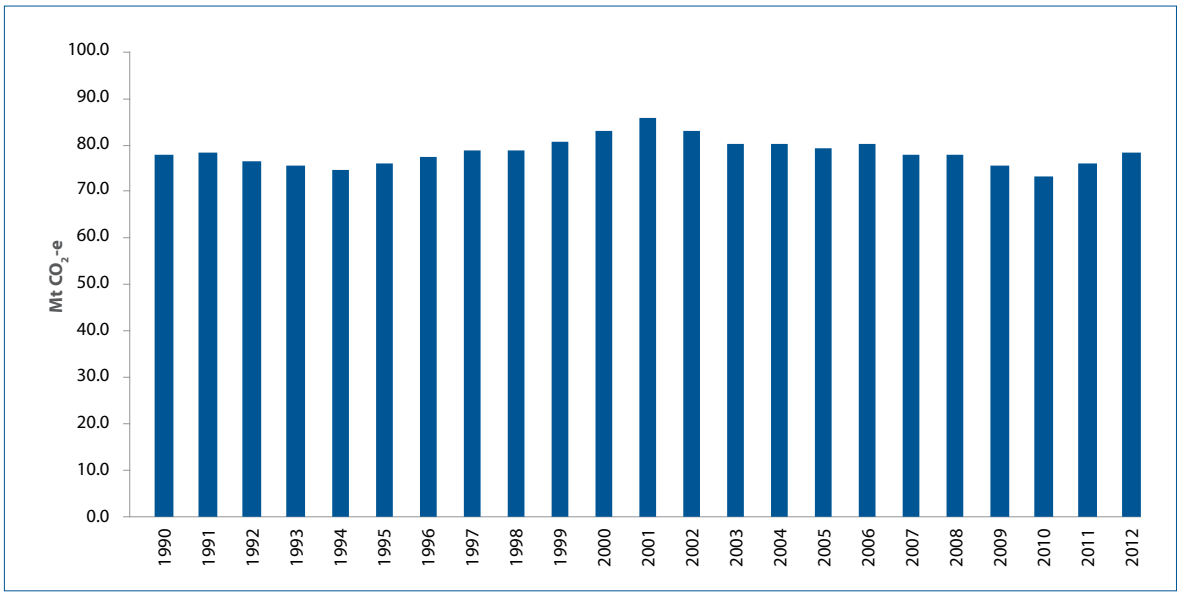
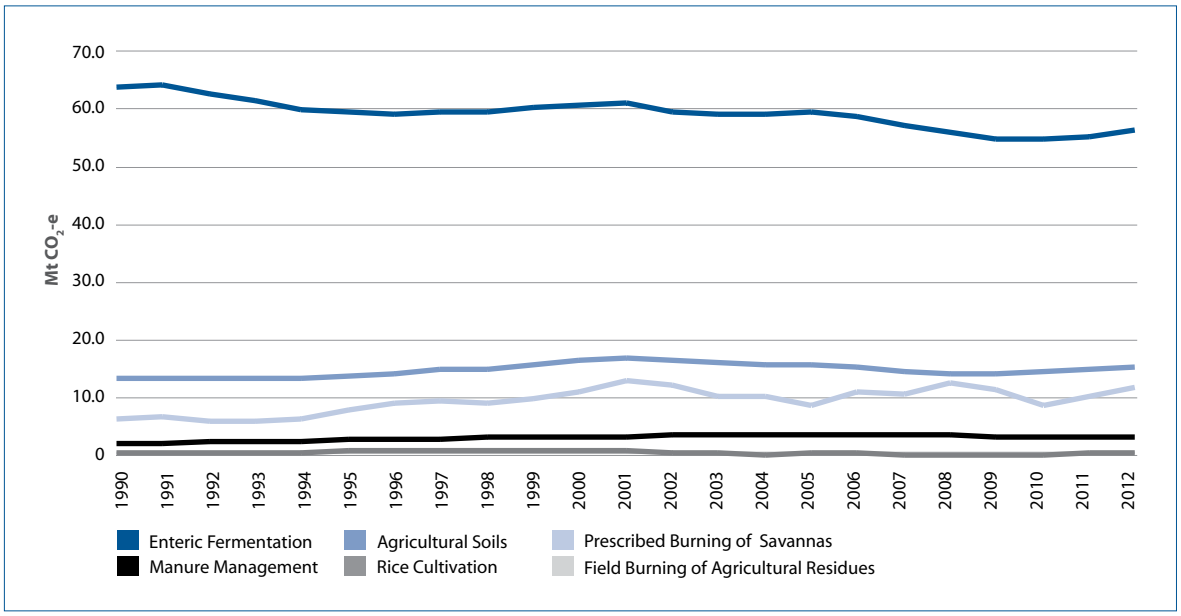


Figure 6.2: CO_2-e emissions from agriculture, by sub-sector, 1990–2012



Manure management emissions have increased by 56.0% (1.2 Mt CO_2-e) between 1990 and 2012 due to the strong growth in the intensive feedlot cattle industry over this period. Manure management emissions declined by 1.2% (0.04 Mt CO_2-e) between 2011 and 2012 reflecting the recent decline in populations of feedlot cattle and pigs in response to reduced export demand.

As all *rice cultivation* in Australia is flood irrigated, this industry is highly responsive to water availability with recent drought severely affecting production. Emissions from *rice cultivation* in 2012 were 2.5% (0.01 Mt CO_2-e) lower than in 1990 and 45.7% (0.1 Mt CO_2-e) higher than in 2011, reflecting the increase in area planted as a result of increased water availability.

Agricultural soils emissions have increased by 14.3% (1.9 Mt CO_2-e) between 1990 and 2012, and by 1.4%

(0.2 Mt CO_2-e) between 2011 and 2012. Contributing to the change since 1990 has been an overall increase in agricultural fertiliser use and increased retention of crops residues as the sugar cane industry has shifted towards green cane harvesting and use of trash blanket. As crop production, animal populations and fertiliser use was reduced during the recent drought, emissions declined between 2001 and 2009. The return to better conditions has seen emissions increase once again.

Emissions from *prescribed burning of savannas* peaked in 2001 and have declined significantly until 2005 when a sinusoidal trend emerges. This trend will not necessarily continue in the future, as emissions from this source are highly variable and largely reflect variations in climatic conditions (Meyer 2004).

Emissions from *field burning of agricultural residues* have increased by 49.1% (0.1 Mt CO_2-e) between 1990 and 2012 and increased by 6.1% (0.03 Mt CO_2-e) between 2011 and 2012. This trend reflects increased production of key crops such as wheat and barley since 1990. The increase has been partially offset by the reductions in sugar cane burning as the industry has shifted to green cane harvesting.

6.1 Overview of Source Category Description and Methodology – Agriculture

CH_4 and N_2O emissions from livestock industries are reported under the enteric fermentation (4A) and manure management (4B). In Australia, the principal species comprise cattle and sheep, with breeds chosen to operate within pasture and paddock management systems and, in many cases, in semi-arid or tropical and sub-tropical climatic conditions. Typical animal performance, as a consequence, tends to vary significantly from those of other Annex I countries.

Other agricultural sources include methane emissions from rice cultivation (4C), nitrous oxide emissions from agricultural soils (4D), methane and nitrous oxide emissions from the burning of savannas (4E) and agricultural crop residues (4F). Emissions of CH_4, N_2O, NO_x, CO and NMVOCs from these sources are produced when living and dead biomass is eaten, consumed, decays or is burnt. These emissions are modified by human activities including cultivation, addition of fertilisers, deliberate burning and by the introduction of ruminant animals.

The Australian agriculture methodology contains both country specific and IPCC default methodologies and EFs (Table 6.2(a) and 6.2(b)).

The agriculture inventory is compiled on a State basis with State emission totals then aggregated to give national totals. The inventory is compiled in this way to reduce errors associated with averaging input data across areas with large physical and management differences. Australia has a land area of 769 million hectares which cover a wide range of climate zones and soil and vegetation types (see Section 7.2.1 for more details). These large physical differences lead to significant differences between States in such things as fuel loads for fires, the quality and availability of feed, and the performance of animals throughout the year. For example, in northern Australia there are two distinct seasons – wet and dry. During the dry season (winter-spring) the quality and availability of fodder is significantly reduced leading to weight loss in cattle, while in the southern states pasture growth and availability is lower during the colder autumn-winter months. As the States climate ranges from warm to temperate, methane conversion factors for manure management systems can also vary significantly between the States.

In accordance with the IPCC (1997, vol. 1) *Guidelines*, emissions are reported as three year averages where possible (i.e. the reported emissions for 1990 are the average of those for 1989, 1990 and 1991).

6.1.1 Data Sources

Data on livestock numbers and crop production are sourced from Australian Bureau of Statistic (ABS) census/survey data collected on 30 June in the relevant year. Relevant industry associations provide some rice and sugar cane data. Data on the number of feedlot cattle are sourced from the Australian Lot Feeders Association (ALFA) quarterly survey. Milk production statistics are sourced from Dairy Australia. Fertiliser data is provided by the Fertiliser Industry Federation of Australia (FIFA). The amount of sewage sludge applied to soil is obtained by facility under the NGER System and DCCEE (2009b). The area of cultivated histosols is derived from CSIRO data on the areas of organosols (http://www.clw.csiro.au/aclep/asc_re_on_line/or/orgasols.htm). The annual activity data used to estimate the emissions are published on the AGEIS (http://ageis.climatechange.gov.au/).

The areas of savanna woodland and grassland burnt are based on a time series of AVHRR satellite images processed by the Western Australian Land Information Authority (trading as Landgate). The assessments of the area burnt in some areas (particularly for earlier years up to the mid-1990s) are based on statistics recorded by the State fire authorities, local records or the expert judgment of district officers. Other primary data used in the algorithms (liveweights, liveweight gains, pasture digestibility, allocation to manure management systems, savanna fuel loads, combustion EFs, etc) are based on reviews of published data and expert assessments.

Process for eliciting expert assessments

Given the extensive nature of most of Australia's agricultural production there are few if any comprehensive State databases of information such as animal and pasture characteristics. As this data is required to estimate emissions it has been necessary to use expert assessments to determine appropriate country specific information. The initial Australian methods and data were developed by expert working groups with representation from government, industry, academia and research institutions. The record of participants and outcomes are documented in the *Australian methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Agriculture, Workbook for Non-CO_2 emissions from the biosphere 5.0* (NGGIC 1994a) and *Workbook for Livestock 6.0* (NGGIC 1994b). The livestock categories contain a large number of expert assessments and these values were reviewed/updated in 1995 (documented in *Workbook for Livestock 6.1* (NGGIC 1996) and again in 2000-01 (documented in Howden *et al.* 2002 and White *et al.* 2002). In each case consultants were used to coordinate the review. The consultant elicited expert assessments either through round table meetings with the experts or through surveys. These assessments were then compiled by the consultants and an agreed value recirculated to experts for final comment. The consultants also undertook a number of reality checks on the expert assessments to ensure that correlated values such as seasonal liveweights and daily liveweight gains, and pasture digestibility and crude protein contents were internally consistent (White *et al.* 2002).

Comparison with international data

The ABS annually report agricultural data to the Food and Agriculture Organisation (FAO) of the United Nations. Some divergence occurs from year to year between the activity data in the inventory CRF tables and those published by the FAO. The reasons for these differences are as follows:

a) Over the time frame of the inventory the ABS has changed the threshold of the Estimated Value of Agricultural Operations (EVAO) used to determine which agricultural operations are included in the census/survey. In the years 1989 to 1993 ABS used EVAO's of $20-25,000 which is considerably higher than the $5000 used since 1994. To ensure time series consistency in the data, a multiplier is applied to adjust the animal numbers to reflect the smaller farms that will have been left out of the 1989-1993 censuses. Furthermore, beef cattle numbers reported in the CRF will also differ from those reported to the FAO as they are the ABS numbers adjusted for annual equivalent number of animals held on feedlots (this applies to all years); and

b) For the 2005-06 census the ABS introduced a new survey frame sourced from the Australian Taxation Office's Australian Business Register (ABR). Due to the progressive deterioration of the previous frame (based on a register of agricultural establishments maintained by ABS) the coverage of the two frames differed. To ensure time-series consistency, bridging estimates developed by ABS were used to revise animal numbers for dairy cattle, range kept cattle, sheep and pigs and production data for wheat, barley, oats, sorghum and other crops from 2002 to 2005.

Table 6.2(a): Summary of methods and emission factors: Agriculture (CH_4 and N_2O)

Greenhouse Gas Source and Sink Categories		CH_4		N_2O	
Method Applied		Emission Factor	Method Applied	Emission Factor	Method Applied
A	**Enteric Fermentation**				
1	Cattle				
	a. Dairy Cattle	CS, T2	CS		
	b. Free-range Beef Cattle	CS, T2	CS		
	c. Feedlot Cattle[a]	CS, T2	CS		
2	Buffalo	T1	IPCC		
3	Sheep	CS, T2	CS		
4	Goats	T1	IPCC		
5	Camels and Llamas	T1	IPCC		
6	Horses	T1	IPCC		
7	Mules and Asses	T1	IPCC		
8	Swine	CS, T2	CS		
9	Poultry	NE	NE		
10	Other (alpacas, deer, emus and ostriches)	T1	CS		
B	**Manure Management**				
1	Cattle				
	a. Dairy Cattle	T2	IPCC, CS	CS, T2	IPCC
	b. Free-range Beef Cattle	CS, T2	CS	CS, T2	IPCC
	c. Feedlot Cattle[a]	T2	IPCC	CS, T2	IPCC
2	Buffalo	CS, T2	CS	CS, T1	IPCC
3	Sheep	CS, T2	CS	CS, T2	IPCC
4	Goats	CS, T2	CS	CS, T1	IPCC
5	Camels and Llamas	CS, T2	CS	CS, T1	IPCC
6	Horses	CS, T2	CS	CS, T1	IPCC
7	Mules and Asses	CS, T2	CS	CS, T1	IPCC
8	Swine	M	IPCC	M	IPCC
9	Poultry	T2	IPCC	CS, T1	IPCC
10	Other (alpacas, deer, emus and ostriches)	CS, T2	CS	CS, T1	IPCC
C	**Rice Cultivation**	**T1**	**CS**		
D	**Agricultural Soils**				
1	Direct Soil Emissions				
	a. Synthetic Fertilisers			T2	CS
	b. Animal Wastes Applied to Soils			T2	CS
	c. N-fixing crops			T1b	IPCC
	d. Crop Residues			T1b	IPCC
	e. Cultivation of Histosols			T1	IPCC
	f. Sewage Sludge Applied to Land			T2	CS

Greenhouse Gas Source and Sink Categories		CH_4		N_2O	
Method Applied		Emission Factor	Method Applied	Emission Factor	Method Applied
2	Animal Production			T2	CS
3	Indirect Emissions				
	a. Atmospheric Deposition			T1	IPCC
	b. Leaching and Run-off			CS	CS
E	**Prescribed Burning of Savannas**	**CS**	**CS**	**CS**	**CS**
F	**Field Burning of Agricultural Residues**	**CS**	**CS**	**CS**	**CS**

Feedlot cattle are reported under Other Livestock in the CRF tables.

Table 6.2(b): Summary of methods and emission factors: Agriculture (NO_x, CO and NMVOC)

Greenhouse Gas Source and Sink Categories		NO_x		CO		NMVOC	
Method Applied		EF	Method Applied	EF	Method Applied	EF	
E	Prescribed Burning of Savannas	CS	CS	CS	CS	CS	CS
F	Field Burning of Agricultural Residues	CS	CS	CS	CS	CS	CS

EF = emission factor, CS = country specific, IPCC = IPCC defaults, T1 = Tier 1, T2 = Tier 2, M = Model and NE= not estimated

6.2 Source Category 4.A Enteric Fermentation

6.2.1 Source Category Description

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which plant material consumed by an animal is broken down by bacteria in the gut under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, CO_2 and CH_4. The fatty acids are absorbed into the bloodstream, and the gases vented by eructation and exhalation by the animal. Unfermented feed and microbial cells pass to the intestines.

6.2.2 Methodology

Australia has identified *enteric fermentation* as a key source category using the tier 1 level and trend assessments as recommended in the IPCC *Good Practice* report (IPCC 2000). In accordance with IPCC *Good Practice* requirements tier 2 methods are therefore used, to estimate enteric fermentation emissions from the major livestock sub-categories.

The proportion of intake that is converted into methane is dependent on both the characteristics of the animal, feed and the amount of feed eaten. The IPCC (2000) tier 2 approach has fixed methane conversion rates for each livestock category. Given the heterogeneity of feed types available within Australia it was considered important to use methodologies developed in Australia or methodologies that could reflect these differences, hence country specific methodologies have been used.

6.2.2.1 Cattle (4.A.1)

Pasture Fed

It was considered that the approach developed by Blaxter and Clapperton (1965; corrected by Wilkerson *et al.* 1995) would be the most appropriate method for estimating methane emissions from pasture feed cattle in temperate Australia. This approach was selected as it has been widely used in methane inventories and is capable of reflecting the effect of feed quality on methane emissions. Although based on animals fed on diets representative of those in the UK, the digestibility of the feeds studied are within the ranges found in temperate Australia.

The equations derived by Blaxter and Clapperton (1965) do not reflect the breeds and feed types used in the tropics and sub-tropics of Australia. In a study of *Bos indicus* (Brahman) cattle on tropical feeds conducted in Australia, Kurihara *et al.* (1999; corrected by Hunter 2007) found methane conversion rates that were significantly higher than the IPCC (2000) defaults (7%) or those calculated by Blaxter and Clapperton (1965). This approach has been used to estimate emissions from beef cattle in tropical areas.

The Blaxter and Clapperton (1965) approach requires the estimation of gross energy intake and then calculates the proportion of this energy that is converted into methane, based on the digestibility at maintenance of the feed energy[7] and the level of feed intake relative to that required for maintenance. The figure for methane can then be expressed on an equivalent mass basis, using the conversion factor of 55.22 MJ/kg CH_4 (Brouwer 1965). The Kurihara *et al.* (1999) approach relates daily methane production with dry matter intake.

Accurate estimation of intake is difficult as it depends on many factors. The IPCC (2000) tier 2 methods for estimating intake are based on work undertaken in the northern hemisphere (McMeniman *et al.* 2008). This method was considered inappropriate for Australia and in line with *Good Practice* (IPCC 2000 pg 4.13) a country-specific method (Minson and McDonald 1987) based on research in Australia is used instead. Minson and McDonald (1987) have derived an equation that estimates feed intake relative to liveweight and liveweight gain of cattle. This relationship includes data for cattle on both tropical and temperate feeds. By setting the liveweight gain component of their equation to zero to calculate maintenance intake, it is possible to estimate the relative feed intake of cattle.

Lot Fed

Moe and Tyrrell (1979) devised equations for predicting methane emissions from dairy cattle fed diets consisting mostly of high digestibility grains and concentrates and high quality forages. The Moe and Tyrrell (1979) equation used relates methane production to the intake of three components of the dietary carbohydrate. These are: soluble residue, hemicellulose and cellulose. As feedlot cattle in Australia are fed diets consisting of high digestibility grains and concentrates, the Moe and Tyrrell (1979) equations were considered appropriate for estimating emissions.

Dairy Cattle

The large volumes of milk produced by dairy cattle under modern management regimes, averaging 5,900 litres per annum per cow in 2012 (Appendix 6.A.8), requires that the lactating cow consume considerably more feed than an equivalent non-lactating cow. The approach used was to compile the average daily milk production per head of milking cows in each State, then calculate the increased energy requirements needed to produce this milk from relationships presented by the Standing Committee on Agriculture (SCA 1990).

[7] It should be noted that Blaxter and Clapperton (1965) use a figure for the digestability of feed energy which is slightly smaller than the dry matter digestability values used for pasture is Australia. However, there is no consolidated data that will allow conversion to be made between the two digestability classes

Table 6.3: Symbols used in algorithms for dairy cattle

State (i)	Dairy Cattle Classes (age) (j)	Season[b] (k)
i = 1 NSW/ACT	j = 1 Milking Cows[(a)]	k = 1 Spring
i = 2 Tasmania	j = 2 Heifers > 1 year	k = 2 Summer
i = 3 Western Australia	j = 3 Heifers < 1 year	k = 3 Autumn
i = 4 South Australia	j = 4 House Cows Milk and Dry	k = 4 Winter
i = 5 Victoria	j = 5 Bulls > 1 year	
i = 6 Queensland	j = 6 Bulls < 1 year	
i = 7 Northern Territory		

(a) Includes cows used for milk production but not currently lactating.

(b) This category relates to Tasmania (i = 2) only. Data was not available to support disaggregation of the other States.

The equation presented in Minson and McDonald (1987) calculates feed intake of non-lactating cattle from liveweight and liveweight gain data. For lactating cattle the additional intake for milk production (MI_{ijk}) is included to give total intake (I_{ijk} kg dry matter/head/day):

$$I_{ijk} = (1.185 + 0.00454W_{ijk} - 0.0000026W_{ijk}^2 + 0.315LWG_{ijk})^2 \times MR_l + MI_{ijk} \quad (4A.1a_1)$$

Where: W_{ijk} = weight in kg (Appendix 6.A.1)

LWG_{ijk} = liveweight gain in kg/day (Appendix 6.A.2)

MR_l = increase in metabolic rate when producing milk (SCA 1990) 1.1 for milking and house cows and 1 for all other classes

The additional intake required for milk production (MI_{ijk} kg DM/head/day) is calculated by:

$$MI_{ijk} = MP_{ijk} \times NE / k_l / q_{m,\,ijk} / 18.4 \quad (4A.1a_2)$$

Where: MP_{ijk} = milk production (kg/head/day) from Dairy Australia State statistics

NE = 3.054 MJ net energy/kg milk (SCA 1990)

k_l = 0.60 efficiency of use of metabolizable energy for milk production (SCA 1990)

$q_{m,\,ijk}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ijk}). So using the equation of Minson and McDonald (1987), $q_{m',\,ijk}$ = 0.00795 DMD – 0.0014; (where DMD is expressed as a %).

The gross energy intake (GEI_{ijk}) is the sum of the intake (I_{ijk}) converted into energy terms assuming a gross energy content of 18.4 MJ/kg (SCA 1990):

$$GEI_{ijk} = I_{ijk} \times 18.4 \quad (4A.1a_3)$$

The intake of the animals relative to that needed for maintenance (L_{ijk}) is calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with liveweight gain set to zero).

$$L_{ijk} = I_{ijk} / (1.185 + 0.00454W_{ijk} - 0.0000026W_{ijk}^2 + (0.315x0))^2 \quad (4A.1a_4)$$

Agriculture

The percentage of the gross energy intake (GEI_{ijk}) that is yielded as methane (Y_{ijk}) is given by Blaxter and Clapperton (1965) as:

$$Y_{ijk} = 1.3 + 0.112DMD_{ijk} + L_{ijk}(2.37 - 0.050DMD_{ijk}) \quad \text{(4A.1a_5)}$$

Where: DMD_{ijk} = digestibility of feed (expressed as a %) (Appendix 6.A.3)

L_{ijk} = intake relative to that needed for maintenance

The total daily production of methane (M_{ijk} kg CH_4/head/day) is thus:

$$M_{ijk} = Y_{ijk} / 100 \times GEI_{ijk} / F \quad \text{(4A.1a_6)}$$

Where: F = 55.22 MJ/kg CH_4 (Brouwer 1965)

Annual Australian methane production (Gg) for all classes of dairy cattle across all states can then be calculated as:

$$E = \Sigma_{i=1,3\text{-}7}\Sigma_j(365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \Sigma_{i=2}\Sigma_j\Sigma_k(91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad \text{(4A.1a_7)}$$

Where: N_{ijk} = numbers of dairy cattle in each class for each State and season

M_{ijk} = methane production (kg/head/day)

Beef Cattle

Table 6.4: Symbols used in algorithms for beef cattle

State (i)	Regions (j)	Season (k)	Beef Cattle Classes (l)
i = 1 NSW/ACT	j = 1 NSW/ACT	k = 1 Spring	l = 1 Bulls > 1 year
i = 2 Tasmania	j = 2 Tas	k = 2 Summer	l = 2 Bulls < 1 year
i = 3 Western Australia	j = 3a South West	k = 3 Autumn	l = 3 Steers < 1 year
	j = 3b Pilbara	k = 4 Winter	l = 4 Cows 1 - 2 year
	j = 3c Kimberley		l = 5 Cows > 2 year
i = 4 South Australia	j = 4 SA		l = 6 Cows < 1 year
i = 5 Victoria	j = 5 Vic		l = 7 Steers > 1 year
i = 6 Queensland	j = 6 Qld		
i = 7 Northern Territory	j = 7 NT		

The equation presented by Minson and McDonald (1987) calculates feed intake (I_{ijkl} kg dry matter/head/day) from liveweight and liveweight gain:

$$I_{ijkl} = (1.185 + 0.00454W_{ijkl} - 0.0000026\,W_{ijkl}^{2} + 0.315\,LWG_{ijkl})^2 \times MA_{ijkl=5} \quad \text{(4A.1b_1)}$$

Where: W_{ijkl} = liveweight in kg (Appendix 6.B.1)

LWG_{ijkl} = live weight gain in kg/head/day (Appendix 6.B.2)

Feed intakes can increase by up to 60% during lactation (ARC 1980). For this study, the intake of all breeding cattle was increased by 30% during the season in which calving occurs and by 10% in the following season based on relationships presented in SCA (1990).

The additional intake for milk production ($MA_{ijkl=5}$) is calculated by:

$$MA_{ijkl=5} = (LC_{ijkl=5} \times FA_{ijkl=5}) + ((1-LC_{ijkl=5}) \times 1) \quad (4A.1b_2)$$

Where: $LC_{ijkl=5}$ = proportion of Cows >2 lactating

$FA_{ijkl=5}$ = feed adjustment (Appendix 6.B.5)

As feed dry matter has, on average, a gross energy content of 18.4 MJ/kg (SCA 1990), the dry matter intake is converted into gross energy intake (GEI_{ijkl} MJ):

$$GEI_{ijkl} = I_{ijkl} \times 18.4 \quad (4A.1b_3)$$

The intake of the animals relative to that needed for maintenance (L_{ijkl}) is calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with liveweight gain is set to zero).

$$L_{ijkl} = I_{ijkl} / (1.185 + 0.00454\, W_{ijkl} - 0.0000026\, W_{ijkl}^{2} + (0.315 \times 0))^{2} \quad (4A.1b_4)$$

The percentage of the gross energy intake that is yielded as methane (Y_{ijkl}) is given by Blaxter and Clapperton (1965) as:

$$Y_{ijkl} = 1.3 + 0.112DMD_{ijkl} + L_{ijkl}(2.37 - 0.050DMD_{ijkl}) \quad (4A.1b_5)$$

Where: DMD_{ijkl} = digestibility of feed (expressed as a %) (Appendix 6.B.3)

L_{ijkl} = feed intake relative to that needed for maintenance

The total daily production of methane (M_{ijkl}, kg CH_4/head/day) for animals on temperate pastures is thus:

$$M_{(i=1\text{-}5)(j=1,2,3a,3b,4,5)\,kl} = Y_{ijkl} / 100 \times GEI_{ijkl} / F \quad (4A.1b_6a)$$

For animals on tropical pastures total daily production of methane (M_{ijkl}, kg CH_4/head/day) is given by Kurihara *et al.* (1999, corrected by Hunter (2007)) as:

$$M_{(i=3,6,7)(j=3c,6,7)\,kl} = (34.9 \times I_{ijkl} - 30.8) / 1000 \quad (4A.1b_6b)$$

Where: $M_{(i=1\text{-}5)(j=1,2,3a,3b,4,5)\,kl}$ = methane emissions from NSW/ACT, Tas, SA, Vic and the South West and Pilbara regions of WA

$M_{(i=3,6,7)(j=3c,6,7)\,kl}$ = methane emissions from Qld, NT and the Kimberley region of WA

F = 55.22 MJ/kg CH_4 from Brouwer (1965)

Feedlot cattle are assumed to originate entirely from the steers > 1 year old beef cattle class. To ensure these cattle are not double counted, it is necessary to subtract feedlot cattle numbers from beef cattle numbers in the steers > 1 year class in that State for the same year. Because feedlot cattle, on average, spend between 75 and 250 days on feedlots prior to slaughtering, an annual equivalent number is derived to represent the figure for feedlot cattle which is subtracted from steers > 1 year old—beef cattle numbers—to calculate emissions. The emissions from the feedlot cattle are calculated in Section 6.2.2.1.

The approach is represented in the following equation:

$$N_{ijkl} = N_{ijk(\,l=1,\,l=2,\,l=3\ldots\,l=6,\,[(l=7)\,-\,\text{total feedlot numbers}]\,)} \quad (4A.1b_7)$$

Where: N_{ijkl} = numbers of non-feedlot beef cattle in each State, region, season and class.

$N_{ijkl=1,\,l=2,\,l=3\ldots\,l=6}$ = number of cattle in State i, region j, season k and class l.

$_{(l=7)\,-\,\text{total feedlot numbers}}$ = from Table 6.4, l=7 corresponds with steers >1 year old. In order to calculate total beef cattle numbers in this class, total feedlot numbers, adjusted to annual equivalence must be subtracted from

l =7. For WA 99 per cent of feedlot cattle are assumed to be sourced from the South-West region and the balance from the Pilbara and Kimberley.

Annual Australian methane production (Gg) for all classes of beef cattle across all seasons can then be calculated as:

$E = \Sigma_i \Sigma_j \Sigma_k \Sigma_l (91.25 \times N_{ijkl} \times M_{ijkl}) \times 10^{-6}$ ..... (4A.1b_8)

Where: N_{ijkl} = numbers of beef cattle in each State, region, season and class

M_{ijkl} = methane production (kg/head/day)

91.25 = number of days in each season

Beef Cattle in Feedlots

Table 6.5: Symbols used in algorithms for feedlot cattle

State (i)	Feedlot Cattle Classes (duration of stay) (j)	Average Length of Stay(days)
i = 1 NSW/ACT	j = 1 Domestic/(70–80 days)	75
i = 2 Tasmania	j = 2 Export/(80–200 days)	140
i = 3 Western Australia	j = 3 Japan ox/(200+ days)	250
i = 4 South Australia		
i = 5 Victoria		
i = 6 Queensland		
i = 7 Northern Territory		

The equation developed by Moe and Tyrrell (1979) to predict daily methane yields (Y_{ij} MJ CH_4/head/day) is:

$Y_{ij} = 3.406 + 0.510SR_{ij} + 1.736H_{ij} + 2.648C_{ij}$ ..... (4A.1c_1)

Where: SR_{ij} = intake of soluble residue (kg/day)

H_{ij} = intake of hemicellulose (kg/day)

C_{ij} = intake of cellulose (kg/day)

Each of SR_{ij}, H_{ij} and C_{ij} is calculated from the total intake of the animal (Appendix 6.C.2), the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C.3) and the soluble residue, hemicellulose and cellulose fractions of each of these components (Appendix 6.C.4).

The total daily production of methane (M_{ij} kg CH_4/head/day) is thus:

$M_{ij} = Y_{ij} / F$ ..... (4A.1c_2)

Where: F = 55.22 MJ/kg CH_4 (Brouwer 1965)

Methane production (Gg) for all classes of feedlot cattle across all States can then be calculated as:

$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij}) \times 10^{-6}$ ..... (4A.1c_3)

Where: N_{ij} = numbers of feedlot cattle as an annual equivalent in each class in each State

M_{ij} = methane production (kg/head/day)

6.2.2.2 Sheep (4.A.3)

Estimated emissions are based on Howden *et al.* (1994) who report a close relationship between dry matter intake and methane production based on an analysis of Australian respiration chamber experiments on sheep (Margan *et al.* 1985, 1987, 1988 and Graham 1964a,b, 1967, 1969). Howden *et al.* (1994) found that feed intake alone explained 87% of the variation in methane production.

The Agriculture and Food Research Council (AFRC 1990) equation for intake is used here, as it corresponded well with intakes reported by State experts for seasonal digestibilities common in their State.

The methodology for estimating emissions from sheep has been independently verified. Leuning *et al.* (1999) found close agreement between the methane emissions estimated by the inventory methods and direct field measurements made using micrometeorological mass-balance and SF_6 tracer techniques. Using the inventory methods and default livestock characterisation Leuning *et al.* (1999) estimated CH_4 emissions to be 12.6 g/head/day compared with 11.9 (±1.5) and 11.7 (±0.4) g/head/day measured by the mass-balance and SF_6 tracer techniques respectively. When the actual experimental livestock characterisation was used with the inventory methods, CH_4 emissions were estimated to be 11.1 g/head/day.

In addition, an analysis of recent Australian respiration chamber experiments by Williams and Wright (2005) showed a very similar relationship between methane output and dry matter intake (CH_4 = 0.0187 x DMI - 0.0003) to that reported in Howden *et al.* (1994) (CH_4 = 0.0188 x DMI + 0.00158).

Table 6.6: Symbols used in algorithms for sheep

State (i)	Season (j)	Sheep Classes (k)
		Sheep > 1 year
i = 1 NSW/ACT	j = 1 Spring	k = 1 Rams
i = 2 Tasmania	j = 2 Summer	k = 2 Wethers
i = 3 Western Australia	j = 3 Autumn	k = 3 Maiden Ewes (intended for breeding)
i = 4 South Australia	j = 4 Winter	k = 4 Breeding Ewes
i = 5 Victoria		k = 5 Other Ewes
i = 6 Queensland		*Sheep* < 1 year
i = 7 Northern Territory		k = 6 Lambs and Hoggets

The potential, or maximum, intake of feed by sheep occurs when feed is abundant and of high quality. Potential intake is determined largely by body size and the proportion of the diet that is able to be metabolised by the animal. Potential intake (PI_{ijk} kg DM/head/day) is given by AFRC (1990) as:

$$PI_{ijk} = (104.7\, q_{m,ijk} + 0.307\, W_{ijk} - 15.0)\, W_{ijk}^{0.75} / 1000 \quad \text{(4A.3_1)}$$

Where: W_{ijk} = liveweight (kg) (Appendix 6.D.1)

$q_{m,\,ijk}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ijk}) so, using the equation of Minson and McDonald (1987), $q_{m,\,ijk}$ = 0.00795 DMD - 0.0014 (DMD is expressed as a %)

However, the actual feed intake of animals is often less than the potential intake. This can be caused by many factors, especially by low feed availability. Relative intake is defined as the proportion of potential intake that the animal will consume. The relative intake due to feed availability is given by White *et al.* (1983) as:

$$RI_{ijk} = 1 - \exp(-2(DMA_{ijk})^2) \quad \text{(4A.3_2)}$$

Where: DMA_{ijk} = dry matter availability tonnes/hectare (Appendix 6.D.3)

Note: Actual feed intake will be less than potential intake only when feed availability is less than 1.63 tonnes/hectare.

The actual intake (I_{ijk} kg DM/head/day) of a sheep is thus:

$$I_{ijk} = PI_{ijk} \times RI_{ijk} \times MA_{ijk=4} \quad \text{(4A.3_3)}$$

Where: $MA_{ijk=4}$ = additional intake for milk production

Feed intakes can increase by up to 60% during lactation (ARC 1980). For emissions estimates, the intake of all breeding ewes was assumed to increase by 30% during the season in which lambing occurs, based on relationships presented in SCA (1990).

The additional intake for milk production ($MA_{ijk=4}$) is calculated by:

$$MA_{ijk=4} = (LE_{ijk=4} \times FA_{ijk=4}) + ((1-LE_{ijk=4}) \times 1) \quad \text{(4A.3_4)}$$

Where: $LE_{ijk=4}$ = proportion of breeding ewes lactating, calculated as the annual lambing rates x proportion of lambs receiving milk in each season (Appendix 6.D.6)

$FA_{ijk=4}$ = feed adjustment (assumed to be 1.3)

Methane production (M_{ijk} kg/head/day) is calculated using daily intake figures (I_{ijk}) via the relationship of Howden *et al.* (1994):

$$M_{ijk} = I_{ijk} \times 0.0188 + 0.00158 \quad \text{(4A.3_5)}$$

The annual methane production (in Gg) of Australian sheep is calculated as:

$$E = \Sigma_i \Sigma_j \Sigma_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad \text{(4A.3_6)}$$

Where: N_{ijk} = numbers of sheep in each class for each season and state

M_{ijk} = methane production (kg/head/day)

6.2.2.3 Pigs (4.A.8)

Pigs are non-ruminant animals, and convert a smaller proportion of feed energy intake into methane than do ruminants. The OECD (1991) estimated that, depending on diet, pigs typically convert around 1% of gross energy intake into methane, compared with around 6–7% for cattle and sheep.

Whittemore (1993) suggests that the output of methane by a 60 kg pig is about 0.2 MJ/day. Assuming that, on average, a 60 kg pig consumes 1.95 kg DM/day of a diet containing 18.6 MJ GE/kg, the GE intake was 36.3 MJ GE. Thus pigs would convert around 0.6% of gross energy into methane.

Other values in the literature suggest methane conversions of 1.2% of gross energy (Christensen and Thorbek 1987), 0.6 to 0.8% of gross energy (Moss 1993) and 0.4% gross energy (Kirchgessner *et al.* 1991).

A methane conversion of 0.7% of gross energy intake is used for Australia.

Table 6.7: Symbols used in algorithms for pigs

State (i)	Pig Classes (j)
i = 1 NSW/ACT	j = 1 Boars
i = 2 Tasmania	j = 2 Sows
i = 3 Western Australia	j = 3 Gilts
i = 4 South Australia	j = 4 Others
i = 5 Victoria	
i = 6 Queensland	
i = 7 Northern Territory	

The relationship for enteric fermentation in pigs gives the total daily production of methane (M_{ij} kg CH_4/head/day) as:

$$M_{ij} = I_{ij} \times 18.6 \times 0.007 / F \quad (4A.8_1)$$

Where: I_{ij} = intake (kg DM/day) (Appendix 6.E.1)

F = 55.22 MJ/kg CH_4 (Brouwer 1965)

18.6 = MJ GE/kg feed DM

The annual production of methane (Gg) for all classes of pigs is calculated as:

$$E = \Sigma_i \Sigma_j (N_{ij} \times M_{ij} \times 365) \times 10^{-6} \quad (4A.8_2)$$

Where: N_{ij} = the number of pigs in each class for each State

M_{ij} = methane production (kg/head/day)

6.2.2.4 Other Livestock (Also Including 4A.2, 4, 5, 7, 9, and 10)

Livestock production in Australia is not confined to sheep, pigs and various types of cattle. A range of 'other livestock' are commercially farmed throughout all States, with a trend towards increasing diversity since 1990. Included in calculations of enteric methane emissions are both ruminants (goats, deer and buffalo), quasi-ruminants (camels and alpacas) and non-ruminants (horses, donkeys, mules, emus, ostriches and a range of poultry).

The contribution of other livestock to total methane production is comparatively small. Given the relative absence of data for enteric methane production for other livestock under Australian conditions, a complex methodology, incorporating relationships between intake and methane generated, is inappropriate. In its place, a simplified methodology, based on the IPCC (1997, vol. 3) tier I method, using aggregated numbers of the various livestock types and an annual methane emissions factor is used.

The IPCC (1997, vol. 3) identifies average emissions factors for a number of minor livestock types, based on the work of Crutzen *et al.* (1986). Findings were presented for developed and developing countries. Values pertaining to developed countries were used for the Australian inventory.

- Goats— 5 kg/head/year
- Buffalo—55 kg/head/year
- Camels—46 kg/head/year
- Horses—18 kg/head/year
- Donkeys and Mules—10 kg/head/year
- Poultry—not estimated by IPCC (1997)

EFs for deer, alpacas, emus and ostriches are not provided by IPCC (1997, 2000), so alternative sources were used. The EF for deer was adopted from Howden (1991). For alpacas, emus and ostriches, estimates were made based on animal size and anatomy, to be equivalent with EFs for donkeys and goats respectively.

- Deer—10.7 kg/head/year
- Alpacas—10 kg/head/year
- Emus and Ostriches—5 kg/head/year

Table 6.8: Symbols used in algorithms for other livestock

State (i)	Other Livestock Types (j)	Digestive Type
i = 1 NSW/ACT	j = 1 Goats	ruminant
i = 2 Tasmania	j = 2 Horses	non-ruminant (equine)
i = 3 Western Australia	j = 3 Deer	ruminant
i = 4 South Australia	j = 4 Buffalo	ruminant
i = 5 Victoria	j = 5 Donkeys/Mules	non-ruminant (equine)
i = 6 Queensland	j = 6 Emus/Ostriches	non-ruminant
i = 7 Northern Territory	j = 7 Alpacas	quasi-ruminant
	j = 8 Camels	quasi-ruminant
	j = 9 Poultry	non-ruminant

The calculation of methane emissions from enteric fermentation in minor livestock types uses a simplified approach based on the default emissions factors listed previously.

By applying the EF to the number of each species in each State, total methane production (Gg) from the enteric fermentation of minor livestock types can be calculated as follows:

$$E = \Sigma_i \Sigma_j (N_{ij} \times M_{ij} \times 10^{-6}) \quad \text{(4A.10_1)}$$

Where: N_{ij} = numbers of 'other livestock' types in each State

M_{ij} = methane EF (kg/head/year) (Appendix 6.F.1)

6.2.3 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for enteric fermentation were estimated to be in the order of 5%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.2.4 Source Specific QA/QC

6.2.4.1 Activity Data

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated.

Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

As recommended by the IPCC GPG (2000), inverse modelling of cattle and sheep populations have been undertaken to ensure consistency with reported populations. These studies show no apparent bias in the sheep numbers (Howden 2001) but possible differences in cattle numbers in the order of 3-4% (Howden and Barrett 2003). It is important to note that, with the limited datasets available for this study, the parameter solutions were non-unique and it is possible that there were no systemic differences in the numbers. Given the size of the possible differences and the inherent uncertainty in animal numbers it was agreed with ABS to incorporate this information into the uncertainty estimates rather than adjust activity data.

6.2.4.2 Implied Emission Factors

As country specific tier 2 methods are used to estimate emissions from cattle, sheep and pigs, the IEFs have been compared with the IPCC defaults (Table 6.9).

The dairy cattle IEF is significantly higher than the IPCC default primarily because the default is based on milk production levels of 1,700 kg/head/yr when Australian milk production generally ranges from about 4500-6000 kg/head/year. Australia's IEF is more consistent with the default values for the regions with comparable milk production (IEFs of 100-118 kg/head/year). The non-dairy cattle IEFs differ from the defaults as the methane conversion rates differ from the IPCC defaults (Section 6.2.4.4).

The lower IEFs for sheep and pigs primarily reflect the inclusion of an age structure in the Australian method and a difference in methane conversion rates for sheep (Section 6.2.4.2).

Table 6.9: Implied emission factors - enteric fermentation (kg/head/year)

Livestock Type	Australia	IPCC Default (Oceania)
Dairy Cattle	115	68
Non-dairy cattle		
Range-kept	72	53
Feedlot	77	53
Sheep	6.9	8
Swine	1.44	1.5

Trends in IEFs

As part of the standard tier 1 QC activities, IEFs are checked for possible anomalies in the time-series. As Australia's tier 2 methods disaggregates animals by age class and regions (in which feed and animal characteristics differ) some inter-annual variability can be expected in the IEFs for cattle, sheep and pigs as the relative numbers in each age class and region change year to year. Only those inter-annual changes outside the expected range are described below:

a) The IEF for feedlot cattle shows a period of increase (from 1990 to 1995), then an abrupt decrease (between 1995 and 1996), after which there is little change to the IEFs. There are two factors influencing the IEF:

   i. The most significant is that there is a step change in the input (average intakes, feed components and liveweight gain) in 1996 (Appendix 6.C). There is an increase in the amount of concentrates fed post 1996 which leads to lower IEFs; and

   ii. The reason for the different trends between the two periods is the rapid shift from animals from domestic consumption towards the Japan Ox market in the early 1990s while from the mid 1990s there are only minor shifts between markets (±10%).

6.2.4.3 Feed Intake

As Australia uses country specific tier 2 methods for estimating feed intake, intakes have been checked for reasonableness and have been compared with average intakes reported by other Parties.

Cattle

For dairy cattle average herd intakes are within the range reported by other Parties. The mean is lower (Table 6.10) because the herd average for Australia includes all animals in the dairy cattle herd not just milking cows and this would drive herd averages down compared with other Parties which have only reported milking cows.

The intakes of Australian dairy cattle are in the order of 1-3% of live weight (range from 1.4% to 3.1%) as recommended by the IPCC (2000).

Comparison of the non-dairy cattle between Parties is complicated by the fact that animals kept under feedlot conditions are not reported separately from range-kept animals as is done in the Australian inventory. The average herd intakes reported in Australia are within the range reported by other Parties although the means are significantly different with range-kept animals lower and feedlot higher than the mean of other Parties (Table 6.10).

Table 6.10: Average herd intake (MJ/head/day)

Livestock Type	Australia		Other Parties	
	Range	Mean	Range	Mean
Dairy Cattle	214-235	228	164-339	258
Non-dairy cattle			95-205	143
Range-kept	129-130	129		
Feedlot	190-200	198		
Sheep	17	17	19-46	25

There is a high level of confidence in the estimates of intake for feedlot cattle as these have been based on standard industry practices and range from 1.9 to 2.7% of live weights.

Intakes for other cattle are calculated based on the relationship of Minson and MacDonald (1987). Howden *et al.* (2002) tested the Australian approach and the IPCC tier 2 approach against animal growth and feed intake data collated from four research papers, and while neither method showed itself superior across all data sets, the Minson and McDonald approach provided better overall performance.

Howden *et al.* (2002) also compared the two approaches against feed intakes drawn from the Australian Feeding Standards (SCA 1990) for different animal sizes, feed digestibility and pregnancy status in Queensland. They found that the IPCC approach consistently over-predicted intake (mean over prediction of 43%). In contrast, the Australian method provided dry matter intake values that were not significantly different from those reported in the Feeding Standards.

On the basis of the above investigations, Howden *et al.* (2002) concluded that the Australian approach to estimating intakes was more robust than the IPCC approach for livestock in Australia.

Sheep

The country specific method used to estimate intake from Australian sheep produces lower average intakes than that reported by other Parties (Table 6.10). However, an analysis of intake as percentage of liveweight shows that intakes are in the order of 1-3% (range from 1.0% to 2.7%) as recommended by IPCC (2000).

The IPCC tier 2 method for estimating intake predicts DMI based on how much feed must be consumed to meet estimated requirements and does not consider the biological capacity of the animal to, in fact, consume the predicted quantify of feed. For example, in Australia the actual feed intake is often less than the estimated intake due to low feed availability. The Australian method calculates the proportion of the potential intake that the animal will actually consume (potential intake is restricted when feed availability is less than 1.63 tonnes/hectare). Restricted feed conditions occur in one or more seasons in all States with animals experiencing weight loss over the season. When intakes are not limited, estimated intakes (average 21 MJ/day) are similar to levels reported by other Parties.

6.2.4.4 Methane Conversion Rates

As Australia uses country specific methods for estimating methane emissions, methane conversion rates (Ym) have been compared against IPCC defaults.

Dairy and Beef Cattle

The conversion rate for dairy cows (6.9-7.2%) is higher than the IPCC *Good Practice Guidance* (2000) default of 6% but is within the range of the 2006 IPCC *Guidelines* default (6.5% ±1%). For other dairy cattle the methane conversion rates are slightly higher with overall herd average rates of about 7.3%.

The average conversion rate for temperate beef cattle (7.4%) is higher than the IPCC *Good Practice Guidance* (2000) default of 6% but is within the range of the 2006 IPCC *Guidelines* default (6.5% ±1%) although at the upper end. The IPCC (2000) indicate that where poorer feed is available the higher bound of emissions are appropriate, and in Australia cattle in temperate regions frequently experience diets with less than 60% digestibility. The IPCC (2000) acknowledge that animals on tropical feeds may have higher methane conversion rates, however the Australian method predicts considerably higher methane yields (9.0%) on tropical feeds than the IPCC defaults (7%). The IPCC (2000, 2006) acknowledges that Ym values outside the default ranges may occur on tropical pastures and that further research is needed in this area.

Feedlot Cattle

The IPCC (2000) indicate that animals fed diets containing 90% concentrates should use Ym values ranging from 3.5-4.5%. The Australian methodology for estimating emissions produces values of about 6%. Australian feedlot cattle diets consist of approximately 70-80% concentrates (predominately grain with small quantities of molasses and other concentrates) rather than the 90% indicated for the default value. The Australian method was tested using intake and feed quality data from Kurihara *et al.* (1999, corrected by Hunter 2007) who measured methane conversion rates of 5.6% using calorimetry chambers for cattle on a high grain (75%) plus lucerne diets compared with the 5.9% estimated by the Australian method.

Sheep

The herd average Ym for Australian sheep is 6.2%. This is lower than the IPCC *Good Practice Guidance* (2000) default of 7% but is within the range of the *2006 IPCC Guidelines* default (6.5% ±1%).

As described in Section 6.2.2.2, independent verification has been undertaken on the emission estimates for sheep.

6.2.4.5 External Review

A comprehensive expert peer review of the methodologies, activity data and livestock characterisation data was conducted in 2000-01 involving agricultural experts from industry, government and academia.

6.2.5 Recalculations Since the 2011 Inventory

Emissions for the most recent year in the *agriculture* sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. In addition, lambing (2007, 2008, 2011) and calving rates (2009-2011), milk production (2011) and wool yields (2011) were updated and the allocation of sheep between age class was corrected for 2004-2005. Changes have also been made to the "other" livestock numbers (1992-2011) to correct errors and replace extrapolated data with interpolated data.

The net effect of these changes was no change to the 1990 estimate, a 27 Gg CO_2-e increase in the 2010 estimate and a 306 Gg CO_2-e increase in the 2011 estimate.

Table 6.11: 4.A Enteric fermentation: recalculation of total CO_2-e emissions, 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	63,919	63,919	0.0	0.0
2000	60,434	60,434	0.0	0.00
2001	60,837	60,836	-0.2	0.00
2002	59,510	59,511	1.0	0.00
2003	59,549	59,189	-360.2	-0.60
2004	59,835	59,108	-727.0	-1.22
2005	60,130	59,402	-728.3	-1.21
2006	59,088	58,722	-366.5	-0.62
2007	57,207	57,207	-0.3	0.00
2008	56,116	56,123	6.5	0.01
2009	54,593	54,610	17.7	0.03
2010	54,676	54,703	26.9	0.05
2011	54,818	55,124	306.1	0.56

6.2.6 Source Specific Planned Improvements

The inventory improvement plan for the *agriculture* sector identifies areas which require updating or review over the next two years. The improvement plan identifies changes which will be required to implement the proposed revision to the UNFCCC Reporting Guidelines for the 2015 submission (Decision 15/CP.17), as well as any issues identified through the UNFCCC expert reviews, domestic QA/QC process or the expected availability of new data or empirical studies which could improve accuracy of the inventory.

For enteric fermentation the following areas have been identified for review and/or change

1. *Tropical beef cattle* - Recently published research on emission from cattle on tropical feed (Kennedy and Charmley 2012) indicates that emissions from tropical cattle are likely to be overestimated in the inventory. The method for tropical cattle will be reviewed and a revised method implemented for the 2015 submission.

2. *Pre-weaning animal classes* – Previous UNFCCC ERT's have identified the need to include a pre-weaning class for dairy cattle to better reflect the effects of milk intake on CH_4 and N_2O emissions. A revised method for dairy calves is currently being prepared and will be implemented in the inventory once it has undergone independent expert review. Over the next two years the methods for beef calves and lambs will also be reviewed.
3. *Feed and animal characteristics* - As these characteristic can change as industry practices change over time the current values need to be reviewed periodically. The pig, feedlot and dairy industries have been identified as priorities for review.

Through the Reducing Emissions from Livestock Research Program, managed by the Department of Agriculture (formerly the Department of Agriculture, Forestry and Fisheries), the Australian Government is funding research into methane emission generation from enteric fermentation under a variety of conditions as well as the estimation of the impacts of changes in management practices on emissions. Once the results from the research program are available they will be used to review the key parameters and methods currently adopted for emissions estimation.

The main areas of activity that received funding in 2010 with completion in 2012 included understanding the amount and range of methane emissions from different animal systems and identifying mitigation options as related to management practices (feed composition and quality including supplements, genetics, animal husbandry including maternal efficiency, and rumen modification).

6.3 Source Category 4.B Manure Management

6.3.1 Source Category Description

Methane is produced from the decomposition of the organic matter remaining in the manure under anaerobic conditions. These conditions occur when large numbers of animals are managed in a confined area where manure is typically stored in large piles or lagoons.

Nitrous oxide emissions from manure management systems can occur via combined nitrification-denitrification of ammoniacal nitrogen contained in the wastes. The amount released depends on the system and duration of waste management.

6.3.2 Methodology

Methane

Methane production from the manure of dairy cattle, feedlot cattle, pigs and poultry are calculated based on the approach of the IPCC (1997) using a combination of default IPCC and country specific input values. Subscripts for the algorithms are the same as used for calculating enteric fermentation.

Australian experts considered that methane production was likely to be negligible in the manure of range-kept livestock (e.g. free-range beef cattle, sheep, goats etc). There was agreement that the generally high temperatures, high solar radiation and low humidity environments of Australia would dry manure rapidly. In combination with scarab (or dung) beetles that rapidly infest manure in most Australian environments, there was considered to be little likelihood of anaerobic conditions and hence little methanogenesis in the manure of range-kept animals. This is supported by González-Avalos and Ruiz-Suárez (2001) who recorded negligible amount of methane from the manure of cattle kept under conditions similar to those experienced in Australia. The González-Avalos and Ruiz-Suárez (2001) methodology is, therefore, used to estimate methane emissions from range-kept livestock manure.

Gonzalez-Avalos and Ruiz-Suarez (2001) calculate their methane emissions factor (M_{ijk} kg/head/year) as follows:

$$M_{ijk} = (\text{kg } CH_4 / \text{ kg DM fresh manure}) \times (\text{kg fresh manure/day}) \times (\text{\% DM}) \times 365$$

The second and third term on the right hand side of the equation quantify the amount of dry matter (DM) in manure. This can be calculated for beef cattle and sheep using estimates of Intake and DMD to estimate DM manure (kg/head/day):

$$DMM_{ijk} = I_{ijk} \times (1 - DMD_{ijk})$$

Gonzalez-Avalos and Ruiz-Suarez (2001) do not document EFs in kg CH_4/kg DM fresh manure. However, this can be calculated from the data in their paper using their Extensive Dual Purpose (temperate and warm) categories. The manure emission factors (MEF) are:

Temperate (21°C) — 1.4 x10^{-5} kg CH_4/kg DM manure

Warm — 5.4 x10^{-5} kg CH_4/kg DM manure

Nitrous Oxide

The methodology for estimating nitrogen excretion is based on equations from SCA (1990) and Freer *et al.* (1997) which have been developed in Australia, rather than the default IPCC (1997) values. This methodology takes a mass balance approach where N output = N input - N storage. The total N output is then split into urinary and faecal components.

The methodology for estimating emissions is based on the IPCC (1997, vol 3) *Guidelines* incorporating manure management systems that reflect Australian conditions. Subscripts for algorithms are the same used for calculating methane emissions with an additional manure management system subscript (Table 6.12). The nitrogen voided in the waste of domestic livestock estimated in this section provides the basis of calculating nitrous oxide emissions from soils in source category 4D.

In the UNFCCC common reporting format tables, nitrous oxide emissions are reported for the different manure management systems rather than on the basis of livestock type. The management system to which the livestock types contribute are shown in Table 6.13. The 'other' category includes pig manure treated in a digester and poultry manure with and without bedding.

Table 6.12: Symbols and emission factors used in algorithms for nitrous oxide emissions

Manure Management Systems (MMS)	Emission Factor [(a)] (kg N_2O-N/kg N excreted)
MMS = 1 Anaerobic lagoon	0.001
MMS = 2 Liquid systems	0.001
MMS = 3 Daily spread	0[(b)]
MMS = 4 Solid storage and drylot	0.02
MMS = 5 Digester	0.001
MMS = 6 Poultry manure with bedding	0.02
MMS = 7 Poultry manure without bedding	0.005
MMS = 8 Pasture range and paddock	0[(b)]

(a) IPCC (1997, 2000).

(b) There are no direct emissions from these sources. Emissions from the soil are reported under Agricultural Soils (4D).

Table 6.13: Manure management system to which livestock contribute

Greenhouse gas source and sink categories	Anaerobic lagoon	Liquid system	Daily spread	Solid storage and dry lot	Pasture range and paddock	Other
Non-Dairy Cattle - Free Range	NO	NO	NO	NO	Source	NO
Dairy Cattle	Source	Source	Source	NO	Source	NO
Sheep	NO	NO	NO	NO	Source	NO
Swine	Source	Source	Source	Source	NO	Source
Poultry	NO	NO	NO	NO	Source	Source
Non-Dairy Cattle - Feedlot	NO	NO	NO	Source	NO	NO
Goats, Horses, Deer, Buffalo, Donkeys, Mules, Emus, Ostriches, Alpacas, Camels	NO	NO	NO	NO	Source	NO

Table based on CRF Table 4.B(b)

6.3.2.1 Cattle (4.B.1)

Dairy Cattle

Methane

Dairy cattle are generally kept in higher rainfall areas than other Australian livestock. This, and the disposal of excreta washed from milking sheds, gives opportunities for the generation of methane. However, only a small fraction of the potential methane emissions appears to be released. Williams (1993) measured methane production from dairy cattle manure under field conditions in Australia and found that only about 1% of the methane production potential was achieved. On this basis, the temperate methane conversion factor values for manure voided in the field were reduced to 1% from the IPCC (1997, vol. 3) default value of 1.5%.

Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for dairy cattle (VS_{ijk} kg/head/day) was estimated using the data developed to calculate enteric methane production as this included information on intakes and dry matter digestibility. For dairy cattle, volatile solids were calculated:

$$VS_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times (1 - A) \quad \text{(4B.1a_1)}$$

Where: I_{ijk} = dry matter intake calculated in Section 6.3.2.1

DMD_{ijk} = dry matter digestibility expressed as a fraction (Appendix 6.A.3)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Methane production from manure (M_{ijk} kg/head/day) is then calculated as:

$$M_{ijk} = VS_{ijk} \times B_o \times MCF \times \rho \quad \text{(4B.1a_2)}$$

Where: B_o = emissions potential - 0.24m^3 CH_4/kg VS (IPCC 1997)

MCF = integrated methane conversion factor—based on the proportion of different manure management regimes (Appendix 6.A.4) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.A.5)

ρ = density of methane (0.662 kg/m^3)

The annual methane production (Gg) from the manure of dairy cattle is calculated as:

$$Total = \Sigma_{i=1,3-7}\Sigma_j(365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \Sigma_{i=2}\Sigma_j\Sigma_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (4B.1a_3)$$

Where: N_{ijk} = numbers of dairy cattle in each State, class and season

M_{ijk} = methane production (kg/head/day)

Nitrous Oxide

The methodology for calculating the excretion of nitrogen from dairy cattle makes use of the following algorithms to calculate crude protein input (CPI_{ijk}) and storage (NR_{ijk}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ijk} (kg/head/day) of dairy cattle is calculated thus:

$$CPI_{ijk} = I_{ijk} \times CP_{ijk} \quad (4B.1a_4)$$

Where: I_{ijk} = dry matter intake (kg/day) as calculated in Section 6.3.2.1

CP_{ijk} = crude protein content of feed intake expressed as a fraction (Appendix 6.A.6)

Dairy calves are usually removed from their mothers very early and are either sold for slaughter or raised as replacements. The calves receive a supplement (milk replacer and feed pellets) and are on average weaned after six weeks. The protein from the supplements is not included in the equation which assumes that intake pre-weaning is from pasture.

Nitrogen excreted in faeces (F_{ijk} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein plus the endogenous faecal protein, such that:

$$F_{ijk} = \{0.3(CPI_{ijk} \times (1-[(DMD_{ijk}+10)/100])) + 0.105(ME_{ijk} \times I_{ijk} \times 0.008) + (0.0152 \times I_{ijk})\}/6.25 \quad (4B.1a_5)$$

Where: DMD_{ijk} = dry matter digestibility expressed as a % (Appendix 6.A.3)

ME_{ijk} = metabolizable energy (MJ/kg DM) calculated as: 0.1604 DMD_{ijk} – 1.037 (Minson and McDonald 1987)

I_{ijk} = dry matter intake (kg/day)

1/6.25 = factor for converting crude protein into nitrogen

The amount of nitrogen that is retained by the body (NR_{ijk} kg/head/day) is calculated as the amount of nitrogen retain in milk and body tissue such that:

$$NR_{ijk} = \{(0.032 \times MP_{ijk}) + \{0.212–0.008(L_{ijk} – 2) – [(0.140-0.008(L_{ijk} – 2)) / (1+\exp(–6(Z_{ijk} – 0.4)))]\} \times (LWG_{ijk} \times 0.92)\}/6.25 \quad (4B.1a_6)$$

Where: MP_{ijk} = milk production in kg/head/day

L_{ijk} = relative intake as calculated in Section 6.3.2.1

Z_{ijk} = relative size (liveweight / standard reference weight (Appendix 6.A.7))

LWG_{ijk} = liveweight gain (kg/day) (Appendix 6.A.2)

Nitrogen excreted in urine (U_{ijk} kg/head/day) is calculated by subtracting NR_{ijk}, F_{ijk} and dermal protein loss from the nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk}/6.25) – NR_{ijk} – F_{ijk} – [(1.1 \times 10^{-4} \times W_{ijk}^{0.75})/6.25] \quad (4B.1a_7)$$

Where: W_{ijk} = liveweight (Appendix 6.A.1)

The total annual faecal (AF_{jk} Gg) and urinary (AU_{jk} Gg) nitrogen excreted is calculated as:

$$AF_{ijk} = \Sigma_{i=1,3-7}\Sigma_j(365 \times N_{ij} \times F_{ij}) \times 10^{-6} + \Sigma_{i=2}\Sigma_j\Sigma_k (91.25 \times N_{ijk} \times F_{ijk}) \times 10^{-6} \quad (4B.1a_8a)$$

$$AU_{ijk} = \Sigma_{i=1,3-7}\Sigma_j (365 \times N_{ij} \times U_{ij}) \times 10^{-6} + \Sigma_{i=2}\Sigma_j\Sigma_k (91.25 \times N_{ijk} \times U_{ijk}) \times 10^{-6} \quad (4B.1a_8b)$$

Where: N_{ijk} = the number of dairy cows in each State, season and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1a_9a)$$

$$Urine_{MMS} = (AU_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1a_9b)$$

$$Total_{MMS} = \Sigma_i\Sigma_j\Sigma_k (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1a_9c)$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems (Appendix 6.A.4).

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.11)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Beef Cattle

Methane

Methane production from the manure (M_{ijkl} kg/head/day) of free-range beef cattle is calculated as:

$$M_{ijkl} = I_{ijkl} \times (1- DMD_{ijkl}) \times MEF \quad (4B.1b_1)$$

Where: I_{ijkl} = dry matter intake calculated in Section 6.3.2.1

MEF = emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001). The warm factor is used for Qld, NT and the Kimberly region of WA and the temperate factor is used for all other States and regions.

The annual methane production (Gg) from the manure of free-range beef cattle is calculated as:

$$Total = \Sigma_i\Sigma_j\Sigma_k\Sigma_l (N_{ijkl} \times M_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_2)$$

Where: N_{ijkl} = numbers of beef cattle in each State, class and season

M_{ijkl} = methane production (kg/head/day)

Nitrous Oxide

The methodology for calculating the excretion of nitrogen from beef cattle makes use of the following algorithms to calculate crude protein input (CPI_{ijkl}) and storage (NR_{ijkl}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ijkl} (kg/head/day) of beef cattle is calculated thus:

$$CPI_{ijkl} = I_{ijkl} \times CP_{ijkl} + (0.032 \times MC_{ijkl}) \quad (4B.1b_3)$$

Where: I_{ijkl} = dry matter intake (kg/head/day) as calculated in Section 6.3.2.1

CP_{ijkl} = crude protein content of feed dry matter expressed as a fraction (Appendix 6.B.4)

MC_{ijkl} = milk intake (kg/day) - for areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) considered to be 4 kg/day for animals in the first season after birth and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) considered to be 6 and 4 kg/day (Appendix 6.B.5)

Nitrogen excreted in faeces (F_{ijkl} kg/head/day) is calculated, using equations developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed, microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijkl} = \{0.3(CPI_{ijkl} \times (1-[(DMD_{ijkl}+10)/100])) + 0.105(ME_{ijkl} \times I_{ijkl} \times 0.008) + 0.08(0.032 \times MC_{ijkl}) + (0.0152 \times I_{ijkl})\}/6.25 \quad (4B.1b_4)$$

Where: DMD_{ijkl} = dry matter digestibility (expressed as a %) (Appendix 6.B.3)

ME_{ijkl} = metabolizable energy (MJ/kg DM) calculated by Minson and McDonald (1987) as: ME = 0.1604 DMD_{ijkl} - 1.037; (DMD expressed as %)

I_{ijkl} = feed intake (kg DM/head/day)

MC_{ijkl} = milk intake (kg/head/day). In areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) milk intake is 4 kg/day for animals in the first season after birth and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) intake is 6 and 4 kg/day (Appendix 6.B.5)

1/6.25 = factor for converting crude protein into nitrogen

The amount of nitrogen that is retained by the body (NR_{ijkl} kg/head/day) is calculated as the amount of nitrogen retained as milk and body tissue such that:

$$NR_{ijkl} = \{(0.032 \times MP_{ijkl}) + \{0.212-0.008(L_{ijkl} - 2) - [(0.140-0.008(L_{ijkl} -2)) / (1+\exp(-6(Z_{ijkl} - 0.4)))]\} \times (LWG_{ijkl} \times 0.92)\}/6.25 \quad (4B.1b_5)$$

Where: MP_{ijkl} = milk production (kg/head/day) calculated as: proportion of cows lactating (LC_{ijkl}) x milk production. In areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) milk production is 4 kg/day for cows >2 years old in the first season after calving and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) considered to be 6 and 4 kg/day (Appendix 6.B.5)

L_{ijkl} = relative intake as calculated in Section 6.3.2.1

Z_{ijkl} = relative size (liveweight / standard reference weight (Appendix 6.B.6))

LWG_{ijkl} = liveweight gain (kg/day) (Appendix 6.B.2)

Nitrogen excreted in urine (U_{ijkl} kg/head/day) is calculated by subtracting NR_{ijkl}, F_{ijkl} and dermal protein loss from the nitrogen intake such that:

$$U_{ijkl} = (CPI_{ijkl} /6.25) - NR_{ijkl} - F_{ijkl} - [(1.1 \times 10^{-4} \times W_{ijkl}^{0.75}) / 6.25] \quad (4B.1b_6)$$

Where: W_{ijkl} = liveweight (Appendix 6.B.1)

The total annual faecal (AF_{ijkl} Gg) and urinary (AU_{ijkl} Gg) nitrogen excreted is calculated as:

$$AF_{ijkl} = (N_{ijkl} \times F_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_7a)$$

$$AU_{ijkl} = (N_{ijkl} \times U_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_7b)$$

Where: N_{ijkl} = the number of beef cattle adjusted for feedlot cattle in each State, region, season and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8a)$$

$$Urine_{MMS} = (AU_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8b)$$

$$Total_{MMS} = \Sigma_i\Sigma_j\Sigma_k\Sigma_l (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1b_8c)$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems. In the case of beef cattle all manure is voided at pasture (MMS = 8).

$EF_{(MMS)}$ = emissions factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.11)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Beef Cattle In Feedlots

Methane

The high density of animals in feedlots results in high concentrations of manure from which methane can be produced when the dung pack becomes moistened and anaerobic microsites occur. This, and the disposal of manure washed out from the facility, gives opportunities for the generation of methane. However, the dry packing arrangement used in most feedlots in Australia is likely to result in only a small fraction of the potential methane emissions being generated (IPCC 1997). The IPCC (1997, vol. 3) default values for drylot Methane Conversion Factors are 1.5% and 5% for temperate and warm regions, respectively.

Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for beef cattle in feedlots (VS_{ij} kg/head/day) was estimated using the data developed to calculate enteric methane production as this included information on intakes and dry matter digestibility:

$VS_{ij} = I_{ij} \times (1 - DMD_{ij}) \times (1 - A)$ (4B.1c_1)

Where: I_{ij} = dry matter intake (Appendix 6.C.2)

DMD_{ij} = digestibility expressed as a fraction (assumed to be 80%)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Methane production from the manure (M_{ij} kg/head/day) is then calculated as:

$Mi_j = VS_{ij} \times B_o \times MCF \times \rho$ ..... (4B.1c_2)

Where: B_o = emissions potential (0.17m^3 CH_4/kg VS (IPCC 1997))

MCF = methane conversion factor. IPCC drylot MCF value for 'warm' regions used for Queensland and the Northern Territory (5%) and MCF value for 'temperate' regions used for all other States (1.5%).

ρ = density of methane (0.662 kg/m^3)

The annual methane production (Gg) from the manure of beef cattle in feedlots is calculated as:

$E = \Sigma_{ij} (365 \times N_{ij} \times M_{ij} \times 10^{-6})$ ..... (4B.1c_3)

Where: N_{ij} = Annual equivalent numbers of beef cattle in feedlots

M_{ij} = methane production (kg/head/day)

Nitrous Oxide

The methodology for calculating the excretion of nitrogen from feedlot cattle makes use of the following algorithms to calculate crude protein input (CPI_{ij}) and storage (NR_{ij}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ij} (kg/head/day) of feedlot cattle is calculated by:

$CPI_{ij} = NI_{ij} \times 6.25$ ..... (4B.1c_4)

Where: NI_{ij} = nitrogen intake (kg/day)

6.25 = factor for converting nitrogen into crude protein

NI_{ij} is calculated from the total intake (Appendix 6.C.2) of the animals as the proportion of the diet that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C.3) and the nitrogen fraction of each of these components (Appendix 6.C.4).

Nitrogen excreted in faeces (F_{ij} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein plus the endogenous faecal protein, such that:

$$F_{ij} = \{0.3(CPI_{ij} \times (1-[(DMD_{ij}+10)/100])) + 0.105(ME_{ij} \times I_{ij} \times 0.008) + 0.0152 \times I_{ij}\} /6.25 \quad \text{(4B.1c_5)}$$

Where: DMD_{ij} = digestibility expressed as a percentage (assumed to be 80%)

ME_{ij} = metabolizable energy (MJ/kg DM) calculated as: 0.1604 DMD_{ij} – 1.037 (Minson and McDonald 1987)

I_{ij} = feed intake (kg/day) (Appendix 6.C.2)

The amount of nitrogen that is retained by the body (NR_{ij} kg/head/day) is calculated as the amount of nitrogen retained as body tissue such that:

$$NR_{ij} = \{[0.212-0.008(L_{ij} - 2) - \{(0.140-0.008(L_{ij} - 2)) / (1+\exp(-6(Z_{ij} - 0.4)))\}] \times (LWG_{ij} \times 0.92)\}/6.25 \quad \text{(4B.1c_6)}$$

Where: L_{ij} = relative intake. Determined by dividing feed intake by the intake require for maintenance (as per Minson and McDonald 1987)

Z_{ij} = relative size (liveweight (Appendix 6.C.1) / standard reference weight Steers>1 (Appendix 6.B.6))

LWG_{ij} = liveweight gain (Appendix 6.C.5)

Nitrogen excreted in urine (U_{ij} kg/head/day) is calculated by subtracting NR_{ij}, F_{ij} and dermal protein loss from the nitrogen intake such that:

$$U_{ij} = (CPI_{ij} / 6.25) - NR_{ij} - F_{ij} - [(1.1 \times 10^{-4} \times W_{ij}^{0.75})/6.25] \quad \text{(4B.1c_7)}$$

Where: W_{ij} = liveweight (Appendix 6.C.1)

The total annual faecal (AF_{ij} Gg) and urinary (AU_{ij} Gg) nitrogen excreted is calculated as:

$$AF_{ij} = (N_{ij} \times F_{ij} \times 365) \times 10^{-6} \quad \text{(4B.1c_8a)}$$

$$AU_{ij} = (N_{ij} \times U_{ij} \times 365) \times 10^{-6} \quad \text{(4B.1c_8b)}$$

Where: N_{ij} = the annual equivalent number of feedlot cattle in each State and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad \text{(4B.1c_9a)}$$

$$Urine_{MMS} = (AU_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad \text{(4B.1c_9b)}$$

$$E_{MMS} = \Sigma_i \Sigma_j (Faecal_{MMS} + Urine_{MMS}) \quad \text{(4B.1c_9c)}$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems. In the case of feedlot cattle all manure is dry packed (MMS = 4).

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.12)

Cg = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.3.2.2 Sheep (4.B.3)

Methane

Methane production from the manure (M_{ijk} kg/head/day) of sheep is calculated as:

$$M_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times MEF \quad (4B.3_1)$$

Where: I_{ijk} = dry matter intake calculated in Section 6.3.2.2

MEF = manure emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001). The warm factor is used for Qld and NT and the temperate factor is used for all other States.

The annual methane production (Gg) from the manure of sheep is calculated as:

$$\text{Total} = \Sigma_i \Sigma_j \Sigma_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_2)$$

Where: N_{ijk} = numbers of sheep in each State, class and season

M_{ijkl} = methane production (kg/head/day)

Nitrous Oxide

The methodology for calculating the excretion of nitrogen from sheep makes use of the following algorithms to calculate crude protein input (CPI_{ijk}) and storage (NR_{ijk}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ijk} (kg/head/day) of sheep is calculated thus:

$$CPI_{ijk} = I_{ijk} \times CP_{ijk} + (0.045 \times MC_{ijk}) \quad (4B.3_3)$$

Where: I_{ijk} = feed intake (kg DM/head/day) as calculated in Section 6.3.2.2

CP_{ijk} = crude protein content of feed intake expressed as a fraction (Appendix 6.D.4)

MC_{ijk} = milk intake (kg/head/day) calculated as: proportion of lambs receiving milk in each season x milk intake (Appendix 6.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

Nitrogen excreted in faeces (F_{ijk} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed, the microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijk} = \{0.3(CPI_{ijk} \times (1-[(DMD_{ijk}+10)/100])) + 0.105(ME_{ijk} \times I_{ijk} \times 0.008) + 0.08(0.045 \times MC_{ijk}) + 0.0152 \times I_{ijk}\}/6.25 \quad (4B.3_4)$$

Where: DMD_{ijk} = digestibility expressed as a percentage (Appendix 6.D.2)

ME_{ijk} = metabolizable energy (MJ/kg DM) calculated as 0.1604 DMD_{ijk} - 1.037 (Minson and McDonald 1987)

MC_{ijk} = milk intake (kg/day) calculated as: proportion of lambs receiving milk in each season x milk intake (Appendix 6.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

1/6.25 = factor for converting crude protein into nitrogen

The amount of nitrogen retained by the body (NR_{ijk} kg/head/day) is calculated as the nitrogen retained in milk, wool and body tissue such that:

$$NR_{ijk} = \{(0.045 \times MP_{ijk}) + (WP_{ijk} \times 0.84) + \{[(212 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) - (140 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) / \{1+\exp(-6(Z_{ijk}-0.4))\}] \times EBG_{ijk}\}/1000\}/6.25 \quad (4B.3_5)$$

Agriculture

Where: MP_{ijk} = milk production (kg/day) calculated as: proportion of ewes lactating (LE_{ijk}) x milk production. Milk production is considered to be 1.6 kg/day for breeding ewes in the first three months after the birth of lambs.

WP_{ijk} = clean wool production (kg/day) based on ABS average greasy wool production per head multiplied by State average clean yield percentage. Wool production may be reduced by 50% for lactating ewes (SCA 1990). Accordingly, wool production of ewes was apportioned pro rata to give recorded annual average wool production. It is assumed that clean wool consists of 16% water and 84% protein.

EBG_{ijk} = empty body gain which is equivalent to LWG_{ijk} x 0.92

SRW_{ijk} = standard reference weight (SCA 1990) in Appendix 6.D.7

Z_{ijk} = relative size (liveweight / standard reference weight)

Nitrogen excreted in urine (U_{ijk} kg/head/day) is calculated by subtracting the nitrogen retained (NR_{ijk}) and the nitrogen excreted in the faeces (F_{ijk}) from the nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk} / 6.25) - NR_{ijk} - F_{ijk} \quad (4B.3_6)$$

The annual faecal (AF_{ijk} Gg) and urinary (AU_{ijk} Gg) nitrogen excreted is calculated as:

$$AF_{ijk} = (N_{ijk} \times F_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_7a)$$

$$AU_{ijk} = (N_{ijk} \times U_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_7b)$$

Where: N_{ijk} = the number sheep in each State, season and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.3_8a)$$

$$Urine_{MMS} = (AU_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.3_9b)$$

$$E_{MMS} = \Sigma_i \Sigma_j \Sigma_k (Faecal_{MMS} + Urine_{MMS}) \quad (4B.3_10c)$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems. In the case of sheep all manure is voided at pasture (MMS = 8).

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.12)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.3.2.3 Pigs (4.B.8)

Methane

In Australia, pigs are generally housed and the liquid waste slurry produced during cleaning is often channelled into lagoons. These lagoons tend to create anaerobic conditions, resulting in a high proportion of the volatile solids being fermented with the formation of methane.

A significant proportion of feed given to pigs can be wasted (ranging from 5-20%). This waste feed also contributes volatile solids to the manure management system and will result in methane emissions. For completeness emissions are estimated from all waste entering the manure management system.

Casey *et al.* (1996) have developed a nutrient balance model for intensive piggeries in Australia-PIGBAL. By entering typical animal characteristic, intakes, diet compositions and wastage rates the model calculates the volatile solids in the animal manure and waste feed (Appendix 6.E and 6.G).

Pigs are fed high quality diets with substantial nitrogen contents. The rapid growth rates of most pigs result in a relatively high proportion of this nitrogen being retained in the body. Pigs may excrete between 45 and 65% of nitrogen consumed in feed (King and Brown 1993, King *et al.* 1993).

Wasted feed also contributes nitrogen to the manure management systems and is included in the estimation of emissions for completeness. The nutrient balance model PIGBAL (Casey *et al.* 1996) is used to estimate total nitrogen in wastes based on typical animal characteristics, intakes, feed types and wastage rates (Appendix 6.E and 6.G).

Methane is formed from the organic fraction (volatile solids) of the faeces and waste feed. Volatile solid production for Australian pigs (VS_{ij} kg/head/day) was estimated using the PIGBAL model (Casey *et al.* 1996).

Using this information methane production from the wastes (M_{ij} kg/head/day) can thus be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad \text{(4B.8_1)}$$

Where: VS_{ij} = volatile solids production (kg/head/day) (Appendix 6.E.2)

B_o = emissions potential (0.45m^3 CH_4/kg VS (IPCC 1997))

MCF = integrated methane conversion factor based on the proportion of different manure management regimes (Appendix 6.E.3) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.E.4).

ρ = density of methane (0.662 kg/m^3)

The annual methane production (Gg) from the wastes of Australian pigs is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad \text{(4B.8_2)}$$

Where: N_{ij} = numbers of pigs in each class for each State

M_{ij} = methane production (kg/head/day)

Nitrous Oxide

The annual nitrogen (AE_{ij} Gg/year) from pig manure and waste feed is calculated as:

$$AE_{ij} = N_{ij} \times E_{ij} \times 10^{-6} \quad \text{(4B.8_3)}$$

Where: N_{ij} = numbers of pigs in each class in each State

E_{ij} = nitrogen in waste (kg/head/year) as calculated by PIGBAL (Appendix 6.E.5)

The total emissions of nitrous oxide from the different manure management systems (E_{MMS} Gg) can then be calculated as follows:

$$E_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times MMS \times EF_{(MMS)} \times C_g) \quad \text{(4B.8_4)}$$

Where: MMS = the fraction of AE that is managed in the different manure management systems (Appendix 6.E.3).

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.12)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.3.2.4 Other Livestock (Including 4.B.2, 4, 5, 6, 7, 9, and 10)

Poultry

Methane

The majority of Australia's poultry population are housed indoors which promotes conditions for the concentration and concentrated treatment of faecal wastes. Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for poultry (VS_{ij} kg/head/day) was estimated using information on intakes and dry matter digestibility:

$$VS_{ij} = I_{ij} \times (1 - DMD_{ij}) \times (1 - A) \quad \text{(4B.9_1)}$$

Where: I_{ij} = dry matter intake (assumed to be 0.11 kg/day)

DMD_{ij} = digestibility expressed as a fraction (assumed to be 80%)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Methane production from the manure (M_{ij} kg/head/day) can then be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad \text{(4B.9_2)}$$

Where: B_o = emission potential (0.32m^3 CH_4/kg VS (IPCC 1997))

MCF = methane conversion factor. IPCC (1997) MCF value for 'warm' regions used for Queensland and the Northern Territory (2%) and MCF values for 'temperate' region used for all other States (1.5%)

ρ = density of methane (0.662 kg/m^3)

The annual methane production (Gg) from the manure of Australian poultry is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad \text{(4B.9_3)}$$

Where: N_{ij} = numbers of all types of poultry

M_{ij} = methane production (kg/head/day)

Nitrous Oxide

The nitrogen excretion from poultry was calculated based on an average intake for both layers and meat chickens of 0.11 kg DM/head/day, with approximately 19% crude protein for meat chickens and 16.5% for layers. If poultry are assumed to retain 43% of the nitrogen intake (McMenimen 2009), this gives rates of nitrogen excretion of 0.7 kg N/bird/year for meat chicken and 0.6 kg N/bird/year for layers.

The nitrogen excretion rates and manure management systems of other poultry types (e.g. turkeys and ducks) are assumed to be the same as for meat chickens.

Other Livestock

Methane

Goats, deer, buffalo, camels, alpaca, horses, donkeys, mules, emus and ostriches are range-kept livestock and hence, manure deposition typically occurs in a dispersed fashion. Little is known about the amount of manure produced by the livestock types in this group. In the absence of adequate information, it was assumed that the rates of manure production (DMM_{ij} kg DM/head/year) can be scaled to those calculated for either sheep or beef cattle based on the comparative size of the animals. For example, the default weight for horses (377 kg) and buffalo (380 kg) are consistent with the average weight of beef cattle (380 kg) while the default weight of donkeys (130 kg) and goats

(38.5 kg) are consistent with one third of beef cattle (127 kg) and sheep (45 kg) weights respectively.

Accordingly, the following assumptions were made:

- goats, alpacas, emus and ostriches are equivalent to those from a sheep (national average 114 kg/head/year)
- deer, donkeys and mules are one-third those of beef cattle (national average 319 kg/head/year)
- horses, buffalo and camels are equivalent to those of beef cattle (national average 957 kg/head/year).

Methane production from the manure (M_{ij} kg/head/day) is calculated as:

$$Mi_{jk} = DMM_{ij} \times MEF \quad \text{(4B.10_1)}$$

Where: DMM_{ij} = dry matter in manure Appendix 6.F.3

MEF = manure emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001). The warm factor is used for Qld and NT and the temperate factor is used for all other States.

The annual methane production (Gg) from the manure of other livestock is calculated as:

$$Total = \Sigma_i \Sigma_j (N_{ij} \times M_{ij}) \times 10^{-6} \quad \text{(4B.10_2)}$$

Where: N_{ij} = numbers of animals in each State

M_{ij} = methane production (kg/head/day)

Little is known about the nitrogen intake and nitrogen excretion rates of the remaining livestock types in this group. The IPCC *Guidelines* (IPCC 1997) provide a single N excretion rate for "other livestock" of 25 kg/head/year. In the absence of adequate species specific information, it was assumed that the rates of nitrogen excretion (E_{ij} kg/head/year) can be scaled to those calculated for either sheep or beef cattle based on the comparative size of the animals. Accordingly, the following assumptions were made:

- goats, alpacas, emus and ostriches are equivalent to those from a sheep (national average 7.0 kg/head/year);
- deer, donkeys and mules are one-third those of beef cattle (national average 13.2 kg/head/year); and
- horses, buffalo and camels are equivalent to those of beef cattle (national average 39.5 kg/head/year).

The annual nitrogen (AE_{ij} Gg/year) excreted from these types of livestock is calculated as:

$$AE_{ij} = (N_{ij} \times E_{ij}) \times 10^{-6} \quad \text{(4B.10_3)}$$

Where: N_{ij} = numbers in each State

E_{ij} = nitrogen excreted (kg/head/year) (Appendix 6.F.2)

The total emissions of nitrous oxide from the different manure management systems (E_{MMS} Gg) can then be calculated as follows:

$$E_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times MMS \times EF_{(MMS)} \times C_g) \quad \text{(4B.10_4)}$$

Where: MMS = the fraction of AE that is managed in the different manure management systems. The manure of all 'other livestock' classes with the exception of poultry is voided at pasture (MMS = 8). For poultry 3% is assumed to be voided at pasture (MMS = 8) and 97% into MMS = 6 for meat birds and MMS = 7 for layers.

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Table 6.12)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.3.3 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for manure management were estimated to be in the order of 10%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.3.4 Source Specific QA/QC

6.3.4.1 Activity data

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated.

Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Section 1.6. The QC procedure "ensuring consistency in data between categories" is of specific importance for this category. The AGEIS ensures that activity and livestock characterisation data used across multiple categories is entered only once and that intakes or emissions calculated in one category form the input for other categories.

6.3.4.2 Implied Emission Factors

Comparison with IPCC defaults

As country specific tier 2 methods are used to estimate emissions from cattle, sheep, pigs and poultry, the IEFs have been compared with the IPCC defaults (Table 6.14).

Table 6.14: Implied emission factors - CH_4 manure management (kg/head/year)

Livestock Type	Australia	IPCC Default (Oceania)	Reason for difference
Dairy Cattle	8.8	32-33	Different waste allocation, CS EF and estimated VS
Non-dairy cattle			
Range-kept	0.04	6-7	CS EF
Feedlot	2.91	6.7	Different waste allocation
Sheep	0.002	0.28-0.37	CS EF
Swine	23	20	Inclusion of waste feed
Poultry	0.04	0.117-0.157	Difference in estimated VS

CS = country specific; EF = emission factor; VS = volatile solids

The IEFs for dairy cattle differ from the IPCC defaults for three reasons:

a) allocation of waste to difference MMS. Australia assumes that at least 90% of waste is voided at pasture (based on average milking times) compared with 76% in the IPCC default;

b) for temperate regions Australia uses a slightly lower MCF for pasture/range than the IPCC default (1% vs 1.5%); and

c) average volatile solid production is lower than the IPCC default (Section 6.3.4.3).

The IEFs for range-kept non-dairy cattle, sheep and all other range kept animals are significantly lower than the IPCC defaults as a country specific EF is used (Section 6.3.2).

Trends in IEFs

As part of the standard tier 1 QC activities, IEFs are checked for possible anomalies in the time-series. As Australia uses tier 2 methods, which disaggregate animals by age class and regions (in which climate ranges from temperate to warm) some inter-annual variability can be expected in the IEFs for cattle, sheep, swine and poultry as the relative numbers in each age class and region change year to year.

6.3.4.3 Volatile solids

The major sources of methane emissions from manure management are from pigs, dairy cattle and feedlot cattle. As the intake calculation for cattle and the volatile solid calculations for pigs differ from the IPCC tier 2 methodology the estimated volatile solids were compared against the IPCC defaults. These were found to be comparable for pigs and feedlot cattle (Table 6.15). The volatile solid production of dairy cows was lower than the IPCC (1997) defaults for north American and western European dairy cows. The main difference from the defaults and the Australian methodology appear to be in the feed digestibility which is 60% in the IPCC *Guidelines*. When the average Australian digestibility (75%) is used with the other IPCC default data, volatile solid levels are similar to those in Australia.

Volatile solids for poultry are considerably lower than the IPCC default. The average intake for both layers and meat chicken is considered to be about 110 g DM/head/day with a digestibility of 80%. This gives volatile solids of 0.0202 kg/head/year. The IPCC default of 0.1kg VS/head/day is not feasible as this is almost the complete daily intake of poultry in Australia.

Table 6.15: Volatile solids (kg/head/day)

	Australia	IPCC defaults
Pigs		
Sows and Gilts (Default - 80kg)	0.4-0.54	0.5
Other Pigs (Default 28-50 kg)	0.22-0.28	0.3
Feedlot Cattle	1.98	2.02
Dairy Cows	3.5	
North American		5.23 (3.8)
Western Europe		5.08 (3.1)
Poultry	0.0202	0.1

Note. Volatile solid values in parenthesis are recalculated defaults using 75% digestibility.

6.3.4.4 Nitrogen excretion

The country specific estimates of nitrogen excretion were compared against the IPCC defaults (Table 6.16) and those reported by other Parties. Pig and poultry excretion rates are consistent with the IPCC (1997) defaults. Sheep excretion rates are significantly lower than the IPCC default but are comparable with those of other Parties applying Tier 2 methods (mean 9 (range 4-21)).

Excretion rates of range kept cattle are at the low range of the IPCC defaults. On reviewing other Parties' excretion rates (mean 51 (range 34-73)) many are estimating excretion rates lower than the IPCC defaults for their region. Australia would expect to be at the low end of the range of excretion rates due to the quality of pasture fed to range-kept cattle. As expected, excretion rates for feedlot cattle were higher than for range-kept animals.

Dairy cattle excretion rates are significantly higher than the IPCC defaults and the rates reported by other Parties. Unfortunately, unlike volatile solids, the IPCC *Guidelines* do not provide the data on which the default excretion/retention rates are based, so it is impossible to determine whether it is the assumption regarding feed quality causing the difference in excretion rates. This source had thus been identified as an area for future review.

Table 6.16: Nitrogen excretion rates (kg/head/day)

	Australia	IPCC defaults
Non-dairy cattle		40-70
Range-kept	40	
Feedlot	85	
Dairy cattle	117	60-100
Sheep	7	12-20
Pigs (sows)	20.7	16-20
Poultry	0.6-0.7	0.6

The current method for calculating nitrogen excretion from dairy cattle assumes that the intake of calves is all from pasture. Although, on average calves are fed milk replacer and feed pellets for six weeks until weaned onto pasture. In response to a recommendation from the 2009 UNFCCC expert review, an analysis was undertaken to determine what effect implementing the pre-weaning feeding regime would have on emissions. This analysis showed that while there would be minor increases in nitrogen excretion and N_2O from the manure management, overall emissions would be slightly lower as enteric fermentation emissions would be reduced. A revised method to include a pre-weaning animal class is currently being prepared and will be implemented in the inventory once it has undergone independent expert review.

In response to a recommendation from the 2008 UNFCCC expert review the N excretion rates for horse and donkeys (mules/assess) were reviewed. The tier 1 default N excretion rate for "other livestock" from the IPCC *Guidelines* (IPCC 1997) is 25 kg/head/year. The excretion rates for horses and donkeys used in the Australian inventory are assumed to be equivalent to rates calculated for beef cattle (39.5 kg) and one third of beef cattle (13.2 kg) respectively based on the comparative sizes of the animals.

The 2006 IPCC *Guidelines* (IPCC 2006) provide a different tier 1 method for estimating N excretion based on the weight of the animals. The IPCC default weight for horses (377 kg) is consistent with that for Australian beef cattle (380 kg) while the default for donkeys (130 kg) is consistent with one third of beef cattle (127 kg). Application of the default weights to the tier 1 2006 IPCC *guidelines* method gives N excretion rates of 41.3 and 14.2 for horses and donkeys respectively. These values are consistent with the values used in the Australian inventory. Based on these results it was concluded that no change in the N excretion rates was required as the rates based on Australia feed quality data are likely to produce more accurate estimates than the IPCC defaults.

6.3.4.5 External review

A comprehensive expert peer review of the methodologies, activity data and livestock characterisation data was conducted in 2000-01 involving agricultural experts from industry, government and academia.

6.3.5 Recalculations Since The 2011 Inventory

Emissions for the most recent year in the *agriculture* sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. In addition, lambing (2007, 2008, 2011) and calving rates (2009-2011), milk production (2011) and wool yields (2011) were updated and the allocation of sheep between age class was corrected for 2004-2005. Changes have also been made to the "other" livestock numbers (1992-2011) to correct errors and replace extrapolated data with interpolated data.

The net effect of these changes was no change to the 1990 estimate, a 0.2 Gg CO_2-e increase in the 2010 estimate and an 8 Gg CO_2-e increase in the 2011 estimate.

Table 6.17: 4.B Manure Management: recalculation of total CO_2-e emissions: 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	2,064	2,064	0	0.0
2000	3297	3297	0.0	0.00
2001	3359	3359	0.0	0.00
2002	3387	3387	0.0	0.00
2003	3385	3384	-0.1	0.00
2004	3438	3438	-0.2	-0.01
2005	3548	3548	-0.2	-0.01
2006	3595	3595	-0.1	0.00
2007	3492	3492	0.0	0.00
2008	3387	3387	0.0	0.00
2009	3293	3293	0.0	0.00
2010	3297	3297	0.2	0.01
2011	3252	3260	8.0	0.25

6.3.6 Source Specific Planned Improvements

The inventory improvement plan for the agriculture sector identifies areas which require updating or review over the next two years. The improvement plan identifies changes which will be required to implement the proposed revision to the UNFCCC Reporting Guidelines for the 2015 submission (Decision 15/CP.17), as well as any issues identified through the UNFCCC expert reviews, domestic QA/QC process or the expected availability of new data or empirical studies which could improve accuracy of the inventory.

For manure management the following areas have been identified for review and/or change:

1. *Pig method* – The Pigbal model used derive input data for the emissions estimates is currently being upgraded by the Queensland Department of Agriculture, Fisheries and Forestry to improve the accuracy of manure production. Once the upgraded model is available (expected in early 2014) a review of the pig method will be conducted.

2. *Pre-weaning animal classes* – Previous UNFCCC ERT's have identified the need to include a pre-weaning class for dairy cattle to better reflect the effects of milk intake on CH_4 and N_2O emissions. A revised method for dairy calves is currently being prepared and will be implemented in the inventory once it has undergone independent expert review. Over the next two years the methods for beef calves and lambs will also be reviewed.
3. *Manure manage system allocations / feed and animal characteristics* - As these allocations and characteristic can change as industry practices change over time the current values need to be reviewed periodically. The pig, feedlot and dairy industries have been identified as priorities for review.

The Reducing Emissions from Livestock Research Program, managed by DAFF, also includes a research project related to manure management emissions which was completed in 2012. This project will provide better estimates for indirect emissions from the deposition of ammonium from composted manure and urine deposition as well as nitrous oxide emissions from the deposition of urine. Once the results are available the current methods with be reviewed.

6.4 Source Category 4.C Rice Cultivation

6.4.1 Source Category Description

Methane is generated during rice growing from the decomposition of plant residues and other organic carbon material in the soil. This generation occurs through microbial action under anaerobic conditions following flooding of the rice crop.

Methane emission rates vary widely, both diurnally in response to immediate environmental factors such as temperature, and also throughout the season in response to crop development and accompanying changes in soil condition. Emission rates are also dependent on more stable factors including soil type and cultivation method (e.g. irrigation regimes, fertiliser application).

All Australian rice is grown under flooded cultivation and production is highly influenced by availability of water for irrigation. Australian rice culture does not have the large inputs of organic matter as rice stubble is usually burnt and urea fertilisers are used rather than manures.

6.4.2 Methodology

For the purpose of estimating the emission rate of CH_4 from rice grown in Australia, the extensive data compilation of field measurements of CH_4 emissions from rice in Texas, USA made by Sass (1994) and Sass and Fisher (1994) is used. The climate and agronomic practice of growing rice in Australia is similar to that in the USA and it is therefore assumed that the rate of emission of methane from rice fields is the same (J.R. Freney and P.E. Bacon, pers. comm.).

The range of 0.5 to 5.5 kg CH_4/ha/day given by Sass (1994) and Sass and Fisher (1994) as the summary of extensive measurements in the USA is used in the estimation of CH_4 emissions from rice in Australia. A seasonally weighted average of this data of 1.5 kg CH_4/ha/day or 225 kg CH_4/ha for the 150 day growing season has been selected as the appropriate average emission rate for Australia.

Table 6.18: Symbols used in algorithms for rice cultivation

State (i)	Activity (j)
1 = NSW	1 = rice cultivation
2 = Tas	
3 = WA	
4 = SA	
5 = Vic	
6 = Qld	
7 = NT	
8 = ACT	

Annual production of methane from rice cultivation is calculated as:

$$E_{ij} = A_{ij} \times EF_j \times 10^{-6} \quad (4C_1)$$

Where: E_{ij} = annual emission (Gg)

A_{ij} = area under rice cultivation (ha).

EF_j = emission factor integrated over the whole season (225 kg CH_4/ha).

6.4.3 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for rice cultivation were estimated to be in the order of 20%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

6.4.4 Source Specific QA/QC

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is one of the providers of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated.

Data quality used in the inventory is also kept under review by the DE. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.4.5 Recalculations Since The 2011 Inventory

Emissions for the most recent year in the *agriculture* sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. This resulted in a 0.4% decrease in emissions in 2011. There have been no other recalculations since the 2011 inventory.

Table 6.19: 4.C Rice Cultivation: recalculation of total CO_2-e emissions (Gg), 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	490	490	0	0.0
2000	741	741	0	0.0
2001	738	738	0	0.0
2002	589	589	0	0.0
2003	399	399	0	0.0
2004	237	237	0	0.0
2005	341	341	0	0.0
2006	265	265	0	0.0
2007	196	196	0	0.0
2008	43	43	0	0.0
2009	46	46	0	0.0
2010	177	177	0	0.0
2011	330	328	-1	-0.4

6.4.6 Planned Improvements

All data and methodologies are kept under review.

6.5 Source Category 4.D Agricultural Soils

6.5.1 Source Category Description

The emissions of nitrous oxide from soils arise from microbial and chemical transformations that produce and consume nitrous oxide in the soil. These transformations involve inorganic nitrogen compounds in the soil, namely ammonium, nitrite and nitrate. These nitrogen compounds can be added to the soil through the following processes:

a) the application of nitrogen fertilisers

b) the application of animal wastes and sewage sludge to pastures

c) biological nitrogen fixation

d) the application of crop residues

e) mineralisation due to cultivation of organic soils

f) atmospheric nitrogen deposition

There is a further source of nitrous oxide associated with the leaching from soils and surface runoff of nitrogen and subsequent denitrification in rivers and estuaries.

6.5.2 Methodology

6.5.2.1 Synthetic Fertiliser

In Australia, synthetic nitrogen fertiliser is applied to a wide range of crops and pastures. The major proportion is applied to rainfed (and relatively low yielding [1-3 t/ha]) cereal grains, and to a lesser degree to sown pastures used for intensive grazing systems. The recommended application rates for these systems, at maximum, 80 kg N/ha for cereal crops and approximately 40 kg N/ha for sown pastures is low relative to international practice. More intensive cropping systems, cotton, sugar cane, irrigated summer crops and horticultural crops require higher rates of synthetic nitrogen application ranging up to 300 kg N/ha.

Recent experimental work on the application of fertilisers to different crop types in Australia and internationally has shown large variations from the IPCC default EF of 1.25% across different classes of crop and pasture systems. Variation in EFs with region and cropping system is to be expected. For example, more than 75% of Australia's cereal production is in low-rainfall regions (<550 mm annual rainfall) with porous soils where both nitrification and the denitrification potential is low. Also, in many of these cropping systems the substantial use of nitrogen fertiliser is a recent practice, with nitrogen use increasing extremely rapidly from a low base in the early 1980s. Consequently, in contrast to European and North American agriculture, there has been little accumulation of soil nitrogen from previous cropping which might predispose these soils to substantial background N_2O emission rates. Finally, it is now becoming more apparent that EFs increase with both the nitrogen application rate and where either irrigation is applied or rainfall exceeds 550mm annually. Consequently, high EFs are obtained when application rates, high soil moisture content and timing of fertiliser application produce soil nitrate levels substantially in excess of plant demand.

The majority of Australian grain production is from rain-fed cultivation in relatively low rainfall areas where the research found much lower EFs (Table 6.20) than the IPCC default EF (1.25%). This difference is largely due to lower rates of nitrogen fertiliser inputs, lower decomposition rates and lower levels of microbial activity (Barton *et al.* 2008) which contribute to a lower denitrification potential. The average EF for rain-fed crops in dryland regions is 0.08% (0.02 to 0.14%). For high-rainfall crops the IPCC default EF of 1.25% is used. From the disaggregation of crop production areas into leaching, non-leaching and irrigated, as defined in the next section, 81% of rain-fed crop production occurs in dryland areas where the lower EF is applicable. Weighting the emission factors by the area of rain-fed cropping in dryland areas yields a national average emission factor for rainfed crops of 0.3%.

Table 6.20: Measured N_2O emission factors from agricultural systems in Australia

Reference	Site	Crop	Treatment [(a)]	EF(%)
Low rainfall crops				
Barker-Reid *et al.* (2005)	Rutherglen, VIC	Rainfed wheat	Cultivation 83N	0.06
			Direct Drill 83N	0.11
Barton *et al.* (2008)	Cundedin, WA	Rainfed wheat	Residue retained 100N	0.02
Barton *et al.* (2010)	Cundedin, WA	Rainfed canola	Residue retained 75N	0.06
Officer *et al.* (2010)	Horsham, VIC	Rainfed wheat	Minimum Till 50N	0.14
Irrigated crops				
Galbally *et al.* (2005)	Griffith, NSW	Irrigated maize	Stubble burning 300N	2.8
			Stubble retention 300N	1.6
Irrigated pastures				
Galbally *et al.* (2005)	Kyabram, VIC	Irrigated dairy pasture	Urine 1000N	0.4-0.5
			Urea 150N	0.4-0.5
Irrigated cotton				
Galbally *et al.* (2005)	Narrabri, NSW	Irrigated cotton (C) in rotation with vetch (V) and wheat (W)	(Rotation sequence)	
			CC 100N	0.03
			CC 200N	0.24
			WVC 100N	0.39
			WVC 200N	0.51
			WVC 300N	2.47
			WC 100N	0.09
			WC 200N	0.26

Notes: (a) Annual application rates of fertiliser nitrogen in kg N/ha are listed with the treatments.

Irrigated crops, particularly summer crops (e.g. maize), typically receive high rates of N-fertiliser of up to 300 kg N/ha in conditions which favour denitrification. In soils amended by stubble retention higher soil porosity tends to mitigate these rates to some degree. Stubble retention is applied to approximately 50% of irrigated summer row crops, therefore an EF of 2.1%, (the average of the incorporated and standard stubble treatments) is used to estimate emissions from irrigated crops and horticultural crops and vegetables.

Several studies of both urine and urea application to grazed pastures have been undertaken in Australia (Gabally *et al.* 1994; 2005). Since the nitrogen content of urine is principally urea there is typically little difference between losses of N_2O from synthetic or animal-source urea (Table 6.20). These local studies indicate that an EF of 0.4% is appropriate for nitrogen fertilisers applied to both irrigated and sown pastures in Australia. Similar EFs have been reported from well drained silty loam soils in New Zealand (de Klein *et al.* 2003) where the agricultural practices are similar to Australia.

Average nitrogen application rates for cotton are 200 kg N/ha, therefore an EF of 0.5 is considered to be a conservative estimate, based on the ranges presented in Table 6.20, and is used to estimate emissions.

The IPCC default EF of 1.25% is currently used to estimate emissions from sugar cane. The results from recent Australian measurement studies are being reviewed with a view to developing a country-specific emission factor for use in future inventories.

The emission factors used in the inventory are summarised in Table 6.22.

Calculation of fertiliser applied to each production system

Total fertiliser use in each State is provided by FIFA. The fraction of fertiliser applied to each production system (FN_{ijk}) was determined for each State by first estimating the mass of N-fertiliser applied to irrigated crops, irrigated pasture, cotton, sugar cane and horticulture using the production areas reported by ABS (e.g. ABS 2010b) and the average fertiliser application rates for each of these crops. The balance of the fertiliser is then distributed to rain-fed crops and modified pastures (derived from Stewart *et al.* 2001) in proportion to their respective areas. The fertiliser application rates assigned to irrigated crops, irrigated pastures, cotton, and horticultural crops and vegetables are respectively 80 kg N/ha, 40 kg N/ha, 200 kg N/ha, and 125 kg N/ha. For sugar cane, a variable application rate is used (see Table 6.H.2). Sugar cane fertiliser application rates in QLD have declined significantly over the time series in response to environmental management legislation.

Table 6.21: Symbols used in algorithms for synthetic fertiliser

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = Synthetic fertilisers	1 = Irrigated pasture
2 = Tas		2 = Irrigated crop
3 = WA		3 = Non-irrigated pasture
4 = SA		4 = Non-irrigated crop
5 = Vic		5 = Sugar cane
6 = Qld		6 = Cotton
7 = NT		7 = Horticulture
8 = ACT		

Table 6.22: Nitrous oxide emissions factors for synthetic fertiliser

Production System	Emission Factor (Gg N_2O-N/ Gg N)
Irrigated pasture	0.004
Irrigated crop	0.021
Non-irrigated pasture	0.004
Non-irrigated crop	0.003
Sugar cane	0.0125
Cotton	0.005
Horticulture	0.021

Notes: These EF are based on total fertiliser N applied, not the fraction post volatilisation. Hence equation 4D1_1 differs from the calculation of F_{sn} in equation 4.22 of the IPCC *Good Practice Guidance* (2000).

Limited amounts of fertiliser are also used in Australian forests. Currently there is no data available to allocate fertiliser use specifically to forestry activities. Given the approach taken to allocating fertiliser, it is assumed that any fertiliser applied for forestry activities will fall under the non-irrigated grassland system and have an EF of 0.4% applied. The non-irrigated grassland EF is considered appropriate for forestry activities as most fertiliser would be applied to plantations, many of which are established on pasture systems.

The mass of fertiliser applied to soils is calculated as

$$M_{ijk} = TM_{ij} \times FN_{ijk} \quad \text{(4D1_1)}$$

Where: M_{ijk} =mass of fertiliser applied to production system k (Gg N)

T_{Mij} = total mass of fertiliser (Gg N)

FN_{ijk} =fraction of N applied to production system k (Appendix 6.H)

Annual nitrous oxide production from the addition of synthetic fertilisers is calculated as:

$$E_{ijk} = \Sigma_i \Sigma_j \Sigma_k (M_{ijk} \times EF_{ijk} \times C_g) \quad \text{(4D1_2)}$$

Where: E_{ijk} = annual emissions from fertiliser (Gg N_2O)

M_{ijk} = mass of fertiliser in production system k applied (Gg N)

EF_{jk} = emission factor (Gg N_2O-N/Gg N applied) (Table 6.22)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.2 Animal Wastes Applied to Soils

Nitrous oxide is emitted from soil through the metabolism of animal manure derived principally from dairies, feedlots, piggeries and poultry houses and applied to crops and pastures as organic fertiliser. The current IPCC default EF for the N_2O emissions from animal nitrogen deposition to pasture is 2% based on emission studies in which synthetic fertiliser, animal urine and faeces, animal manure or combinations of these were applied to pastures. In 2002, Bouwman *et al.* published a summary of experimental studies of this type. In reviewing the experiments in which animal manure alone was applied to crops and pastures (Table 6.23) it suggests that while the potential range of emissions is large (0.04% to 3.3% of applied N), the average is lower than the IPCC default EF. It appears that it is primarily the organic manures which have the higher EFs while wastes from waste management systems and animal houses are less active sources.

The average of the generic class 'organic', sewage sludge and wastes from animal waste management systems (0.4%), gives an EF of 1% (0.01 Gg N_2O-N/Gg N deposited) for manure spread on pastures and crops. Inputs to this subsector are calculated in section 6.3.

Table 6.23: N_2O emissions factors (% applied N) for manure applied to crops and pastures

Fertilizer type	Mean	Range
Organic	1.56	0.21 - 3.31
Sewage sludge	0.90	0.80 - 1.00
AWMS effluent	0.40	
Cattle slurry	*0.25*	*0.04 - 0.57*
Pig slurry	*0.45*	*0.17 - 0.95*
Poultry litter	*0.50*	*0.50 - 0.50*

Source: Bouwman *et al.* 2002

Table 6.24: Symbols used in algorithms for animal wastes

State (i)	Activity (j)	Subset (k)	Manure Management Systems (MMS)
1 = NSW	1 = manure applied to soils	1 = dairy cattle	1 = Anaerobic lagoon
2 = Tas		2 = feedlot cattle	2 = Liquid systems
3 = WA		3 = pigs	3 = Daily spread
4 = SA		4 = other livestock	4 = Solid storage and drylot
5 = Vic			5 = Digester
6 = Qld			6 = Poultry manure with bedding
7 = NT			7 = Poultry manure without bedding
8 = ACT			8 = Pasture range and paddock

The amount of nitrogen applied to soils is the nitrogen excreted adjusted for the nitrogen that has already been lost as N_2O, NH_3 and NO_x during storage in the different manure management systems.

Thus the nitrogen content of animal manure applied to agricultural soils (4D1b) is calculated as:

$$MN\ Soil = \Sigma_{MMS=1\text{-}7}\ ((AE_{ij} \times MMS_{=1\text{-}7}) - (E_{MMS=1\text{-}7} / C_g) - MNatmos_{iMMS=1\text{-}7}) \quad (4D1_3)$$

Where: AE = mass of nitrogen excreted as calculated in section 6.4. For dairy and feedlot cattle AE is the sum of faecal (AF) and urinary (AU) nitrogen.

MMS = the fraction of AE that is managed in the different manure management systems.

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

$E_{MSS=1\text{-}7}$ = total emissions of nitrous oxide from the different manure management systems as estimated in section 6.4

$MNatmos_{mms}$ = mass of animal wastes N volatilised as calculated in section 6.5.2.8 Atmospheric deposition

Annual nitrous oxide production is calculated as:

$$E_{ijk} = \Sigma_i \Sigma_j \Sigma_k\ (MN\ Soil_{ijk} \times EF_j \times C_g) \quad (4D1_4)$$

Where: E_{ijk} = annual emission from animal waste (Gg N_2O)

$MN\ Soil_{ijk}$ = mass of nitrogen in manure applied to agricultural soils (Gg N) (as calculated above)

EF_j = emission factor (Gg N_2O-N/Gg N deposited)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.3 Nitrogen Fixing Crops

The method used to estimate emissions from N fixing crops and pastures is based on the IPCC tier 1b method and emission factor but uses country-specific crop and pasture information.

Table 6.25: Symbols used in algorithms for N fixing crops

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = N fixing crops	1 = Pulse
2 = Tas		2 = Legume Pasture
3 = WA		3 = Peanuts
4 = SA		
5 = Vic		
6 = Qld		
7 = NT		
8 = ACT		

The mass of N fixed by crops and legume pastures is calculated as:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \quad \text{(4D1_5)}$$

Where: M_{ijk} = mass of N fixed by crops and pastures (Gg N)

P_{ik} = annual production of crop (Gg)

R_k = residue to crop ratio (kg crop residue/kg crop) (Appendix 6.I)

DM_k = dry matter content (kg dry weight/kg crop residue) (Appendix 6.I))

CC_k = mass fraction of carbon in crop residue (Appendix 6.I))

NC_k = nitrogen to carbon ratio in crop residue (Appendix 6.I))

Annual nitrous oxide production is calculated as:

$$E_j = \Sigma_i \Sigma_k (M_{jkl} \times EF_{ijk} \times C_g) \quad \text{(4D1_6)}$$

Where: E_j = annual emissions from N fixing crops (Gg N_2O)

M_{ijk} = mass of N fixed by crops and pastures (Gg N)

EF_j = 0.0125 (Gg N_2O-N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.4 Crop Residues

The method used to estimate emissions from crop residues returned to the soil is based on the IPCC tier 1b method and emission factor but uses country-specific crop information.

Table 6.26: Symbols used in algorithms for crop residues

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = crop residues	1=Wheat
2 = Tas		2=Barley
3 = WA		3=Maize
4 = SA		4=Oats
5 = Vic		5=Rye
6 = Qld		6=Rice
7 = NT		7=Millet
8 = ACT		8=Sorghum
		9=Triticale
		10=Pulse
		11=Tuber and Roots
		12=Sugar Cane
		13=Peanuts
		14=Other Crops

The mass of N in crop residues returned to soils is calculated as:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \times (1 - F_{ik} - FFOD_{ik}) \quad \text{(4D1_7)}$$

Where: M_{ijk} = mass of N in crop residues (Gg N)

P_{ik} = annual production of crop (Gg)

R_k = residue to crop ratio (kg crop residue/kg crop) (Appendix 6.I)

DM_k = dry matter content (kg dry weight/kg crop residue) (Appendix 6.I)

CC_k = mass fraction of carbon in crop residue (Appendix 6.I)

NC_k = nitrogen to carbon ratio in crop residue (Appendix 6.I)

F_{ik} = fraction of the crop that is burnt (Appendix 6.I)

$FFOD_{ik}$ = fraction of the crop that is removed (Appendix 6.I)

Annual nitrous oxide production is calculated as:

$$E_j = \Sigma_i \Sigma_k (M_{ijk} \times EF_{ijk} \times C_g) \quad \text{(4D1_8)}$$

Where: E_j = annual emissions from crop residues (Gg N_2O)

M_{ijk} = mass of N in crop residues (Gg N)

EF_j = 0.0125 (Gg N_2O-N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

6.5.2.5 Cultivation Of Histosols

The default IPCC tier 1 methodology is used to estimate emissions from the cultivation of histosols.

The areas of cultivated histosols are very small in Australia occurring only in Queensland where they are mostly used for sugar cane production and small locations of Gippsland and Western Victoria where peatlands were cleared and subsequently grazed or cropped. The individual patches are typically very small, which leads to significant uncertainty when estimating the national area.

Table 6.27: Symbols used in algorithms for cultivation of histosols

State (i)	Activity (j)
1 = NSW	1 = cultivation of histosols
2 = Tas	
3 = WA	
4 = SA	
5 = Vic	
6 = Qld	
7 = NT	
8 = ACT	

Annual nitrous oxide production is calculated as:

$E_j = \Sigma_i (A_{ij} \times EF_{ij} \times C_g \times 10^{-6})$ ..... (4D1_9)

Where: E_j = annual emissions from cultivation of histosols (Gg N_2O)

A_{ij} = area of cultivated histosols (ha)

EF_{ij} = 8 kg N_2O-N/ha. IPCC (2000) default emissions factor for mid-latitude organic soils

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.6 Sewage Sludge Applied to Land

Treated sewage sludge is applied to land in Australia for the purposes of disposal rather than as a fertiliser for agricultural production due to health concerns. A country specific emission factor based on experimental studies where sewage sludge was applied to soils (Bouwman *et al.* 2002) is used to estimate emissions. The experiments gave an average N_2O emissions factor of 0.9% (0.8 to 1.0%)(Table 6.23) which is lower than the IPCC default of 1.25%.

Table 6.28: Symbols used in algorithms for Sewage sludge applied to lands

State (i)	Activity (j)
1 = NSW	1 = Sewage sludge applied to land
2 = Tas	
3 = WA	
4 = SA	
5 = Vic	
6 = Qld	
7 = NT	
8 = ACT	

Annual nitrous oxide production is calculated as:

$E_j = \Sigma_i (A_{ij} \times EF_{ij} \times C_g)$ ..... (4D1_10)

Where: E_j = annual emissions from treated sewage sludge applied to lands (Gg N_2O)

M_{ij} = Mass of sewage sludge N applied to lands (Gg)

EF_{ij} = 0.009 (Gg N_2O-N/Gg N).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.7 Animal Production

Nitrous oxide is emitted from soil through the metabolism of urine and faeces deposited directly on pastures. The current IPCC default EF for the N_2O emissions from animal nitrogen deposition to pasture is 2% based on emission studies in which synthetic fertiliser, animal urine and faeces, animal manure or combinations of these were applied to pastures.

There are still relatively few measurements of EFs from animal faeces deposited directly to soil in the absence of urine. Nitrogen in faecal matter is primarily organic and therefore must first be mineralised before it becomes a source of N_2O. In regions of higher rainfall this occurs at significant rates, however in dryland regions, decay of deposited faeces is much slower, with the faeces remaining largely intact for months to years. Approximately 55% of sheep and 65% of beef cattle are grazed in dryland areas. Table 6.29 reports three studies where N_2O emissions from soil to which animal faeces had been added. The average EF, 0.5%, is used to estimate N_2O emissions from animal faecal deposition to soil.

The EF for urine deposition to soil is assumed to be 0.4% of applied N based on experiments conducted on rainfed legume and annual pastures at Book Book, central NSW (Galbally *et al.* 1994), and irrigated pastures in Kyabram, Victoria (Galbally *et al.* 2005).

Table 6.29: Animal waste-derived N_2O emissions: (% of N deposited emitted as N_2O-N)

Application	Per cent nitrogen emitted as N_2O	Reference
Faeces		
Cattle faeces	0.5	Flessa *et al.* (1996)
Dung	0.3	Yamulki and Jarvis (1997)
Animal faeces	0.7	Oenema *et al.* (1997)

In summary, EFs of 0.005 and 0.004 Gg N_2O-N/Gg N deposited are considered to be appropriate for nitrous oxide emissions from faeces, and urine voided in the field by grazing livestock respectively. Inputs to this subsector are calculated in section 6.3.

Table 6.30: Symbols used in algorithms for animal production

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = urine excreted on pastures	1 = dairy cattle
2 = Tas	2 = faeces excreted on pastures	2 = beef cattle
3 = WA		3 = sheep
4 = SA		4 = other livestock
5 = Vic		
6 = Qld		
7 = NT		
8 = ACT		

Thus the faecal and urinary nitrogen excreted on pasture range and paddock (4D2) is calculated as:

$$FN\ Soil = \Sigma_{MMS=8} (AF_{ij} \times MMS_{=8}) \quad (4D2_1)$$

$$UN\ Soil = \Sigma_{MMS=8} (AU_{ij} \times MMS_{=8}) \quad (4D2_2)$$

Where: AF and AU = mass of faecal and urinary nitrogen excreted as calculated in section 6.3. For the 'other livestock' class category AF is calculated as AE x PMF and AU is calculated as AE x PMU.

$MMS_{=8}$ = the fraction of nitrogen that is managed on pasture range and paddock.

AE = total mass of nitrogen excreted

PMF = the proportion of waste that is faeces. Assumed to be 0.29 (based on average of cattle and sheep) for all 'other livestock' classes except poultry, For poultry PMF is assumed to be 1.

PMU = the proportion of waste that is urine. Assumed to be 0.71 (based on average of cattle and sheep) for all 'other livestock' classes except poultry, For poultry PMU is assumed to be 0.

Annual nitrous oxide production is calculated as:

$$E_{ijk} = \Sigma_i \Sigma_j \Sigma_k ((FN\ Soil_{ijk} \times EF_j \times C_g) + (UN\ Soil_{ijk} \times EF_j \times C_g)) \quad (4D2_3)$$

Where: E_{ijk} = annual emission from animal waste (Gg N_2O)

EF_j = emission factor (Gg N_2O-N/Gg N deposited)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.8 Atmospheric Deposition

The default IPCC tier 1 methodology is used to estimate emissions from the atmospheric deposition. Country-specific values are applied for FracGASM. During a review of this category in 2005 it was identified that losses of N during waste treatments can be significantly higher than the IPCC default value of 0.2 (IPCC 1997) and can vary significantly between treatment types (e.g. Kruger *et al.* 1995). Australia has used the FracGASM values from the 2006 IPCC Guidelines (IPCC 2006 – Table 10.22) as they provide values that are consistent with the IPCC manure management system reporting categories and were derived from a synthesis of the available literature.

Table 6.31: Symbols used in algorithms for atmospheric deposition

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = Atmospheric deposition	1=Synthetic fertiliser
2 = Tas		2=Manure
3 = WA		3=Savanna burning
4 = SA		4=Field burning of agricultural residues
5 = Vic		5 =Sewage sludge applied to land
6 = Qld		
7 = NT		
8 = ACT		

The mass of N fertiliser volatilised is calculated as:

$M_{ijk=1} = TM_{ijk=1} \times FracGASF_j$ ..... (4D3_1)

Where: $M_{ijk=1}$ =mass of synthetic fertiliser volatilised (Gg N)

TM_{ijk} = total mass of fertiliser (Gg N)

$FracGASF_j$ = 0.1 (Gg N/Gg applied) IPCC default fraction of synthetic fertiliser N that volatilised as NH_3- N and NO_x-N. .

The mass of animal waste volatilised is calculated as:

$M_{ijk=2} = \Sigma_{MMS} (AE \times MMS \times FracGASM_{MMS})$ ..... (4D3_2)

Where: AE = mass of nitrogen excreted as calculated in section 6.4. For cattle and sheep AE is the sum of faecal (AF) and urinary (AU) nitrogen.

MMS = the fraction of AE that is managed in the different manure management systems.

$FracGASM_{MMS}$ = the fraction of N volatilised in each manure management systems (Table 6.32).

Table 6.32: Fraction of N volatilised in each manure management system (FracGASM)

	Dairy Cattle	Feedlot Cattle	Swine	Other
Anaerobic lagoon	0.35		0.4	
Liquid slurry	0.4		0.48	
Solid storage	0.3		0.45	
Drylot	0.2	0.3	0.45	
Daily spread	0.07		0.07	
Pasture range and paddock	0.2			0.2
Digester			0	
Poultry manure with bedding				0.4
Poultry manure without bedding				0.55

Source: IPCC 2006 (Table 10.22)

The mass of savanna burning and field burning of agricultural residue NO_x-N emissions that volatilise is calculated as:

$M_{ijk=3,4} = (E_{ik=3,4} / (46/14))$ ..... (4D3_3)

Where: M_{ijk} = mass of N volatilised from savanna burning and field burning of agricultural residues NO_x emissions (Gg N)

$E_{ik=3,4}$ = NO_x emissions from savanna burning and field burning of agricultural residues (Gg NO_x) as estimated in sections 6.6 and 6.7

46/14 = factor to convert elemental mass of NO_x to molecular mass

The mass of sewage sludge N volatilised is calculated as:

$M_{ijk=1} = TM_{ijk=5} \times FracGASS_j$ ..... (4D3_4)

Where: $M_{ijk=5}$ =mass of sewage sludge volatilised (Gg N)

TM_{ijk} = total mass of sewage sludge (Gg N)

$FracGASS_j$ = 0.2 (Gg N/Gg applied) IPCC default fraction of sewage sludge that volatilises as NH_3-N and NO_x-N.

Annual nitrous oxide production from atmospheric deposition is calculated as:

$$E = \Sigma_i \Sigma_k (M_{ijk} \times EF_{ijk} \times C_g) \quad \text{(4D3_5)}$$

Where: E = annual emissions from atmospheric deposition (Gg N_2O)

M_{ijk} = mass of N volatilised from subset k (Gg N)

EF_{jk} = 0.01 (Gg N_2O-N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.2.9 Leaching And Runoff

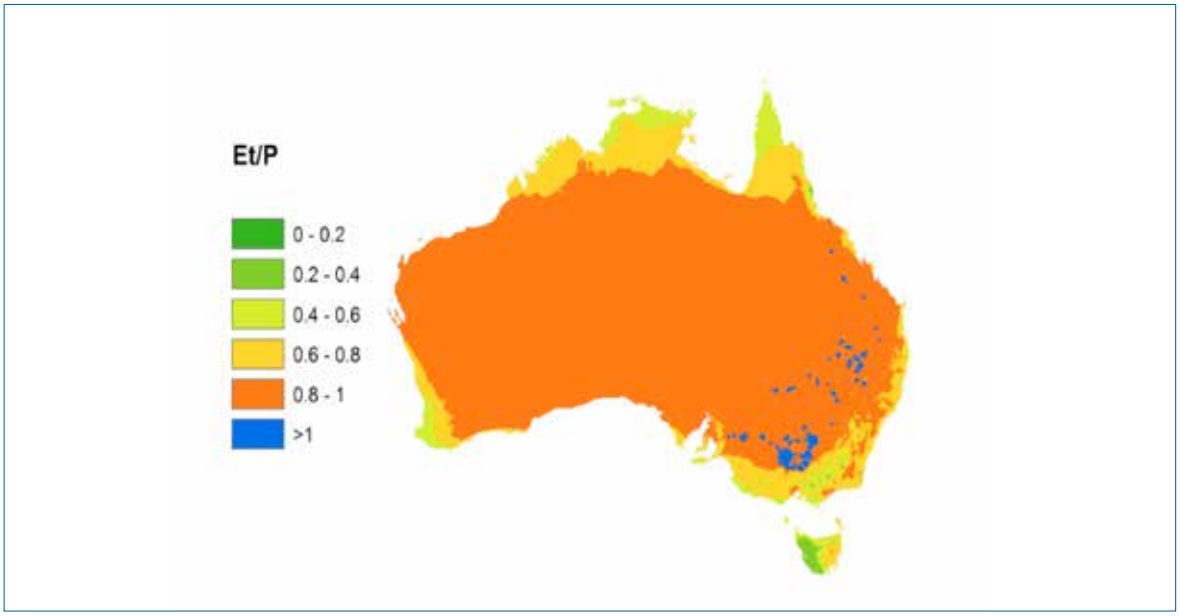
Australia is the driest continent, with substantially less runoff than all other continents. In Australia, much of the cropping takes place in semi-arid regions, or regions of marginal rainfall. The revised 1996 IPCC methodology makes no allowance for reduced rates of leaching in regions of low rainfall and/or high evaporative demand. However, in the 2006 IPCC *Guidelines* it is accepted that leaching of applied nitrogen into waterways and estuaries is unlikely where evaporation exceeds precipitation.

The areas of Australia which are unlikely to be susceptible to significant leaching can be identified using the ratio of evapotranspiration to annual precipitation (Et/P). Evapotranspiration is a better measure than evaporation as it takes into account climatic factors (rainfall, humidity, temperature, wind speed) as well as the effect of differences in vegetation classes (forest, shrubland, grassland) on the demand for soil water.

Evapotranspiration has been estimated using the biogeochemical model BIOS (Raupach *et al.* 2000) for the National Land and Water Audit. Et/P ranges up to 1 where all rainfall is returned to the atmosphere. In areas such as wetlands and irrigation areas in inland regions, where water supply additional to precipitation is available Et/P can exceed 1.

In this methodology, we consider leaching to occur where Et/P <0.8 or Et/P >1 (Figure 6.4). Regions outside these areas are considered to be 'dryland' and not subject to leaching. The fraction of each crop and animal class occurring outside the dryland areas (Frac WET) were determined by overlaying the dryland area mask onto the spatial map of crops, pastures and animal density from the 1997 Agricultural census.

Figure 6.3: The ratio of mean annual evapotranspiration to annual precipitation (Et/P)



Agriculture

The IPCC EF for leaching and runoff incorporates three components which are the factors for groundwater and surface drainage (0.015), rivers (0.0075), and estuaries (0.0025). Recent studies indicated that the previously used factor for groundwater and surface drainage was too high and should be reduced to 0.0025 kg N_2O-N/kg N (Reay *et al.* 2004, Sawamoto *et al.* 2005). Therefore, the EF has been changed from the IPCC default of 0.025 to 0.0125 kg N_2O-N/kg N leached/runoff as recommended in the 2006 IPCC *Guidelines* (IPCC 2006).

Table 6.33: Symbols used in algorithms for leaching and runoff

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = Leaching and runoff	1 = Synthetic fertiliser
2 = Tas		2 = Animal waste
3 = WA		3 = Sewage sludge
4 = SA		
5 = Vic		
6 = Qld		
7 = NT		
8 = ACT		

The mass of fertiliser N applied to soils that is lost through leaching and runoff is calculated as:

$$M_{ijk=1} = M_{ik} \times FracWET_{ik} \times FracLEACH_j \quad \text{(4D3_6)}$$

Where: M_{ijk}=1 = mass of synthetic fertiliser lost through leaching and runoff (Gg N)

M_{ik} = mass of fertiliser in each production system (Gg N)

$FracWET_{ik}$ = fraction of N available for leaching and runoff (Appendix 6.J.1)

$FracLEACH_j$ = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff. .

The mass of animal waste N applied to soils that is lost through leaching and runoff is calculated as:

$$M_{ijk=2} = (MNsoil_{ik} + UNsoil_{ik} + FNsoil_{ik}) \times FracWET_{ik} \times FracLEACH_j \quad \text{(4D3_7)}$$

Where: $M_{ijk=2}$ = mass of animal waste N lost through leaching and runoff (Gg N)

$MNsoil_{ik}$ = mass of manure N applied to soils (Gg N) as calculated in the section 6.5.2.2 (Animal Wastes Applied to Soils)

$UNsoil_{ik}$ = mass of urinary N applied to soils (Gg N) as calculated in the section 6.5.2.7 (Animal Production)

$FNsoil_{ik}$ = mass of faecal N applied to soils (Gg N) as calculated in the section 6.5.2.7 (Animal Production

$FracWET_{ik}$ = fraction of N available for leaching and runoff (Appendix 6.J.2)

$FracLEACH_j$ = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

The mass of sewage sludge N applied to soils that is lost through leaching and runoff is calculated as:

$$M_{ijk=1} = M_{ik} \times FracWET_{ik} \times FracLEACH_j \quad \text{(4D3_8)}$$

Where: M_{ijk}=1 = mass of sewage sludge lost through leaching and runoff (Gg N)

M_{ik} = mass of sewage sludge in each production system (Gg N)

$FracWET_{ik}$ = fraction of N available for leaching and runoff = 1.0

$FracLEACH_j$ = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff. .

Annual nitrous oxide production from leaching and runoff is calculated as:

$$E = \Sigma_i \Sigma_k (M_{ijk} \times EF_{ijk} \times C_g) \quad (4D3_9)$$

Where: E = annual emissions from leaching and runoff (Gg N_2O)

M_{ijk} = mass of N lost through leaching and runoff (Gg N)

EF_{jk} = 0.0125 (Gg N_2O-N/Gg N)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.5.3 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for agricultural soils were estimated to be in the order of –30 to +50%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

6.5.4 Source Specific QA/QC

6.6.4.1 Quality Control

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by DE.

This source category is also covered by the general QA/QC procedures detailed in Section 1.6. The QC procedure 'ensuring consistency in data between categories' is of specific importance for this category. The AGEIS ensures that data used across multiple categories is entered only once and that intakes or emissions calculated in one category form the input for other categories.

6.6.4.2 Quality Assurance

As data from additional research studies into the fertiliser EFs are published the results are used to QA the selected CS EFs. For example:

- *Irrigated pasture* - the study by Phillips *et al.* (2007) has been used to QA the EF for irrigated pasture. Phillips *et al.* (2007), using micrometerological techniques to measure N_2O emission, found emission rates associated with application of animal waste and fertiliser to irrigated pasture of 0.32-0.37% which are comparable with the CS EF of 0.4%.

Where new studies give values that are significantly different from the CS EFs these EFs are identified for review (see section on Planned Improvement below).

6.5.5 Recalculations Since The 2011 Inventory

Emissions for the most recent year in the *agriculture* sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. There was a complete time series recalculation to the emissions for agricultural soils due to the inclusion of a new time-series of fertiliser application rates for sugar cane. In addition revisions to the biomass burnt for prescribed burning of savannas and residue burning as explained sections 6.6 and 6.6 resulted in changes to emission estimations for atmospheric deposition (section 6.5.2.8). Animal input and activity data have also been revised as described in section 6.3.5.

The net effect of these changes was a 0.1 Gg CO_2-e increase in the 1990 estimate, a decrease of 138 Gg CO_2-e in the 2010 and an increase of 100 Gg CO_2-e in the 2011 estimates.

Table 6.34: 4.D Agricultural Soils: recalculations of total CO_2-e emissions, 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	13,382	13,382	0	0.0
2000	16,251	16,286	35	0.2
2001	16,722	16,781	59	0.4
2002	16,322	16,306	-16	-0.1
2003	16,032	15,923	-109	-0.7
2004	15,985	15,735	-250	-1.6
2005	15,980	15,735	-245	-1.5
2006	15,468	15,307	-162	-1.0
2007	14,759	14,675	-84	-0.6
2008	14,354	14,276	-78	-0.5
2009	14,272	14,182	-90	-0.6
2010	14,499	14,362	-138	-0.9
2011	14,980	15,080	100	0.7

6.5.6 Planned Improvements

The Australian Government research programs such as the Climate Change Research Program (CCRP) and Filling the Research Gap managed by the Department of Agriculture are undertaking research into key strategies for mitigating nitrous oxide emissions through management practice change. As data from the research studies are published the results will be reviewed to determine if changes are required to the selected EFs.

Results from projects on high rainfall and irrigated crops indicate that the current CS EFs which are based on the IPCC default (1.25%) and irrigated maize (2.1%) EFs respectively may be too high (Table 6.35). Recent studies on sugar cane have found EFs which are higher than the IPCC default. Additional data on emissions from these cropping systems is expected through projects funded under Filling the Research Gap program. Once all this data is available the EFs for sugar cane, rain fed and irrigated crops with be reviewed and revised as appropriate.

The CS EF for cotton was selected to be an appropriate average EF based on the average fertiliser application rates. There is a growing body of studies showing a non-linear relationship between N_2O emissions and N input. The Department is currently consulting with technical experts to determine if an EF that varies with rate can be supported with the available measurement data.

Table 6.35: Recently published EFs for irrigated and high rainfall crops and sugar cane

Reference	Site	Crop	Treatment	EF(%)
Schwenke *et al*. (2010)	Tamworth NSW	Rainfed canola	Zero Till 80N	0.33
Wang *et al.* (2011)	Warwick, QLD	Rainfed wheat	Cultivated, residue burnt 90N	0.9
			Cultivated, residue retained 90N	1.2
			No till, residue burnt 90N	0.5
			No-till, Residue retained 90N	0.8
Scheer *et al*. (2012)[(a)]	Toowoomba QLD	Irrigated wheat	High irrigation 200N	0.38
			Medium irrigation 200N	0.22
			Low irrigation 200N	0.23
Denmead *et al.* (2010)	Mackay QLD	Sugarcane	150N	2.8
Allen *et al.* (2010)	Jacobs Well QLD	Sugarcane	100N split application	1
			100N subsurface	1.07
			200N split application	2.95
			200N subsurface	6.7
Wang *et al.* (2008)	Mackay QLD	Sugarcane	80N	1.19
			150N	1.32

(a) Uncorrected for background emissions

6.6 Source Category 4.E Prescribed Burning of Savannas

6.6.1 Source category description

Savanna burning is a key source of CH_4 and N_2O and is an important source of CO, NO_x and NMVOCs. Carbon dioxide emissions from savanna burning are estimated and reported as stock changes in the grassland remaining grassland category in the LULUCF sector.

The definition of savanna used by IPCC is 'tropical and sub-tropical formations with continuous grass cover occasionally interrupted by trees and shrubs' (IPCC, 1997). This includes monsoonal through to semi arid grasslands. In the Australian inventory, this reporting category also includes burning of temperate grasslands in southern Australia and Tasmanian moorland.

Savanna and temperate grassland ecosystems in Australia are burnt either anthropogenically or as a result of wildfires. The anthropogenic burning occurs for a variety of reasons including pasture management, fuel reduction, prevention of uncontrollable wildfires, and traditional Aboriginal burning. These anthropogenic fires replace wildfires that would occur naturally otherwise, albeit later in the dry season, or at other times of the year. Anthropogenic fires probably have occurred in Australian savannas and grasslands since at least 38,000 BP (Singh *et al.* 1981). Non-anthropogenic fires result from natural ignition processes such as lightning strikes. As recommended by the IPCC (1997) all fires in Australian savannas and temperate grasslands are included in the inventory.

6.6.2 Methodology

A country specific tier 2 methodology is used to estimate emissions from savanna burning. The method is based on empirical data, disaggregated spatially with country-specific EFs and parameters.

Fuel and fire parameter values are derived mainly from the Western Arnhem Land Fire Abatement (WALFA) project area, and described in detail by Russell-Smith *et al.* (2009). This project uses controlled fire management in savanna woodland to shift the seasonality of burning from the Late Dry Season (LDS) towards the Early Dry Season (EDS).

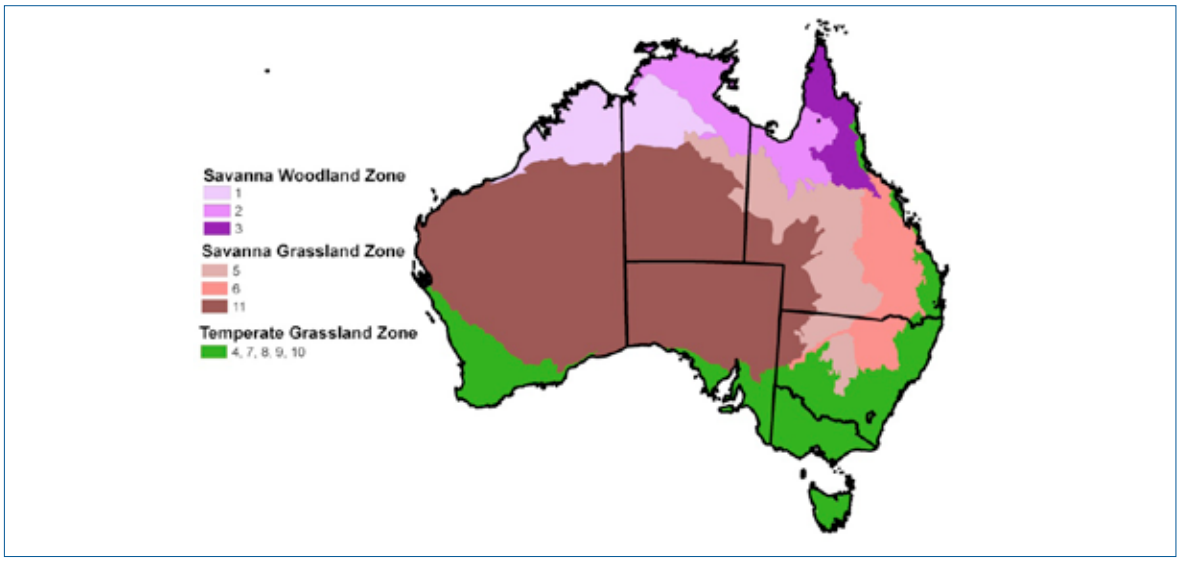
6.7.2.1 Stratification of Savanna Types

The inventory methodology stratifies Australia into three broad vegetation zones. These are defined in terms of the agro ecological zones (AEZs) of the Interim Biogeographic Regionalisation for Australia (IBRA)[8] version 4.1.

The 11 AEZs are an aggregation of the IBRA regions based mainly on rainfall, soils and climatic conditions and are used to help identify key land and vegetation management issues at a regional level. The inventory methodology uses groupings of the AEZs as a proxy for classifying regions as savanna woodland, savanna grassland or temperate grassland.

The northern part of the Northern Territory (NT), Western Australia (WA) and Queensland (Qld), is characterised by savanna woodland and higher rainfall than the arid centre and is known as the 'Top End'. The Top End corresponds approximately to AEZ 1, AEZ 2 and AEZ 3 which are predominantly woodland with smaller areas of open forest and grassland. The inventory methodology uses these three zones as its definition of savanna woodlands. The savanna grasslands of the arid interior of central Australia ('the Centre') comprise AEZ 5, AEZ 6 and AEZ 11 of the NT, WA, Qld, South Australia (SA) and New South Wales (NSW) and these zones are used as the inventory definition of savanna grassland. The higher rainfall south-western and south-eastern corners of the Australian mainland and Tasmania are not classified as savanna, and makes up the source category comprising temperate grasslands. These zones are shown in Figure 6.4.

Figure 6.4: Distribution of savanna types by agro ecological zones



[8] IBRA is a framework used for sustainable resource management and conservation planning. The 80 IBRA regions in IBRA version 4.1 represent a landscape-based approach to classifying the land surface from a range of continental data on environmental attributes such as vegetation, geology, soils and climate. Background information and a map of the IBRA regions is available at www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html

6.7.2.2 Area Burnt

Areas of savanna woodland and savanna grassland burnt for the years 1989 to 2012 are mapped monthly by the Western Australian Land Information Authority (trading as Landgate) using AVHRR satellite imagery at a spatial resolution of 100 hectares. The fire scar areas are mapped at a resolution of 400 hectares, i.e. four pixels. In the temperate grassland areas however, the areas of individual grass fires are frequently less than 100 hectares and therefore statistics recorded by the State fire authorities for the years 1989 to 2012 are the basis of estimates. These temperate grassland fire scar areas are based on local records or the expert judgment of district officers.

No AVHRR derived fire scar area maps are available for Qld for the 1989 late fire season (August to December) and calendar years 1994, 1995 and 1996 (Table 6.36). For years with AVHRR derived fire scar area maps Qld averages 23% of national annual source category emissions. For the periods with no AVHRR derived fire scar area maps the savanna woodland area burnt data was supplemented with statistically predicted areas based on rainfall using NT fire scar area as a predictor. For savanna grassland where no suitable correlation was identified data were derived using the long term mean.

Table 6.36: Savanna woodland and grassland area burnt data (A) source by inventory year

State	NSW	NT	Qld	SA	WA
1990	AVHRR	AVHRR	AVHRR and statistically predicted	AVHRR	AVHRR
1991-1992	AVHRR	AVHRR	AVHRR	AVHRR	AVHRR
1993	AVHRR	AVHRR	AVHRR and statistically predicted	AVHRR	AVHRR
1994-1996	AVHRR	AVHRR	Statistically predicted	AVHRR	AVHRR
1997	AVHRR	AVHRR	AVHRR and statistically predicted	AVHRR	AVHRR
1998+	AVHRR	AVHRR	AVHRR	AVHRR	AVHRR

6.7.2.2 Fuel Loads

For savanna grasslands and temperate grasslands fuel loads are assumed to be constant from year to year and throughout the year. In these vegetations types, and some savanna woodland types, data on fuel loads for various fuel components have been aggregated into a single value for fuel load (aggregated fuel). In most savanna woodland vegetation types Russell-Smith *et al.* (2009) found fuel loads to be dependent on vegetation class, fuel components (fuel size class) and fire interval.

Savanna woodland vegetation classes are derived using a combination of validated vegetation, land use and geological data sets available in the public domain (Meyer 2011). These classes are applied on the basis of reliable estimation of various parameters that effect fire emissions including fuel load estimates and gaseous EFs. For most savanna woodland vegetation classes fuel components are aggregated by fine, coarse, heavy and shrub fuel size classes where fuel load for fine fuel accumulates with increasing fire interval and dependant on vegetation class. Fuel loads (FL_j) are calculated as:

$$FL_j = FL_{max} (1 - e^{-Dt_{yslb}}) \quad (4E_1)$$

Where: t_{yslb} = number of years since the last fire (YSLB) (Table 6.38);

FL_{max} = equilibrium fuel load (Table 6.37)

D = decay constant (Table 6.37); and

j = vegetation class (Table 6.37).

Table 6.37: Parameter values for the fine fuel accumulation model

Vegetation classes (j)	FLmax (Equilibrium fuel load - Mg/Ha)	D (Decay constant)
Eucalypt Open Forest	6.08	0.6
Eucalypt Woodland	4.53	1.82
Melaluca Woodland	4.53	1.82
Sandstone Heath	16.65	0.12
Sandstone Woodland	5.74	0.45
Shrub	16.65	0.12

In applying Equation 4E_1there are operational benefits in limiting the range of values by grouping the years since last burnt in a way that does not have a material effect on precision. To investigate potential groupings, fire interval data in the WALFA project area were assessed. Satellite sensing show fires in consecutive years in 55% of pixels with 83% of pixels experiencing another fire in two years or less. These fire return intervals are similar in other fire prone regions of high rainfall savannas (Edwards and Russell-Smith 2009). It was determined that the groupings presented in Table 6.38 decreased complexity without materially affecting precision.

Table 6.38: Model values for the number of years since the last fire (t_{yslb})

Subcategory	t_{yslb}
>5 YSLB (years since last burnt)	10
1 YSLB (year since last burnt)	1
2 YSLB (years since last burnt)	2
3 YSLB (years since last burnt)	3
4 YSLB (years since last burnt)	4
5 YSLB (years since last burnt)	5
N/A	0

For the periods where no AVHRR derived fire scar area maps are available to derive the YSLB each vegetation class's long term average was applied. These averages were derived from data from 2001 to 2011 for Qld and from 1994 to 2011 for all other states.

Fuel loads for non-fine fuel size classes are assumed to be constant from year to year and throughout the year. Estimates of savanna woodland fuel loads are drawn from the field measurements in a number of studies. Fuel loads in the savanna grassland and temperate grassland regions are based on values in the scientific literature or the experience of State government experts (Table 6.39).

Table 6.39: Savanna fuel loads (FL) (Mg/Ha)

Subsource	Vegetation classes (j)	State	Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland	Rangeland[(c), (d)]	NSW, NT, Qld, SA, WA	3	NA	NA	NA	NA
Savanna Woodland	Eucalypt Open Forest[(f)]	WA, NT, Qld	NA	IE	1.43	4.81	1.46
	Eucalypt Woodland[(f)]	WA, NT, Qld	NA	IE	0.9	2.18	0.49
	Melaluca Woodland[(f)]	WA, NT, Qld	NA	IE	0.9	2.18	0.49
	Other vegetation types[(c)]	WA, NT, Qld	3	NA	NA	NA	NA
	Sandstone Heath[(f)]	WA, NT, Qld	NA	IE	0.58	1.68	1.77
	Sandstone Woodland[(f)]	WA, NT, Qld	NA	IE	1.23	3.42	1.71
	Shrub[(f)]	WA, NT, Qld	NA	IE	0.58	1.68	1.77
Temperate Grassland	Temperate Grassland	ACT[(a)]	11.1	NA	NA	NA	NA
		NSW[(b)]	6.9	NA	NA	NA	NA
		SA[(a)]	3	NA	NA	NA	NA
		TAS[(e)]	9	NA	NA	NA	NA
		VIC[(b)]	11.7	NA	NA	NA	NA
		WA[(c)]	3		NA	NA	NA

(a) Tolhurst (1994)

(b) Chatto (1997)

(c) Russell-Smith *et al.* (2004), Meyer (2004)

(d) Carter *et al.* (2000), Dyer *et al.* (2001), Carter and Henry (2003)

(e) Marsden-Smedley and Catchpole (1995a, b)

(f) Russell-Smith *et al.* (2009), Meyer (2011)

6.7.2.3 Burning Efficiencies

The burning efficiency is the product of two parameters; the pyrolysis efficiency, i.e. the fraction of fuel exposed to flame that is volatilised, and the fraction of fire scar area that is burnt, i.e. the fire patchiness.

Fires in savanna woodlands are classified by the season of burning as Early Dry Season (EDS) or Late Dry Season (LDS). EDS fires are characterised by low intensity or severity, a high degree of patchiness, a greater propensity to extinguish spontaneously and reduced total fuel consumption. LDS fires are characterised by high intensity, low levels of patchiness, a greater propensity to spread and high total fuel consumption. For most savanna woodland vegetation classes burning efficiency is a function of seasonality, severity of fire and fuel size class.

Fires in savanna grasslands are not categorised into seasons. This is because the seasons that define the northern savanna woodland areas do not extend south into these arid rangelands regions of the savannas and fires behave in a way that is adequately parameterised annually. For savanna grasslands and temperate grasslands burning efficiencies are assumed to be constant from year to year and throughout the year.

Estimates of patchiness, frequency of fire severity classes by season (for savanna woodlands) and burning efficiencies are drawn from the field measurements published in the scientific literature or the experience of State government experts (Table 6.40, Table 6.41 and Table 6.42).

Table 6.40: Patchiness (P) - Fraction of fire scar area that is burnt

Seasonality	Patchiness (P)
EDS (Early Dry Season) [(a)]	0.709
LDS (Late Dry Season) [(a)]	0.889
Annual	1

(a) Russell-Smith *et al.* (2009)

Table 6.41: Severity Class (S) - Fraction of fires in each fire severity class

Seasonality	Unclassed	Low Severity	Moderate Severity	High Severity
EDS (Early Dry Season) [(a)]	NA	0.72	0.2	0.08
LDS (Late Dry Season) [(a)]	NA	0.19	0.47	0.34
Annual	1	NA	NA	NA

(a) Russell-Smith *et al.* (2009)

Table 6.42: Burning Efficiency (BEF) and fire severity class (S) for each fuel size class

Subsource	Fire Severity Class	Fuel size class				
		Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland[(a)]	Annual	0.76	NA	NA	NA	NA
Savanna Woodland[(b)]	Low severity	NA	0.69	0.05	0.12	0.26
	Moderate severity	NA	0.85	0.32	0.19	0.24
	High severity	NA	0.97	0.58	0.58	0.68
	Annual	0.76	NA	NA	NA	NA
Temperate Grassland[(c)]	Annual	0.72	NA	NA	NA	NA

(a) Meyer (2004)

(b) Russell-Smith *et al.* (2009)

(c) Tolhurst (1994)

The timing of the transition between EDS and LDS varies between regions. It was considered that calculating the transition between EDS and LDS based on regional observations would not materially affect the reported emissions and the significant resources required for their inclusion was not justified (C. Meyer, J. Russell-Smith pers. comm.). Thus the transition from EDS to LDS in the methodology is static, set as the last day of July. This characterisation is based on indigenous fire management practices and observations of changes in ambient humidity and wind speed sufficient to support fire propagation through the night; this allows fires to spread for several days and fires to reach high intensities (Haynes 1985, Meyer 2011, Russell-Smith *et al.* 1997a).

For savanna burning the inventory year commences with the LDS and ends with the EDS of the following year (August 1 to July 31). For example the data for 1990 includes burning data from 1 August 1989 until July 31 1990.

For Qld during the periods where no AVHRR derived fire scar area maps are available to derive the areas burnt during each fire season (Table 6.36), each vegetation class's long term average distribution for 2001-2011 was applied.

6.7.2.5 Composition of Biomass

The carbon mass fraction and the nitrogen to carbon ratio of the biomass burnt are based on measurements from fires in Australia (Carter and Henry 2003, Hurst *et al.* 1994a, b, Russell-Smith *et al.* 2004, Russell-Smith *et al.* 2009). For most savanna woodland vegetation types these the parameters vary by fuel size class (Russell-Smith *et al.* 2009).

Table 6.43: Carbon Mass Fraction Burnt in Fuel Burnt (C)

Subsource	Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland[(a)]	0.439	NA	NA	NA	NA
Savanna Woodland[(a)]	0.439	0.494	0.501	0.501	0.502
Temperate Grassland[(b)]	0.460	NA	NA	NA	NA

(a) Russell-Smith *et al.* (2009)

(b) Hurst *et al.* (1994 a, b)

Table 6.44: Nitrogen to Carbon Ratio in Fuel Burnt (NC)

Subsource	Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland[(a)]	0.0087	NA	NA	NA	NA
Savanna Woodland[(a)]	0.0087	0.0101	0.0081	0.0081	0.0093
Temperate Grassland[(b)]	0.0120	NA	NA	NA	NA

(a) Russell-Smith *et al.* (2009)

(b) Carter and Henry (2003), Hurst *et al.*, (1994a) and Russell-Smith *et al.*, (2004)

6.7.2.6 Emission Factors

The emission factors used in the Australian methodology are derived from direct field measurements from experimental savanna fire in the Northern Territory (Meyer and Cook 2011, Hurst *et al.*1994a, b). Meyer and Cook (2011) investigated the seasonality in savanna woodland and savanna grassland EFs and concluded that: (1) the EFs for N_2O were independent of season or vegetation class; and (2) the EFs for CH_4 were independent of season, but for most savanna woodland vegetation types were strongly dependent on vegetation class, primarily through fuel architecture. These findings are consistent with the IPCC *Guidelines* (IPCC, 2006) and are presented in Table 6.45 and Table 6.46.

Table 6.45: CH_4 Emission Factors (Gg CH_4-C/Gg C)

Subsource	Vegetation classes (j)	Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland[(a)]	Rangeland	0.0012	NA	NA	NA	NA
Savanna Woodland[(a)]	Eucalypt Open Forest	NA	0.0031	0.0031	0.01	0.0031
	Eucalypt Woodland	NA	0.0031	0.0031	0.01	0.0031
	Melaluca Woodland	NA	0.0031	0.0031	0.01	0.0031
	Other vegetation types	0.0012	NA	NA	NA	NA
	Sandstone Heath	NA	0.0015	0.0015	0.01	0.0015
	Sandstone Woodland	NA	0.0031	0.0031	0.01	0.0031
	Shrub	NA	0.0015	0.0015	0.01	0.0015
Temperate Grassland[(b)]	Temperate Grassland	0.0035	NA	NA	NA	NA

(a) Meyer and Cook (2011)

(b) Hurst *et al.* (1994 a, b)

Table 6.46: N_2O Emission Factors (Gg N_2O-N/Gg N)

Subsource	Vegetation classes (j)	Aggregated Fuel	Fine Fuel	Coarse Fuel	Heavy Fuel	Shrub Fuel
Savanna Grassland[(a)]	Rangeland	0.0066	NA	NA	NA	NA
Savanna Woodland[(a)]	Eucalypt Open Forest	NA	0.0075	0.0075	0.0036	0.0075
	Eucalypt Woodland	NA	0.0075	0.0075	0.0036	0.0075
	Melaluca Woodland	NA	0.0075	0.0075	0.0036	0.0075
	Other vegetation types	0.0066	NA	NA	NA	NA
	Sandstone Heath	NA	0.0066	0.0066	0.0036	0.0066
	Sandstone Woodland	NA	0.0075	0.0075	0.0036	0.0075
	Shrub	NA	0.0066	0.0066	0.0036	0.0066
Temperate Grassland[(b)]	Temperate Grassland	0.0076	NA	NA	NA	NA

(a) Meyer and Cook (2011)

(b) Hurst *et al.* (1994 a, b)

Table 6.47: Emission Factors (CO, NMVOC and NO_X)

Gas	Unit	Data_Value
CO	Gg CO-C/Gg C	0.078
NMVOC	Gg NMVOC-C/Gg C	0.0091
NO_X	Gg NO_x-N/Gg N	0.21

Hurst *et al.* (1994 a, b)

6.7.2.7 Form of the equations

The formulas for calculating methane and nitrous oxide emissions from savanna burning in each State are provided in Equations 4E_2, 4E_3 and 4E_4 (Russell-Smith *et al.* 2009).

The mass burnt (M_{ijklm} Gg) is calculated as:

$$M_{ijklm} = A_{jkl} \times P_l \times FL_{jm} \times S_{nm} \times BEF_{nm} \times 10^{-3} \quad \text{4E_2}$$

Then for CH_4, CO, and NMVOCs calculate emissions:

$$E_i = \Sigma_j \Sigma_k \Sigma_l \Sigma_m (M_{ijklm} \times CC_{jl} \times EF_{jl} \times C_g) \quad \text{4E_3}$$

and for NO_X, N_2O:

$$E_i = \Sigma_j \Sigma_k \Sigma_l \Sigma_m (M_{ijklm} \times CC_{jl} \times NC_{jl} \times EF_{jl} \times C_g) \quad \text{4E_3}$$

Where: E = annual emissions from savanna fires

M = mass of fuel burnt in fire (G_g)

A = fire scar area (ha) (Table 6.36);

P = patchiness (Table 6.40);

FL = fuel load (Mg/ha) (Table 6.39);

CC = carbon content;

NC = nitrogen: carbon ratio (Table 6.44);

BEF = burning efficiency (Table 6.42);

S = severity (Table 6.41);

EF = emission factor (g N or C emitted as trace species / g fuel N or C emitted);

C_g = elemental to molecular mass conversion factor (Table 6.48);

And

i = State (NSW, Vic, Qld, NT, SA, WA, Tas, ACT);

j = vegetation class;

k = fire season class (EDS, LDS, annual);

l = fuel size class (fine, coarse, heavy, shrub);

m = fire severity class (low, moderate, high).

Table 6.48: Elemental to molecular mass conversion factors (C_g)

Gas	C_g
CH_4	16/12
N_2O	44/28
NO_X	46/14
CO	28/12
NMVOC	14/12

6.6.3 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for prescribed burning of savannas were estimated to be in the order of –25 to +25%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

6.6.4 Source Specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Section 1.6. In 2013, an external consultant was engaged to test that the savanna burning method had been implemented correctly in the AGEIS. Using the same activity data as used in the AGEIS the consultant developed a spreadsheet to estimate the savanna burning emissions. The results of the spreadsheet calculations were then compared with the AGEIS estimates and were found to give a complete match.

6.6.5 Recalculations Since The 2011 Inventory

Emissions for the most recent year in the agriculture sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. Updates were also made to the area of temperate grassland burnt in the years 2010-2011. This change led to a 0.7 Gg CO_2-e decrease in the 2011 estimate.

Table 6.49: 4.E Prescribed Burning of Savannas: Recalculation of CO_2-e emissions 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	6,359	6,359	0	0.0
2000	11,085	11,085	0	0.0
2001	13,055	13,055	0	0.0
2002	12,249	12,249	0	0.0
2003	10,085	10,085	0	0.0
2004	10,338	10,338	0	0.0
2005	8,673	8,673	0	0.0
2006	11,066	11,066	0	0.0
2007	10,746	10,746	0	0.0
2008	12,502	12,502	0	0.0
2009	11,342	11,342	-0.5	0.0
2010	8,618	8,617	-1.2	-0.01
2011	10,350	10349	-0.7	-0.01

6.6.6 Planned Improvements

The Australian Government is supporting research to improve understanding of the accumulation of live and dead savanna woodland coarse, heavy and shrub fuels and soil carbon in high rainfall areas due to a shift in fire regime to one dominated by low intensity early dry season fires. The field programme for live vegetation and debris fuel loads, burning efficiency, seasonality and patchiness, which commenced in the West Arnhem Land Fire Abatement (WALFA) project region, is being extended to lower rainfall regions of northern Australia. This project is funded by the Department as part of the Indigenous Carbon Farming Fund Research and Development (ICFFR&D) grants program with the projects managed by North Australian Indigenous Land and Sea Management Alliance (NAILSMA) and CSIRO. The NAILSMA ICFFR&D grants program project is investigating assignment of fire severity classes to each area burnt and may inform future development of regionalised savanna burning methodology in higher and lower rainfall areas based on fire severity.

Previously AVHRR fire scar map data was not available for all States for the entire time-series so activity data was based on statistical predictions. Additional AVHRR maps are now available for these regions so it is planned to replace the statistical prediction with AVHRR data where possible.

6.7 Source Category 4.F Field Burning of Agricultural Residues

6.7.1 Source Category Description

The burning of residual crop material also releases CH_4, N_2O, CO, NO_x and NMVOCs into the atmosphere. These gases are formed from carbon and nitrogen in the plant material during the combustion process. As per the IPCC *Guidelines* (IPCC 1997) the CO_2 emissions from burning of agricultural residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 is removed by regrowing vegetation in the following year.

Traditionally, burning of agricultural residues in Australia consists of stubble burning (notably for wheat crops), and burning of the sugar cane crop immediately before harvest.

Stubble burning involves firing the standing stalks in either late autumn or spring. Increasingly, as a form of land management, it is being replaced by stubble retention, which reduces erosion and conserves nutrients. In this latter practice the stubble is grazed some weeks after harvest and the next crop is sown by drilling though the remaining vegetation. Firing of sugar cane has also become less common with the rapid introduction of green cane mechanical harvesting. Sugar cane crops are now burnt once every three or four years at the end of the sowing/ratoon cycle.

The amount of crop residue at the time of burning is in most cases, less than that at the time of harvest. This applies particularly to crops where there is a long interval between harvest and burning. Vegetation decay and grazing by animals can, over several months, reduce the amount of residue per unit area by one half (R. Jarvis pers. comm., Mulholland *et al.* 1976). This loss is allowed for in the algorithm.

The amount of material burnt is calculated from the harvested crop yield via information on the residue to crop ratio and the fraction of crop residue remaining at the time of burning etc as presented in Appendix 6.I. This information is derived from Robinson and Kirby (2002), Milthorpe (1982), Saffigna *et al.* (1982), Galbally *et al.* (1992), Australian Canegrowers (Milford, pers. comm.) and other agricultural industry sources.

The burning efficiency is estimated to be 96% (Hurst *et al.* 1994 a, b). The EFs appropriate to high temperature stubble fires are assumed to be the same as observed in savanna burning (Table 6.50).

Table 6.50: Burning of agricultural residues – emission factors

Gas species		Emission factor [(a)] EF_{ijk} (Gg element in species/Gg element in fuel burnt)	Elemental to molecular mass conversion factor (C_g)
1.	CH_4	0.0035	16/12
2.	N_2O	0.0076	44/28
3.	NO_x	0.2100	46/14
4.	CO	0.0780	28/12
5.	NMVOC	0.0091	14/12

(a) Hurst *et al.* (1994 a, b)

Table 6.51: Symbols used in algorithms for burning of agricultural residues

State (i)	Activity (j)	Subset (k)
1 = NSW	1 = burning of agricultural residues	1=Wheat
2 = Tas		2=Barley
3 = WA		3=Maize
4 = SA		4=Oats
5 = VIC		5=Rye
6 = Qld		6=Rice
7 = NT		7=Millet
8 = ACT		8=Sorghum
		9=Triticale
		10=Pulse
		11=Tuber and Roots
		12=Sugar Cane
		13=Peanuts
		14=Other Crops

The mass of fuel burnt is calculated as:

$$M_{ijk} = P_{ik} \times R_k \times S_k \times DM_k \times Z_j \times F_{ik} \quad \text{(4F_1)}$$

Where: M_{ijk} = mass of residue burnt from crop (Gg)

P_{ik} = annual production of crop (Gg)

R_k = residue to crop ratio (kg crop residue/kg crop) (Appendix 6.I)

S_k = fraction of crop residue remaining at burning (Appendix 6.I)

DM_k = dry matter content (kg dry weight/kg crop residue) (Appendix 6.I)

Z_j = burning efficiency (fuel burnt/fuel load) for residue from crop

F_{ik} = fraction of the annual production of crop that is burnt (ha burnt/ ha harvested) (Appendix 6.I)

The mass of fuel burnt is converted to an emission of CH_4, CO or NMVOC by multiplying by the carbon content of the fuel, and an EF. That is:

$$E_{ijk} = M_{ijk} \times CC_{jk} \times EF_j \times C_g \quad \text{(4F_2)}$$

Where: E_{ijk} = annual emission from burning crop residue (Gg)

CC_{jk} = carbon mass fraction in crop residue

EF_j = emission factor (Gg element /Gg burnt) (Table 6.50)

C_g = factor to convert from elemental mass of gas to molecular mass

For N_2O and NO_x an additional term in the algorithm, the nitrogen to carbon ratio (NC_j), is required in order to calculate the fuel nitrogen content. Hence:

$$E_{ijk} = M_{ijk} \times CC_{jk} \times NC_{jk} \times EF_j \times C_g \quad \text{(4F_3)}$$

Where: E_{ijk} = annual emission from burning crop residue (Gg)

CC_{jk} = mass fraction of carbon in crop residue

NC_{jk} = nitrogen to carbon ratio in crop residue

EF_j = emission factor (Gg element /Gg burnt) (Table 6.50)

C_g = factor to convert from elemental mass of gas to molecular mass

6.7.2 Uncertainties and Time Series Consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for the burning of agricultural residues were estimated to be in the order of –40 to +55%. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

6.7.3 Source Specific QA/QC

ABS the principal data supplier has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.7.4 Recalculations Since The 2011 Inventory

Emissions for the most recent year in the *agriculture* sector are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available. A correction was also made to the fraction of sugar cane burnt in 2010. These changes led to a 3.8 Gg CO_2-e decrease in the 2011 estimate.

Table 6.52: 4.F Field Burning of Agricultural Residues: recalculation of total CO_2-e emissions 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	292	292	0	0.0
2000	410	410	0	0.0
2001	422	422	0	0.0
2002	357	357	0	0.0
2003	365	365	0	0.0
2004	335	335	0	0.0
2005	407	407	0	0.0
2006	339	339	0	0.0
2007	313	313	0	0.0
2008	274	274	0	0.0
2009	314	311	-2.6	-0.8
2010	365	362	-2.6	-0.7
2011	414	410	-3.8	-0.9

6.7.5 Planned Improvements

All data and methodologies are kept under review.

Appendix 6.A: Dairy Cattle

Table 6.A.1: Dairy cattle – liveweight (kg)

State	Milking Cows	Heifers >1	Heifers <1	House Cows Milk and Dry	Dairy Bulls >1	Dairy Bulls <1
NSW/ACT	550	425	240	450	650	300
Tasmania	500	350	220	400	600	250
Western Australia	550	350	180	450	550	250
South Australia	550	450	260	500	500	350
Victoria	550	450	250	450	600	250
Queensland	580	400	150	500	650	200
Northern Territory	500	350	220	400	550	250

Table 6.A.2: Dairy cattle – liveweight gain (kg/day)

State	Milking Cows	Heifers >1	Heifers <1	House Cows Milk and Dry	Dairy Bulls >1	Dairy Bulls <1
NSW/ACT	0.04	0.6	0.6	0.04	0.2	0.9
Tasmania	0.04	0.5	0.8	0.04	0.1	1
Western Australia	0.06	0.8	0.8	0.06	0.1	1
South Australia	0.06	0.5	0.8	0.06	0.1	1
Victoria	0.04	0.5	0.6	0.04	0.1	1
Queensland	0.06	0.7	0.7	0.06	0.1	0.7
Northern Territory	0.06	0.5	0.8	0.06	0.1	1

Table 6.A.3: Dairy cattle – dry matter digestibility of feed intake (%)

State	Milking Cows (%)	Heifers >1 (%)	Heifers <1 (%)	House Cows Milk and Dry (%)	Dairy Bulls >1 (%)	Dairy Bulls <1 (%)
NSW/ACT	75	75	75	75	75	75
Tasmania						
Spring	75	75	75	75	75	75
Summer	65	65	65	65	65	65
Autumn	65	65	65	65	65	65
Winter	75	75	75	75	75	75
Western Australia	75	75	75	75	75	75
South Australia	75	75	75	75	75	75
Victoria	78	78	78	78	78	78
Queensland	70	65	65	60	65	65
Northern Territory	75	75	75	75	75	75

Table 6.A.4: Dairy cattle – allocation of waste to manure management systems

State	Milking Cows				Other Dairy Cattle
	Lagoon (%)	Liquid/slurry (%)	Daily Spread (%)	Voided at Pasture (%)	Voided at Pasture (%)
NSW/ACT	6.0	0.5	1.5	92.0	100
Tasmania	6.0	0.5	1.5	92.0	100
Western Australia	2.0	0.0	6.0	92.0	100
South Australia	10.0	0.5	1.0	88.5	100
Victoria	6.0	0.5	1.5	92.0	100
Queensland	3.0	0.0	7.0	90.0	100
Northern Territory	3.0	0.0	7.0	90.0	100

Table 6.A.5: Dairy cattle – Methane Conversion Factors (MCF)

State	Manure Management System – Methane Conversion Factors (MCF)				Integrated MCF	
	Lagoon (%)	Liquid/ slurry (%)	Daily Spread (%)	Voided at Pasture (%)	Milking Cows (%)	Other Dairy Cattle (%)
NSW/ACT	90	35	0.5	1.0	6.50	1.0
Tasmania	90	35	0.5	1.0	6.50	1.0
Western Australia	90	35	0.5	1.0	2.75	1.0
South Australia	90	35	0.5	1.0	10.07	1.0
Victoria	90	35	0.5	1.0	6.50	1.0
Queensland	90	65	1.0	2.0	4.57	2.0
Northern Territory	90	65	1.0	2.0	4.57	2.0

Table 6.A.6: Dairy cattle – crude protein content of feed intake (%)

State	Milking Cows (%)	Heifers >1 (%)	Heifers <1 (%)	House Cows Milk and Dry (%)	Dairy Bulls >1 (%)	Dairy Bulls <1 (%)
NSW/ACT	20	16	16	15	16	16
Tasmania						
Spring	22	18	18	17	18	18
Summer	18	16	16	15	16	16
Autumn	12	10	10	9	10	10
Winter	20	18	18	17	18	18
Western Australia	20	15	15	14	15	15
South Australia	15	15	15	15	15	15
Victoria	20	16	16	15	16	16
Queensland	18	16	16	15	16	16
Northern Territory	15	15	15	15	15	15

Table 6.A.7: Dairy cattle – standard reference weights

State	Milking Cows (kg)	Heifers >1 (kg)	Heifers <1 (kg)	House Cows Milk and Dry (kg)	Dairy Bulls>1 (kg)	Dairy Bulls<1 (kg)
NSW/ACT	580	580	580	450	770	770
Tasmania	550	550	550	400	770	770
Western Australia	550	550	550	450	770	770
South Australia	550	550	550	550	770	770
Victoria	550	550	550	450	770	770
Queensland	580	580	580	400	770	770
Northern Territory	550	550	550	400	770	770

Based on SCA 1990

Table 6.A.8: Dairy cattle – Average milk production (kg/head/year)

State	1990	2008	2009	2010	2011	2012
NSW/ACT	3,602	5,031	5,420	5,329	5,203	5,549
Tasmania	3,791	4,961	5,140	4,640	5,349	5,629
Western Australia	4,205	5,907	6,355	6,641	6,466	5,823
South Australia	3,934	5,799	6,053	5,907	6,257	6,566
Victoria	3,920	5,393	5,807	5,518	5,836	6,212
Queensland	3,122	4,163	5,032	5,052	4,966	5,009
Northern Territory	3,122	4,163	5,032	5,052	4,966	5,009

Source: Dairy Australia

Appendix 6.B: Beef Cattle

Table 6.B.1: Beef cattle – liveweight (kg)

State	Region	Season	Bulls>1 (kg)	Bulls<1 (kg)	Steers<1 (kg)	Cows 1 to 2 (kg)	Cows>2 (kg)	Cows<1 (kg)	Steers>1 (kg)
NSW/ACT		Spring	480	80	75	300	440	75	380
		Summer	520	170	160	360	470	160	420
		Autumn	550	240	220	390	490	220	450
		Winter	560	280	260	410	500	260	460
Tasmania		Spring	700	105	90	300	490	85	480
		Summer	750	480	160	350	530	150	460
		Autumn	725	250	215	360	500	200	490
		Winter	700	260	230	380	460	210	470
Western Australia	South West	Spring	800	340	300	420	550	260	480
		Summer	780	380	340	450	530	300	470
		Autumn	680	100	100	320	480	80	340
		Winter	700	190	170	330	490	150	360
	Pilbara	Spring	450	80	80	260	340	70	370
		Summer	500	150	150	310	360	140	400
		Autumn	550	230	230	330	380	220	420
		Winter	500	250	250	340	360	240	390
	Kimberley	Spring	500	220	210	300	320	180	340
		Summer	550	110	100	220	380	90	390
		Autumn	600	170	160	270	390	140	430
		Winter	550	200	190	280	350	150	400
South Australia		Spring	800	250	230	400	500	220	420
		Summer	800	320	290	420	500	280	420
		Autumn	700	80	75	300	450	70	400
		Winter	700	160	150	350	450	140	400
Victoria		Spring	820	250	240	410	560	240	510
		Summer	850	280	270	440	550	260	520
		Autumn	700	100	95	300	450	95	410
		Winter	720	150	140	320	470	140	440
Queensland		Spring	750	80	75	300	480	65	350
		Summer	800	170	160	350	500	150	420
		Autumn	760	250	240	390	470	225	470
		Winter	700	320	295	420	450	280	480
Northern Territory		Spring	620	220	210	275	360	190	280
		Summer	650	110	100	240	380	90	260
		Autumn	670	170	160	280	400	140	300
		Winter	660	200	190	290	380	170	285

Table 6.B.2: Beef cattle – liveweight gain (kg/head/day)

State	Region	Season	Bulls>1 (kg/day)	Bulls<1 (kg/day)	Steers<1 (kg/day)	Cows 1 to 2 (kg/day)	Cows>2 (kg/day)	Cows<1 (kg/day)	Steers>1 (kg/day)
NSW/ACT		Spring	0.2	0.5	0.5	0.4	0.3	0.5	0.4
		Summer	0.4	1.0	0.9	0.7	0.3	0.9	0.4
		Autumn	0.3	0.8	0.7	0.3	0.2	0.7	0.3
		Winter	0.1	0.4	0.4	0.2	0.1	0.4	0.1
Tasmania		Spring	0.50	1.0	1.0	1.0	0.5	1.0	0.50
		Summer	0.55	0.82	0.77	0.55	0.44	0.71	0.5
		Autumn	0.50	0.77	0.6	0.11	-0.33	0.55	0.33
		Winter	-0.27	0.11	0.16	0.22	-0.44	0.11	-0.22
Western Australia	South West	Spring	1.10	1.64	1.42	0.99	0.66	1.21	1.10
		Summer	-0.22	0.44	0.44	0.33	-0.22	0.44	-0.11
		Autumn	0.00	0.60	0.60	0.22	-0.55	0.60	0.00
		Winter	0.22	0.99	0.77	0.11	0.11	0.77	0.44
	Pilbara	Spring	-0.55	0.70	0.70	0.22	-0.22	0.70	-0.22
		Summer	0.55	0.77	0.77	0.66	0.55	0.77	0.33
		Autumn	0.55	0.88	0.88	0.22	0.22	0.88	0.22
		Winter	-0.55	0.22	0.22	0.11	-0.22	0.22	-0.33
	Kimberley	Spring	-0.55	0.22	0.22	0.22	-0.33	0.33	-0.66
		Summer	0.55	0.80	0.80	0.44	0.66	0.70	0.55
		Autumn	0.55	0.66	0.66	0.55	0.11	0.55	0.44
		Winter	-0.55	0.33	0.33	0.11	-0.44	0.11	-0.33
South Australia		Spring	1.10	0.99	0.88	0.55	0.55	0.88	0.22
		Summer	0.00	0.77	0.66	0.22	0.00	0.66	0.00
		Autumn	-1.10	0.90	0.80	0.22	-0.55	0.70	-0.22
		Winter	0.00	0.88	0.82	0.55	0.00	0.77	0.00
Victoria		Spring	1.10	1.10	1.10	0.99	0.99	1.10	0.77
		Summer	0.33	0.33	0.33	0.33	-0.10	0.22	0.11
		Autumn	0.20	0.50	0.55	0.44	0.20	0.55	0.20
		Winter	0.22	0.55	0.49	0.22	0.22	0.49	0.33
Queensland		Spring	0.55	1.00	0.90	0.22	0.33	0.80	0.60
		Summer	0.55	0.99	0.93	0.55	0.22	0.93	0.77
		Autumn	-0.44	0.88	0.88	0.44	-0.33	0.82	0.55
		Winter	-0.66	0.77	0.60	0.33	-0.22	0.60	0.11
Northern Territory		Spring	-0.44	0.22	0.22	-0.16	-0.22	0.22	-0.05
		Summer	0.33	0.8	0.8	0.55	0.22	0.8	0.55
		Autumn	0.22	0.66	0.66	0.44	0.22	0.55	0.44
		Winter	-0.11	0.33	0.33	0.11	-0.22	0.33	-0.16

Table 6.B.3: Beef cattle – dry matter digestibility of feed intake (%)

State	Region	Season	Bulls >1	Bulls <1	Steers <1	Cows 1 to 2	Cows >2	Cows <1	Steers >1
			(%)	(%)	(%)	(%)	(%)	(%)	(%)
NSW/ACT		Spring	55	55	55	55	55	55	55
		Summer	65	65	65	65	65	65	65
		Autumn	60	60	60	60	60	60	60
		Winter	50	50	50	50	50	50	50
Tasmania		Spring	75	75	75	75	75	75	75
		Summer	60	60	60	60	60	60	60
		Autumn	70	70	70	70	70	70	70
		Winter	75	75	75	75	75	75	75
Western Australia	South West	Spring	80	80	80	80	80	80	80
		Summer	58	58	58	58	58	58	58
		Autumn	50	50	50	50	50	50	50
		Winter	75	75	75	75	75	75	75
	Pilbara	Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45
	Kimberley	Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45
South Australia		Spring	70	70	70	70	70	70	70
		Summer	55	55	55	55	55	55	55
		Autumn	55	55	55	55	55	55	55
		Winter	75	75	75	75	75	75	75
Victoria		Spring	80	80	80	80	80	80	80
		Summer	55	55	55	55	55	55	55
		Autumn	60	60	60	60	60	60	60
		Winter	76	76	76	76	76	76	76
Queensland		Spring	55	55	55	55	55	55	55
		Summer	65	65	65	65	65	65	65
		Autumn	58	58	58	58	58	58	58
		Winter	52	52	52	52	52	52	52
Northern Territory		Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45

Table 6.B.4: Beef cattle – crude protein content of feed intake (%)

State	Region	Season	Bulls >1 (%)	Bulls <1 (%)	Steers <1 (%)	Cows 1 to 2 (%)	Cows >2 (%)	Cows <1 (%)	Steers >1 (%)
NSW/ACT		Spring	7	7	7	7	7	7	7
		Summer	13	13	13	13	13	13	13
		Autumn	10	10	10	10	10	10	10
		Winter	6	6	6	6	6	6	6
Tasmania		Spring	20	20	20	20	20	20	20
		Summer	10	10	10	10	10	10	10
		Autumn	16	16	16	16	16	16	16
		Winter	20	20	20	20	20	20	20
Western Australia	South West	Spring	20	20	20	20	20	20	20
		Summer	9	9	9	9	9	9	9
		Autumn	6	6	6	6	6	6	6
		Winter	20	20	20	20	20	20	20
	Pilbara	Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	9	9	9	9	9	9	9
		Winter	6	6	6	6	6	6	6
	Kimberley	Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	9	9	9	9	9	9	9
		Winter	6	6	6	6	6	6	6
South Australia		Spring	16	16	16	16	16	16	16
		Summer	7	7	7	7	7	7	7
		Autumn	9	9	9	9	9	9	9
		Winter	20	20	20	20	20	20	20
Victoria		Spring	25	25	25	25	25	25	25
		Summer	7	7	7	7	7	7	7
		Autumn	10	10	10	10	10	10	10
		Winter	21	21	21	21	21	21	21
Queensland		Spring	5	5	5	5	5	5	5
		Summer	15	15	15	15	15	15	15
		Autumn	11	11	11	11	11	11	11
		Winter	6	6	6	6	6	6	6
Northern Territory		Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	7	7	7	7	7	7	7
		Winter	5	5	5	5	5	5	5

Table 6.B.5: Beef Cattle – feed intake adjustment and milk production and intake

State	Region	Season	Feed adjustment	Milk intake / production (kg/day)
NSW/ACT		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Tasmania		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Western Australia	South West	Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
	Pilbara	Spring	1.3	4
		Summer	1.1	3
		Autumn	0	0
		Winter	0	0
	Kimberley	Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0
South Australia		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Victoria		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Queensland		Spring	1.3	4
		Summer	1.1	3
		Autumn	0	0
		Winter	0	0
Northern Territory		Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0

Table 6.B.6: Beef cattle – standard reference weights

State	Bulls >1 (kg)	Bulls <1 (kg)	Steers <1 (kg)	Cows1 to 2 (kg)	Cows >2 (kg)	Cows <1 (kg)	Steers >1 (kg)
NSW/ACT	700	700	600	500	500	500	600
Tasmania	770	770	660	550	550	550	660
Western Australia	770	770	660	550	550	550	660
South Australia	770	770	660	550	550	550	660
Victoria	770	770	660	550	550	550	660
Queensland	770	770	660	550	550	550	660
Northern Territory	770	770	660	550	550	550	660

Based on SCA 1990

Appendix 6.C: Feedlot Cattle

Table 6.C.1: Feedlot cattle – mean liveweight (kg)

Feedlot Cattle Class/Average time on Feed	1990–1995[a]	1996+[b]
domestic/ 75 days	300	360
export/ 140 days	385	490
Japan ox/ 250 days	575	565

(a) Working Group estimates, (b) van Sliedregt *et al.* (2000)

Table 6.C.2: Feedlot cattle – intake (kg/day)

Feedlot Cattle Class/Average time on Feed	1990–1995[a]	1996+[b]
domestic/ 75 days	7.20	9.8
export/ 140 days	8.47	11.7
Japan ox/ 250 days	11.50	11.0

(a) Working group estimates based on the assumption that intake is 2.4%, 2.2% and 2.0% of liveweight for domestic, export and Japanese ox markets respectively
(b) van Sliedregt *et al.* (2000)

Table 6.C.3: Feedlot cattle – proportion of feed components

State	Total grain (incl. molasses)	Other Concentrates	Grasses	Legumes
1990–1995[a]	0.708	0.072	0.118	0.102
1996+[b]	0.779	0.048	0.138	0.035

(a) based on working group estimates, (b) van Sliedregt *et al.* (2000).

Table 6.C.4: Feedlot cattle – composition of feed components

Diet Components	Concentrates		Roughage	
	grain	other conc.	grass	legume
Cellulose	0.07	0.19	0.31	0.36
Hemicellulose	0.04	0.11	0.31	0.20
Soluble residue	0.68	0.19	0.21	0.21
Nitrogen	0.02	0.05	0.026	0.032

Based on AFIC 1987 and working group estimates

Table 6.C.5: Feedlot cattle – liveweight gain (kg/day)

Feedlot Cattle Class/Average time on Feed	1990–1995[a]	1996+[b]
domestic/ 75 days	1.2	1.7
export/ 140 days	1.2	1.5
Japan ox/ 250 days	1.2	1.2

(a) based on working group estimates, (b) van Sliedregt *et al.* (2000).

Appendix 6.D: Sheep

Table 6.D.1: Sheep – liveweight (kg)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
NSW/ACT	Spring	75	62	44	54	56	20
	Summer	75	55	42	49	51	27
	Autumn	69	55	43	50	50	32
	Winter	69	55	45	50	51	34
Tasmania	Spring	90	55	45	50	50	14
	Summer	90	55	45	50	50	24
	Autumn	75	50	45	50	50	36
	Winter	75	45	50	55	50	42
Western Australia	Spring	75	60	50	55	55	30
	Summer	65	55	45	50	50	30
	Autumn	65	48	40	45	45	10
	Winter	65	48	45	50	50	20
South Australia	Spring	80	70	52	55	55	40
	Summer	70	65	52	55	55	45
	Autumn	70	60	52	55	55	20
	Winter	70	60	52	55	55	30
Victoria	Spring	70	60	50	55	50	22
	Summer	65	55	45	50	50	28
	Autumn	65	52	43	48	50	33
	Winter	60	50	40	45	50	35
Queensland	Spring	58	50	35	40	45	20
	Summer	61	55	40	45	50	25
	Autumn	63	55	40	45	50	20
	Winter	60	50	35	42	48	25

Table 6.D.2: Sheep – dry matter digestibility of feed intake (%)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(%)	(%)	(%)	(%)	(%)	(%)
NSW/ACT	Spring	75	75	75	75	75	75
	Summer	61	61	61	61	61	61
	Autumn	64	64	64	64	64	64
	Winter	72	72	72	72	72	72
Tasmania	Spring	75	75	75	75	75	75
	Summer	55	55	55	55	55	55
	Autumn	67	67	67	67	67	67
	Winter	70	70	70	70	70	70
Western Australia	Spring	73	73	73	73	73	73
	Summer	55	55	55	55	55	55
	Autumn	50	50	70	70	50	70
	Winter	76	76	76	76	76	76
South Australia	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	55	55	55	55	55	55
	Winter	75	75	75	75	75	75
Victoria	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	65	65	65	65	65	65
	Winter	60	60	60	60	60	60
Queensland	Spring	51	51	51	51	51	51
	Summer	55	55	55	55	55	55
	Autumn	59	59	59	59	59	59
	Winter	58	58	58	58	58	58

Table 6.D.3: Sheep – feed availability (t/ha)

State	Season	Sheep > 1					Sheep< 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(t/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)
NSW/ACT	Spring	2.90	2.90	2.90	2.90	2.90	2.90
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.60	1.60	1.60	1.60	1.60	1.60
	Winter	1.70	1.70	1.70	1.70	1.70	1.70
Tasmania	Spring	2.50	2.50	2.50	2.50	2.50	2.50
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.30	1.30	1.30	1.30	1.30	1.30
	Winter	0.80	0.80	0.80	0.80	0.80	0.80
Western Australia	Spring	3.50	3.50	3.50	3.50	3.50	3.50
	Summer	1.50	1.50	1.50	1.50	1.50	1.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	1.20	1.20	1.20	1.20	1.20	1.20
South Australia	Spring	4.00	4.00	4.00	4.00	4.00	4.00
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	0.90	0.90	0.90	0.90	0.90	0.90
Victoria	Spring	3.20	3.20	3.20	3.20	3.20	3.20
	Summer	3.00	3.00	3.00	3.00	3.00	3.00
	Autumn	1.80	1.80	1.80	1.80	1.80	1.80
	Winter	1.00	1.00	1.00	1.00	1.00	1.00
Queensland	Spring	1.50	1.50	1.50	1.50	1.50	1.50
	Summer	2.00	2.00	2.00	2.00	2.00	2.00
	Autumn	2.20	2.20	2.20	2.20	2.20	2.20
	Winter	1.70	1.70	1.70	1.70	1.70	1.70

Table 6.D.4: Sheep – crude protein content of feed intake (%)

State	Season	Sheep > 1					Sheep < 1
		Ram	Wether	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(%)	(%)	(%)	(%)	(%)	(%)
NSW/ACT	Spring	20	20	20	20	20	20
	Summer	10	10	10	10	10	10
	Autumn	12	12	12	12	12	12
	Winter	18	18	18	18	18	18
Tasmania	Spring	20	20	20	20	20	20
	Summer	7	7	7	7	7	7
	Autumn	14	14	14	14	14	14
	Winter	16	16	16	16	16	16
Western Australia	Spring	18	18	18	18	18	18
	Summer	6	6	6	6	6	6
	Autumn	6	6	16	16	6	16
	Winter	21	21	21	21	21	21
South Australia	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	9	9	9	9	9	9
	Winter	20	20	20	20	20	20
Victoria	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	13	13	13	13	13	13
	Winter	10	10	10	10	10	10
Queensland	Spring	8	8	8	8	8	8
	Summer	10	10	10	10	10	10
	Autumn	9	9	9	9	9	9
	Winter	7	7	7	7	7	7

Table 6.D.5: Sheep – liveweight gain (kg/day)

State	Season	Sheep > 1					Sheep < 1
		Rams (kg/day)	Wethers (kg/day)	Maiden Ewes (intended for breeding) (kg/day)	Breeding Ewes (kg/day)	Other Ewes (kg/day)	Lambs & Hoggets (kg/day)
NSW/ACT	Spring	0.07	0.08	0.07	0.04	0.05	0.16
	Summer	0	-0.08	0.00	-0.05	-0.05	0.08
	Autumn	-0.07	0.00	0.00	0.01	-0.01	0.05
	Winter	0.00	0.00	0.02	0.00	0.01	0.04
Tasmania	Spring	0.16	0.11	0.03	-0.02	0.00	0.15
	Summer	0.00	0.00	0.00	0.00	0.00	0.11
	Autumn	-0.20	-0.10	0.00	0.00	0.00	0.13
	Winter	0	-0.10	0.5	0.02	0.00	0.07
Western Australia	Spring	0.11	0.13	0.05	0.05	0.05	0.11
	Summer	-0.11	-0.05	-0.05	-0.05	-0.05	0.00
	Autumn	0.00	-0.08	0.11	-0.05	-0.05	0.11
	Winter	0.00	0.00	0.05	0.05	0.05	0.11
South Australia	Spring	0.11	0.11	0.00	0.00	0.00	0.11
	Summer	-0.10	-0.10	0.00	0.00	0.00	0.05
	Autumn	0.00	-0.10	0.00	0.00	0.00	0.16
	Winter	0.00	0.00	0.00	0.00	0.00	0.16
Victoria	Spring	0.11	0.11	0.16	0.11	0.00	0.15
	Summer	-0.05	-0.05	-0.05	-0.05	0.00	0.07
	Autumn	0.00	-0.03	-0.02	-0.02	0.00	0.05
	Winter	-0.05	-0.02	-0.03	-0.03	0.00	0.02
Queensland	Spring	-0.02	0.00	0.00	-0.02	-0.03	0.20
	Summer	0.03	0.05	0.05	0.05	0.05	0.05
	Autumn	0.02	0.00	0.00	0.00	0.00	0.20
	Winter	-0.03	-0.05	-0.05	-0.03	-0.02	0.05

Table 6.D.6: Sheep – proportion of lambs receiving milk in each season

State	Spring	Summer	Autumn	Winter
NSW/ACT	0.4	0.1	0.2	0.3
Tasmania	0.6	0	0.1	0.3
Western Australia	0.15	0.1	0.15	0.6
South Australia	0.15	0.05	0.3	0.5
Victoria	0.3	0.1	0.25	0.35
Queensland	0.5	0	0.5	0

Source: Based on breed weighted season of joining (+ 2 seasons) as reported in the MLA 2002 Lamb Survey. Queensland and Tasmania estimates based on information provided by State experts.

Table 6.D.7: Sheep – standard reference weights (kg)

State	Sheep > 1					Sheep< 1
	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
NSW/ACT	78	62	57	57	57	60
Tasmania	77	66	55	55	55	60
Western Australia	84	72	60	60	60	66
South Australia	84	72	60	60	60	66
Victoria	70	60	50	50	50	55
Queensland	70	60	50	50	50	55

Based on SCA 1990

Appendix 6.E: Pigs

Table 6.E.1: Pigs – feed intake (kg DM/head/day)

Year	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	2.20	2.20	2.97	1.20
1991	2.20	2.26	2.98	1.23
1992	2.20	2.32	2.98	1.26
1993	2.20	2.38	2.99	1.29
1994	2.20	2.44	2.99	1.32
1995	2.20	2.50	2.99	1.35
1996	2.20	2.56	3.00	1.37
1997	2.20	2.62	3.00	1.40
1998	2.20	2.68	3.01	1.43
1999	2.20	2.74	3.01	1.46
2000+	2.20	2.80	3.02	1.49

Table 6.E.2: Pigs – volatile solids (kg/head/day) entering manure management system

Year	Volatile Solids (kg/head/day)			
	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	0.38	0.40	0.47	0.22
1991	0.38	0.42	0.47	0.23
1992	0.38	0.43	0.47	0.23
1993	0.39	0.44	0.48	0.24
1994	0.39	0.46	0.48	0.24
1995	0.39	0.47	0.48	0.25
1996	0.39	0.48	0.48	0.26
1997	0.39	0.50	0.49	0.26
1998	0.39	0.51	0.49	0.27
1999	0.39	0.52	0.49	0.28
2000+	0.39	0.54	0.49	0.28

Estimate includes volatile solids from waste feed

Table 6.E.3: Pigs – allocation of waste to manure management systems

State	Manure Management Systems				
	Lagoon (%)	Liquid/slurry (%)	Drylot (%)	Daily Spread (%)	Digester (%)
NSW/ACT	73	0	0	27	0
Tasmania	0	0	0	100	0
Western Australia	65	0	30	5	0
South Australia	73	0	0	27	0
Victoria	71	0	0	27	2
Queensland	92	1.5	5	1.5	0
Northern territory	100	0	0	0	0

Table 6.E.4: Pigs – Methane Conversion Factor (MCF)

State	Manure Management System MCF				Integrated MCF	
	Lagoon (%)	Liquid/slurry (%)	Drylot (%)	Daily Spread (%)	Digester (%)	(%)
NSW/ACT	90	35	1.5	0.5	10	65.84
Tasmania	90	35	1.5	0.5	10	0.50
Western Australia	90	35	1.5	0.5	10	58.98
South Australia	90	35	1.5	0.5	10	65.84
Victoria	90	35	1.5	0.5	10	64.24
Queensland	90	65	5.0	1.0	10	84.04
Northern Territory	90	65	5.0	1.0	10	90.00

Table 6.E.5: Pigs – nitrogen (kg /head/year) entering the manure management system

Year	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	15.29	16.36	20.76	10.37
1991	15.22	15.95	20.75	10.44
1992	15.15	15.53	20.74	10.51
1993	15.08	15.12	20.74	10.57
1994	15.01	14.71	20.73	10.64
1995	14.94	14.30	20.73	10.71
1996	14.87	13.88	20.72	10.77
1997	14.80	13.47	20.71	10.84
1998	14.73	13.06	20.71	10.91
1999	14.66	12.65	20.70	10.98
2000+	14.59	12.23	20.70	11.04

Estimate includes nitrogen in waste feed

Appendix 6.F: Other Livestock

Table 6.F.1: 'Other livestock' – enteric fermentation emission factors (kg CH_4/head/year)

State	Livestock Type								
	Goats	Horses	Deer	Buffalo	Donkeys / Mules	Emus/ Ostriches	Alpacas	Camels	Poultry
All States	5	18	10.7	55	10	5	10	46	NE

Table 6.F.2: 'Other livestock' – nitrogen excretion factors (kg N/head/year)

State	Livestock Type									
	Goats	Horses	Deer	Buffalo	Donkeys /Mules	Emus/ Ostriches	Alpacas	Camels	Poultry Meat	Poultry Layers
All States	7.0	39.5	13.2	39.5	13.2	7.0	7.0	39.5	0.7	0.6

Table 6.F.3: 'Other livestock' – manure production (kg DM/head/year)

State	Livestock Type							
	Goats	Horses	Deer	Buffalo	Donkeys/ Mules	Emus/ Ostriches	Alpacas	Camels
All States	114	957	319	957	319	114	114	957

Appendix 6.G: Pigbal Analysis

The estimation of volatile solids and nitrogen in the waste stream of piggeries was calculated using the nutrient balance model PIGBAL (Casey *et al.* 1996). Pig industry experts provided information on average intakes and other relevant details for a typical herd in 1990 and 2000. The waste produced for each pig class was then calculated in PIGBAL based on a 1,000 sow herd.

Changes in the herd and feed characteristics are assumed to have occurred gradually from 1990 to 2000. Intake and volatile solids for the years 1991–1999 were, therefore, estimated using a linear regression analysis.

As population statistics are only available for Boars, Gilts, Sow and Other Pigs, weighted averages of intake, volatile solids and nitrogen (as reported in Appendix 6.E) were developed for Sows and Other Pigs based on the herd modelled by PIGBAL.

Table 6.G.1: 1990 feed specification for pigs

Class	Intake (kg/day/pig)	Feed wasted (%)	Crude Protein (%)
Boars	2.20	5.00	13
Gilts	2.20	10.00	18
Gestating sows	2.66	5.00	13
Lactating sows	4.50	5.00	18
Suckers	0.10	20.00	24
Weaner pigs	0.90	15.00	22
Grower pigs	1.50	10.00	21
Finisher pigs	2.20	10.00	18

Table 6.G.2: 2000 feed specifications for pigs

Class	Intake (kg/day/pig)	Feed wasted (%)	Crude Protein (%)
Boars	2.20	5.00	13
Gilts	2.80	10.00	14
Gestating sows	2.66	5.00	13
Lactating sows	5.50	5.00	17
Suckers	0.10	20.00	23
Weaner pigs	1.10	15.00	21
Grower pigs	1.80	10.00	18
Finisher pigs	2.20	10.00	14

Table 6.G.3: Herd characteristics used in PIGBAL

Herd Details		1990	2000
Average lactation length	(days)	28	21
Age out of farrowing accommodation	(days)	28	21
Age out of weaner accommodation	(weeks)	10	10
Age out of grower accommodation	(weeks)	16	16
Age at turnoff	(weeks)	21	24
Age at mating	(weeks)	30	30
Average live pig birth mass	(kg)	1.4	1.4
Average pig weaning mass	(kg)	8.0	6.5
Average pig mass out weaner accom.	(kg)	25	27
Average pig mass out grower accom.	(kg)	55	60
Average pig mass out finisher accom.	(kg)	100	110
Average LW at mating	(kg)	160	170
Average LW at farrowing	(kg)	215	225
Average LW boars at turnoff	(kg)	300	300
Average dressed weight backfatters	(kg)	130	140
Dressing percentage	(%)	76	78
Average dressed weight finishers sold	(kg)	76	86

Appendix 6.H: Synthetic Fertilisers

Table 6.H.1: Fraction of fertiliser N applied to each production system, 1990-2012

State	Production System	1990-1995	1996 - 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NSW	Non-irrigated crops	0.0352	0.0352	0.0352	0.0465	0.0485	0.0544	0.0555	0.0736	0.0643	0.0448	0.0418	0.0413	0.0268	0.0278
	Non-irrigated pasture	0.0892	0.0892	0.0892	0.1223	0.1506	0.1286	0.1161	0.1667	0.1415	0.1234	0.1227	0.0745	0.0718	0.0974
	Irrigated crops	0.2549	0.2549	0.2553	0.2232	0.2338	0.67	0.2167	0.1656	0.1926	0.2479	0.2092	0.2506	0.2050	0.2293
	Irrigated Pasture	0.3833	0.3833	0.3838	0.3033	0.3197	0.3865	0.3968	0.2658	0.2874	0.4263	0.3881	0.4025	0.3458	0.3656
	Sugar	0.0146	0.0146	0.0137	0.0263	0.0262	0.0372	0.0219	0.0291	0.0426	0.0152	0.0185	0.0144	0.0114	0.2151
	Cotton	0.1860	0.1860	0.1860	0.2146	0.1606	0.1081	0.1354	0.2133	0.1671	0.0525	0.1196	0.0864	0.2784	0.0122
	Horticultural crops	0.0368	0.0368	0.0368	0.0638	0.0607	0.0584	0.0576	0.0859	0.1045	0.0899	0.1001	0.1303	0.0609	0.0526
NT	Non-irrigated crops	0.0208	0.0208	0.0208	0.1572	-	-	-	-	-	0.0130	0.0130	0.0252	0.0317	0.0000
	Non-irrigated pasture	0.0256	0.0256	0.0256	0.0045	-	-	-	-	-	0.0000	0.0000	0.0000	0.0221	0.0000
	Irrigated crops	0.2085	0.2085	0.2085	0.2223	0.7256	0.7340	0.5540	0.0845	0.2935	0.2762	0.2762	0.1109	0.0159	0.0261
	Irrigated Pasture	0.0105	0.0105	0.0105	0.0052	0.0537	0.0543	0.0547	0.0021	0.0941	0.0634	0.0634	0.0015	0.0002	0.0014
	Sugar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cotton	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Horticultural crops	0.7345	0.7345	0.7345	0.6109	0.2208	0.2117	0.3913	0.9134	0.6124	0.6474	0.6474	0.8624	0.9301	0.9725
QLD	Non-irrigated crops	0.0193	0.0193	0.0193	0.0140	0.0169	0.0169	0.0148	0.0197	0.0212	0.0222	0.0162	0.0211	0.0094	0.0092
	Non-irrigated pasture	0.0287	0.0287	0.0287	0.0234	0.0395	0.0379	0.0274	0.0316	0.0342	0.0634	0.0560	0.0242	0.0133	0.0137
	Irrigated crops	0.0048	0.0048	0.0414	0.1339	0.1697	0.2092	0.1798	0.1746	0.2274	0.3256	0.2381	0.2924	0.2979	0.2626
	Irrigated Pasture	0.0032	0.0032	0.0279	0.0716	0.0809	0.1304	0.1089	0.0971	0.0923	0.1668	0.1552	0.1496	0.1701	0.1516
	Sugar	0.6359	0.6359	0.5745	0.5029	0.5453	0.4465	0.4582	0.4566	0.4984	0.3192	0.3884	0.3140	0.2249	0.1787
	Cotton	0.2315	0.2315	0.2315	0.1702	0.0809	0.1018	0.1542	0.1488	0.0562	0.0346	0.0843	0.0867	0.2311	0.3317
	Horticultural crops	0.0766	0.0766	0.0766	0.0838	0.0669	0.0573	0.0569	0.0715	0.0702	0.0681	0.0617	0.1120	0.0533	0.0525

State	Production System	1990-1995	1996 - 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
SA	Non-irrigated crops	0.0184	0.0184	0.0184	0.0233	0.0264	0.0266	0.0329	0.0355	0.0324	0.0359	0.0268	0.0252	0.0199	0.0178
	Non-irrigated pasture	0.0093	0.0093	0.0093	0.0036	0.0081	0.0053	0.0078	0.0091	0.0066	0.0137	0.0087	0.0047	0.0054	0.0072
	Irrigated crops	0.3349	0.3349	0.3349	0.3332	0.3042	0.3069	0.2916	0.2925	0.2911	0.2946	0.2940	0.3251	0.3233	0.3291
	Irrigated Pasture	0.5443	0.5443	0.5443	0.4951	0.5396	0.5534	0.5241	0.4952	0.5147	0.5147	0.5359	0.5228	0.5443	0.5372
	Sugar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cotton	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Horticultural crops	0.0931	0.0931	0.0931	0.1448	0.1216	0.1078	0.1436	0.1678	0.1552	0.1411	0.1346	0.1222	0.1071	0.1087
Tas	Non-irrigated crops	0.0936	0.0936	0.0936	0.0648	0.0665	0.0798	0.0779	0.0933	0.0801	0.1079	0.0986	0.1126	0.0664	0.0854
	Non-irrigated pasture	0.1005	0.1005	0.1005	0.0100	0.0697	0.0668	0.0485	0.0411	0.0272	0.0514	0.0402	0.0782	0.0589	0.0700
	Irrigated crops	0.3358	0.3358	0.3358	0.5934	0.6594	0.6066	0.6292	0.6105	0.7411	0.6074	0.6059	0.6112	0.6867	0.5110
	Irrigated Pasture	0.2410	0.2410	0.2410	0.1165	0.0856	0.1076	0.1038	0.1269	0.0665	0.1170	0.1361	0.0786	0.0910	0.2108
	Sugar	-	-	0.0000	0.0000	-	-	-	-	-	-	-	-	-	-
	Cotton	-	-	0.0000	0.0000	-	-	-	-	-	-	-	-	-	-
	Horticultural crops	0.2290	0.2290	0.2290	0.2153	0.1188	0.1392	0.1406	0.1283	0.0850	0.1163	0.1192	0.1194	0.0970	0.1228
Vic	Non-irrigated crops	0.1707	0.1707	0.1707	0.1400	0.1207	0.1290	0.1354	0.1487	0.0773	0.0945	0.0773	0.0676	0.0577	0.0761
	Non-irrigated pasture	0.0276	0.0276	0.0276	0.0206	0.0301	0.0312	0.0229	0.0296	0.0132	0.0217	0.0241	0.0083	0.0120	0.0224
	Irrigated crops	0.3976	0.3976	0.3976	0.4622	0.4178	0.4045	0.4026	0.3980	0.4573	0.3965	0.3902	0.4399	0.4466	0.4293
	Irrigated Pasture	0.2896	0.2896	0.2896	0.2573	0.3285	0.3378	0.3463	0.3087	0.3596	0.3634	0.3874	0.3950	0.4112	0.3951
	Sugar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cotton	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Horticultural crops	0.1145	0.1145	0.1145	0.1200	0.1029	0.0975	0.0928	0.1150	0.0926	0.1239	0.1211	0.0891	0.0725	0.0772
WA	Non-irrigated crops	0.0019	0.0019	0.0019	0.0017	-	0.0014	0.0011	0.0024	0.0020	0.0025	0.0018	0.0021	0.0027	0.0017
	Non-irrigated pasture	0.0013	0.0013	0.0013	0.0000	-	0.0002	0.0007	0.0026	0.0003	0.0015	0.0011	0.0008	0.0018	0.0016
	Irrigated crops	0.3895	0.3882	0.3882	0.4435	0.3948	0.3796	0.3732	0.3897	0.4264	0.3982	0.3732	0.3709	0.3793	0.3721
	Irrigated Pasture	0.5905	0.5884	0.5884	0.5283	0.5855	0.6013	0.6101	0.5819	0.5514	0.5772	0.6079	0.6129	0.5990	0.6098
	Sugar	-	0.0030	0.0030	0.0032	0.0030	0.0030	0.0025	0.0040	0.0030	0.0017	-	-	-	0.0006
	Cotton	-	0.0005	0.0005	0.0005	-	-	-	-	-	-	-	-	-	-
	Horticultural crops	0.0167	0.0167	0.0167	0.0227	0.0168	0.0145	0.0124	0.0192	0.0170	0.0189	0.0160	0.0133	0.0171	0.0143

Table 6.H.2: Sugar cane N fertiliser application rates

Year	NSW	QLD
1990-2000[(a)]	165	205
2001	155	185
2002	150	181
2003	148	175
2004	155	178
2005	148	173
2006	158	177
2007	161	172
2008	97	150
2009	154	180
2010	141	143
2011	176	164
2012[(b)]	148	169

Source: Incitec Pivot

(a) 1990 – 2000 rates based on the average of 1996-2000;

(b) based on average of previous 10 years.

Appendix 6.I: Crop And Pasture Attributes

Table 6.I.1: Crop and pasture attributes[a]

Crop type	Residue: Crop ratio	Fraction of residue remaining at time of burning[b]	Dry matter content	Carbon mass fraction in dry matter	Elemental N:C ratio (by mass)	Fraction burnt	Fraction Removed
k	R_k	S_k	DM_k	CC_k	NC_k	F_{ik}	$FFOD_{ik}$
Wheat	1.50	0.5	0.9	0.40	0.008	0.23	0.09
Barley	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Maize[c]	1.50	1.0	0.8	0.42	0.0179	0.3	0.09
Oats	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Rye	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Rice [c]	1.31	1.0	0.8	0.42	0.0155	0.815	0.06
Millet	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Sorghum	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Triticale	1.50	0.5	0.8	0.40	0.008	0.23	0.09
Pulses	2.1	0.5	0.8	0.4	0.05	0.24	0.09
Tuber and Roots	NA	NA	NA	NA	NA	0	1
Sugar cane	0.25	1.0	0.2	0.40	0.025	Table 6.I.2	[d]
Peanuts	1	0.5	0.8	0.40	0.05	0	0.09
Other Crops	1.5	0.5	0.8	0.40	0.008	0.08	0.05
Legume Pastures	1	NA	0.87	0.40	0.08	NA	NA

(a) Sourced from Milthorpe (1982), Saffigna *et al.* (1982), Galbally *et al.* (1992) unless otherwise specified;

(b) Mulholland *et al.* (1976) and R Jarvis pers. comm,

(c) Robinson and Kirby 2002;

(d) 0.03 for QLD and zero for WA and NSW.

Table 6.I.2: Fraction of sugar cane burnt in each State

Year	NSW	WA	QLD	Australia
1989	1.000	NO	0.735	0.750
1990	0.978	NO	0.686	0.701
1991	0.987	NO	0.664	0.680
1992	0.987	NO	0.639	0.662
1993	0.987	NO	0.641	0.663
1994	0.965	NO	0.596	0.618
1995	0.949	NO	0.585	0.606
1996	0.975	1.000	0.505	0.532
1997	0.976	1.000	0.430	0.465
1998	0.951	1.000	0.404	0.439
1999	0.951	1.000	0.307	0.354
2000	0.928	1.000	0.346	0.389
2001	0.920	1.000	0.390	0.434
2002	0.897	1.000	0.357	0.398
2003	0.884	1.000	0.331	0.372
2004	0.915	1.000	0.329	0.374
2005	0.963	1.000	0.306	0.348
2006	0.975	1.000	0.282	0.325
2007	0.947	1.000	0.434	0.472
2008	0.947	1.000	0.271	0.314
2009	0.733	NO	0.263	0.316
2010	0.797	NO	0.287	0.316
2011	0.874	1.000	0.359	0.391
2012	0.958	1.000	0.374	0.408
2013	0.896	NO	0.265	0.284

Source: QLD Cane Growers Association and NSW Sugar Milling Cooperative Ltd

Appendix 6.J: Nitrogen Leaching and Runoff

Table 6.J.1: Fraction of fertiliser N available for leaching and runoff (FracWET)

	NSW	NT	Qld	SA	Tas	Vic	WA
Irrigated Pasture	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Irrigated crops	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Non-irrigated pasture	0.334	0.811	0.128	0.708	0.991	0.855	0.508
Non-irrigated crops	0.192	0.777	0.043	0.279	0.985	0.438	0.223
Sugar	0.990		0.656				0.759
Cotton (in rotation with wheat and vetch)	0.246		0.075				0.759
Horticultural crops	0.599	0.857	0.293	0.667	0.996	0.702	0.911

Table 6.J.2: Fraction of animal waste available for leaching and runoff (FracWET)

State	Region	Dairy Cattle	Free range beef cattle	Feedlot cattle	Sheep	All other categories
ACT		0.96	0.785	0	0.812	0.665
NSW		0.646	0.365	0.192	0.269	0.335
NT		1	0.237	0	0	0.773
QLD		0.348	0.114	0.043	0.018	0.107
SA		0.721	0.691	0.279	0.516	0.415
TASMANIA		1	0.997	0	0.987	0.995
VIC		0.9	0.914	0.438	0.873	0.768
WA		0.996		0.223	0.51	0.668
	South West		0.823			
	Pilbara		0.089			
	Kimberley		0.381			

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