



Australian Government

Department of Climate Change

AUSTRALIA'S NATIONAL GREENHOUSE ACCOUNTS



The Australian Government Submission to the UN Framework Convention on Climate Change May 2009

National Inventory Report 2007 **Volume 1**



thinkchange

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The Australian National Greenhouse Accounts are available on the Internet at the following address: <http://www.climatechange.gov.au/inventory>.

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Executive summary

Background Information on Greenhouse Gas Inventories

This is Australia's *National Inventory Report 2007* submitted under the United Nations Framework Convention on Climate Change (UNFCCC). It contains national greenhouse gas emission estimates for the period 1990-2007, and updates the estimates presented in the *National Inventory Report 2006* submitted in June 2008. Parties to the Convention are committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs). This submission also constitutes Australia's voluntary submission under the Kyoto Protocol.

This report is compiled in accordance with the Inventory Reporting Guidelines agreed by the UNFCCC 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.

The *National Inventory Report 2007* 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 2).

The responsibility for Australia's greenhouse emissions reporting has been assigned to the Department of Climate Change (DCC), within the Prime Minister's portfolio. The DCC 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 *Report*, the DCC publishes a range of supporting emission estimates that, together, constitute the *Australian National Greenhouse Accounts*. In addition to the *National Inventory Report*, the Department of Climate Change also prepares:

- the *National Greenhouse Gas Inventory*, prepared under the reporting provisions applicable to the Kyoto Protocol¹;
- 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 DCC website at www.climatechange.gov.au/inventory. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

Summary of the National Emission and Removal Related Trends

In 2007, Australia's total greenhouse gas emissions were 541.2 million tonnes (Mt), CO₂-equivalent (CO₂-e) excluding the land use, land use change and forestry (LULUCF) sector. This represents an increase of 6.7 Mt or 1.3% on net emissions recorded in 2006 and an increase of 30.0% (125.0 Mt) on 1990 levels (Table ES.1).

When the LULUCF sector emissions and removals are included in the total, Australia's net greenhouse gas emissions in 2007 were 825.9 Mt CO₂-e. This represents an increase of 372.1 Mt or 82.0% on net emissions recorded in 1990. From year to year the LULUCF sector may change from a net source to a net sink. In 2007, the LULUCF sector was a net source of 284.7 Mt. The trends in the LULUCF sector are primarily driven by inter-annual climate variability and natural disturbance, which tends to mask other, underlying patterns in the sector directly associated with human activities.

¹ Separate estimates of Australia's emissions are compiled according to the inventory reporting requirements for the UNFCCC and the Kyoto Protocol. The principal difference between the two approaches relates to the treatment of the land use, land use change and forestry activities. The UNFCCC inventory also includes reporting of indirect greenhouse gases for which global warming potentials are not available.

Table ES.1: Australia's net greenhouse gas emissions by sector

Sector and Subsector	Emissions Mt CO ₂ -e			Per cent change
	1990	2006	2007	1990-2007
1 All energy (combustion + fugitive)	286.4	400.1	408.2	42.5
<i>Stationary energy</i>	195.1	287.1	291.7	49.5
<i>Transport</i>	62.1	78.6	78.8	26.9
<i>Fugitive emissions from fuel</i>	29.2	34.3	37.7	28.9
2 Industrial Processes	24.1	29.4	30.3	25.7
3 Solvent and other product use ^(a)	IE	IE	IE	IE
4 Agriculture	86.8	90.8	88.1	1.5
6 Waste	18.8	14.2	14.6	-22.5
Total net emissions (excluding LULUCF)	416.2	534.5	541.2	30.0
5 Land use, land use change and forestry	37.6	16.6	284.7	656.6
Total net emissions (including LULUCF)	453.8	551.1	825.9	82.0

Source: a) Included Elsewhere - emissions are included in industrial processes for confidentiality reasons

Overview of Source and Sink Category Emission Estimates and Trends

The *energy* sector was the largest source of greenhouse gas emissions in 2007 comprising 75.4% (408.2 Mt) of total net emissions (excluding LULUCF). *Energy* emissions increased by 42.5% between 1990 and 2007 and by 2.0% between 2006 and 2007 (Table 2.1). For the *energy* subsectors in 2007:

- *Stationary energy* was the main contributor to total net emissions (53.9%). Emissions increased by 1.6% between 2006 and 2007 ,
- *Transport* (14.6% of total net emissions) emissions increase by 0.2% between 2006 and 2007
- *Fugitive emissions from fossil fuels* (7.0% total net emission) increased by 9.6% between 2006 and 2007,

Industrial processes made up 5.6% (30.3 Mt) of the total net emissions (excluding LULUCF) for 2007. In 2007 emissions had increased 3.3% since 2006.

Agriculture emissions made up 16.3% (88.1 Mt) of total net emissions (excluding LULUCF) in 2007. Emissions from *agriculture* decreased by 3.0% between 2006 and 2007.

The *waste* sector contributed 2.7% (14.6 Mt) of the total net emissions (excluding LULUCF) in 2007. *Waste* emissions increased by 2.7% between 2006 and 2007.

The *land use, land use change and forestry* sector was a net source in 2007. There was an increase of 268.1 Mt between 2006 and 2007.

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 introduction to chapters 3 - 6 in Volume 1 and chapters 7 and 8, contained in Volume 2.

Other Information (eg indirect greenhouse gases)

The National Inventory Report also presents estimates of emissions of indirect greenhouse gases, including NO_x, CO, NMVOC and SO₂. For these gases, no Global Warming Potentials are available to enable their conversion to carbon dioxide equivalent emissions. Consequently these emissions sources are not able to be aggregated and nor are they covered by the reporting provisions of the Kyoto Protocol. Estimates of Australia's emissions from NO_x, CO, NMVOC and SO₂ are presented in chapter 2.

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Sector	Consultant	Organisation
Energy	Dr Hugh Saddler Mr Graham Anderson Dr George Wilkenfeld Mr Steven Oliver Mr Glen Whitehead Mr Mark Hunstone	Energy Strategies Pty Ltd Energy Strategies Pty Ltd George Wilkenfeld and Associates Pty Ltd Department of Climate Change Department of Climate Change Department of Climate Change
Industrial processes and solvents	Dr Jeff Deslandes Mr Mark O'Brien Mr Mark Hunstone	EnerGreen Consulting Beyond Neutral Pty Ltd Department of Climate Change
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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 ₂ F ₆	perfluoroethane (a perfluorocarbon)
CH ₄	Methane
CO	carbon monoxide
CO ₂	carbon dioxide
HFCs	hydrofluorocarbons
N ₂ O	nitrous oxide
NM VOC	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 ₂ O = 310	HFC-134a = 1,300
CF ₄ = 6,500	HFC-143a = 3,800
C ₂ F ₆ = 9,200	SF ₆ = 23,900

Conversion Factors

From element basis to molecular mass

C → CO₂: $\times 44/12 = 3.67$

C → CH₄: $\times 16/12 = 1.33$

N → N₂O: $\times 44/28 = 1.57$

From molecular mass to element basis

CO₂ → C: $\times 12/44 = 0.27$

CH₄ → C: $\times 12/16 = 0.75$

N₂O → N: $\times 28/44 = 0.64$

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

1. Introduction and Inventory Context

1.1 Background Information on Greenhouse Gas Inventories

Australia's *National Inventory Report 2007* provides estimates of Australia's net greenhouse gas emissions for the period 1990-2007 and is submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as part of Australia's reporting obligations under that Convention. This submission also constitutes Australia's voluntary submission under the Kyoto Protocol.

The *National Inventory Report 2007* covers sources of greenhouse gas emissions and removals by sinks resulting from human (anthropogenic) activities for the major greenhouse gases – carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF₆). Also covered in ancillary fashion are the indirect greenhouse gases-carbon monoxide (CO), oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Sulphur dioxide (SO₂), 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 (CO₂-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 CO₂-e allows the integrated effect of emissions of the various gases to be compared.

Emissions and removals have been grouped under six sectors that have been defined by the Intergovernmental Panel on Climate Change (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.

The *National Inventory Report 2007* has been compiled in accordance with the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000); *Good Practice Guidance on Land Use, Land Use Change and Forestry* (IPCC 2003) and the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). 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.

The structure of this *National Inventory Report* has been organised to conform with UNFCCC reporting guidelines (FCCC/SBSTA/2006/9). The *National Inventory Report* provides estimates of Australia's total net emissions in 2007 and identifies trends in emissions between 1990 and 2007 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 inventory preparation processes in order to facilitate international review and comparisons with the inventories of other countries.

² GWPs used are, 1 for CO₂, 21 for CH₄, 310 for N₂O, 6,500 for the PFC perfluoromethane (CF₄), 9,200 for the PFC perfluoroethane (C₂F₆), and 23,900 for SF₆. 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

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

- the *National Greenhouse Gas Inventory*, prepared under the reporting provisions applicable to the Kyoto Protocol;
- 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 DCC website www.climatechange.gov.au/inventory. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

1.2 Institutional Arrangements

The Australian inventory is supported by a set of institutional arrangements which is designed to facilitate close co-ordination of the compilation of the inventory, efficient emissions data management, broadly based quality assurance processes; and secure and reliable data collections.

Single national entity

The responsibility for Australia's greenhouse emissions reporting has been assigned to the Department of Climate Change, within the Prime Minister's portfolio, under the Administrative Arrangements Orders of the Australian Government (25 January 2008). The DCC 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.

Centralised emissions estimation

Estimation of emissions is conducted by the DCC utilising the Australian Greenhouse Emissions Information System (AGEIS) and, for the *land use, land use change and forestry* sector, the National Carbon Accounting System (NCAS) (as illustrated below).

The DCC introduced the AGEIS into the inventory production process in 2005. The AGEIS was 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 Inventory Accounts publicly accessible through an interactive web interface at www.climatechange.gov.au/inventory.

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 commencement of the integration of the National Greenhouse and Energy Reporting (Measurement) Determination 2008 into the AGEIS; construction of a range of QC tools to enhance and automate existing tools; facilitation of more timely production of emissions estimates; and the implementation of a carbon balance for fossil fuel consumption across the economy.

While the AGEIS is used for final preparation of the National Greenhouse Accounts, the system uses the National Carbon Accounting System (NCAS) estimates of the emissions and removals from the *land use, land use change and forestry* sector.

Figure 1.1: Department of Climate Change inventory asset structures and relationships

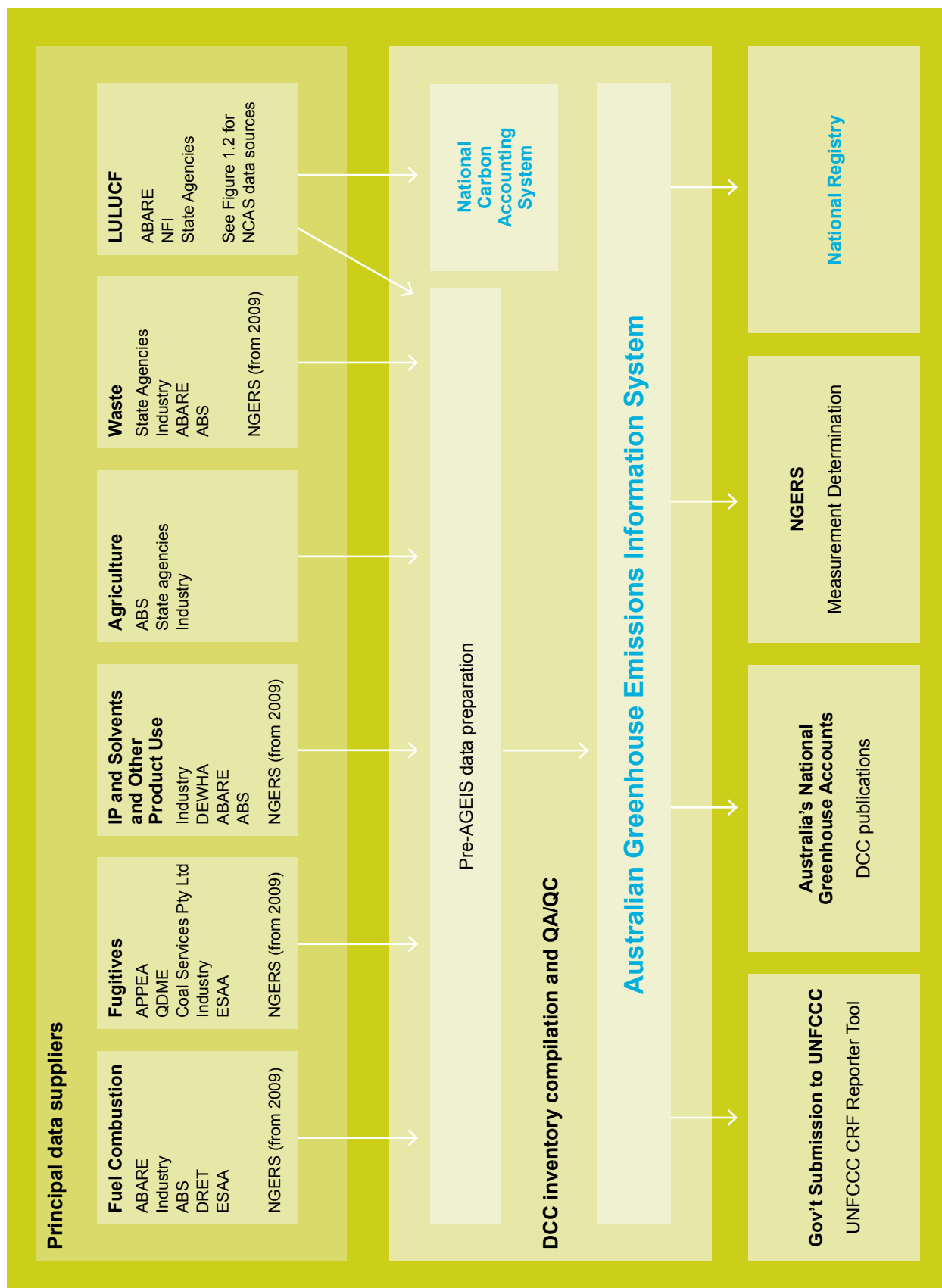
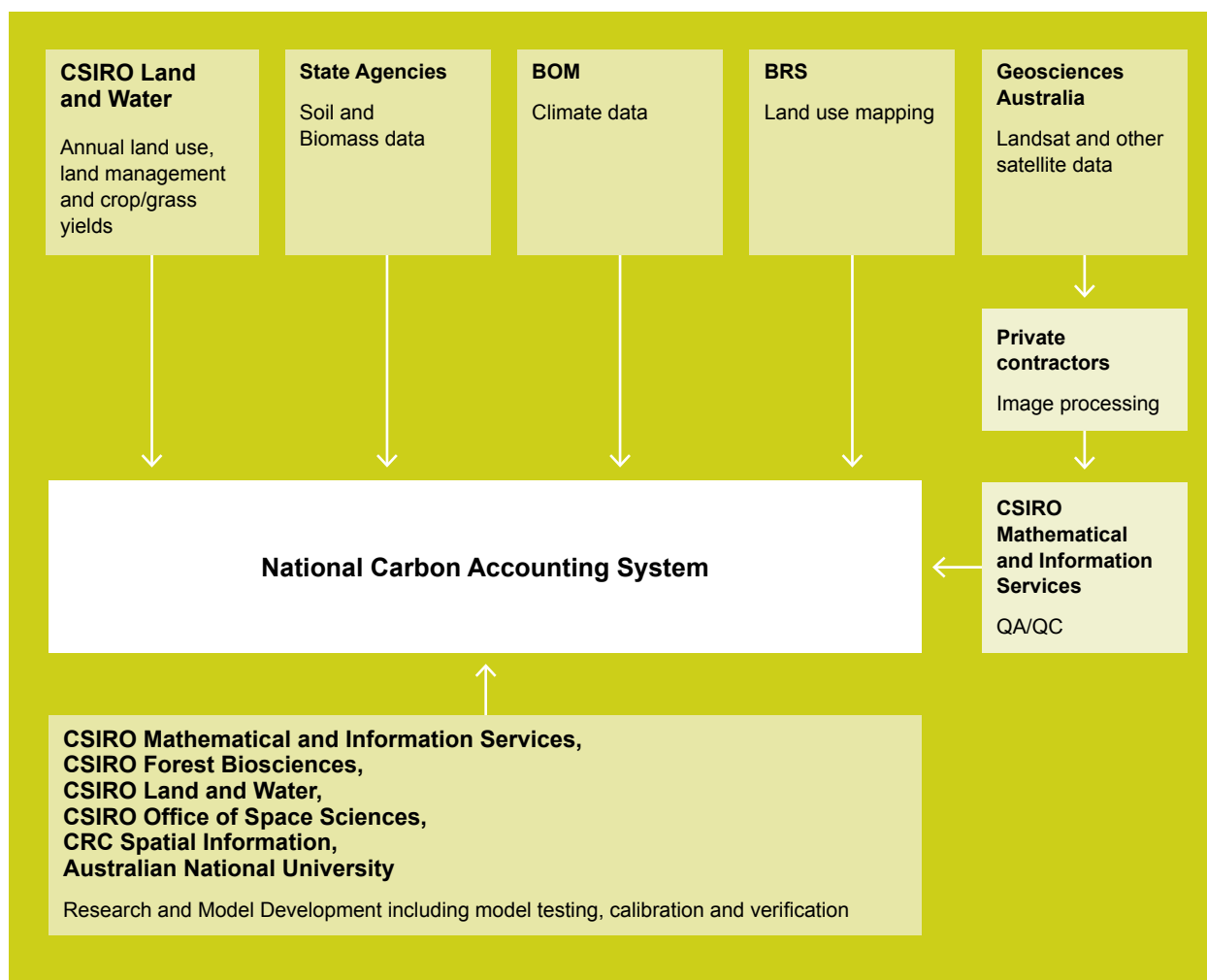


Figure 1.2: National Carbon Accounting System institutional arrangements



Framework for data collection

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

The data collection process 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) and the Australian Bureau of Agricultural and Resource Economics (ABARE). The ABS is the national statistical agency with legislative backing for its collection powers. It is the source of agricultural activity and some commodity and energy related data. The energy consumption data are sourced from ABARE, which publishes data from a survey of energy use that has operated for 30 years and which are used to fulfil Australia's reporting requirements to the International Energy Agency.

The DCC employs consultants to collect data directly from companies for the *industrial processes* sector and to process the satellite imagery to determine land cover change for the *land use, land use change and forestry* sector. Data to support estimates of HFCs, are sourced from compulsory reporting by importers 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.

Future data collection framework

The National Greenhouse and Energy Reporting Act 2007 establishes the legislative framework for a national greenhouse and energy reporting system. This legislation was introduced to the Australian Parliament on 15 August 2007 and received Royal Assent on 28 September 2007.

The reporting system established by the Act will underpin the introduction of a future Australian Carbon Pollution Reduction Scheme (CPRS), and inform government policy and the Australian public. The Act provides for a reporting system that will ensure:

- robust and transparent emissions reporting for the CPRS;
- a single streamlined national reporting point for greenhouse gas emissions and energy data to assist Commonwealth, State and Territory government programs and activities;
- Australia's international reporting obligations are met.

The Act will make reporting mandatory for companies whose energy production, energy use, or greenhouse gas emissions (from the energy, industrial process and waste sectors) meet certain thresholds. The first reporting period under the NGERs Act is 2008-09. Mandatory reporting will occur through a streamlined national reporting system.

The preparation of regulations under the Act have been designed to ensure that 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. The default methods are the national inventory methods and the default emission factors have been derived using the AGEIS.

The Act, regulations, and updated information on the national greenhouse and energy reporting system can be accessed at: www.climatechange.gov.au/reporting.

Process for Official Consideration and Approval of the Inventory

The *National Inventory Report* is prepared by the Department of Climate Change. Prior to the adoption of new methods and the finalisation of the National Inventory Report, each new method and report is considered by the National Greenhouse Gas Inventory Committee, which comprises representatives of the Australian, State and Territory governments and has been in place since the early 1990s. The Committee is the principal mechanism for review of the *National Inventory 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 National Greenhouse Gas Inventory Committee.

Release of each year's new inventory and submission to the UNFCCC is approved by the Minister for Climate Change and Water of the Australian Government.

Changes to the National System

There have been no changes to the national system since the 2008 submission.

National Registry

Under the Kyoto Protocol, Parties are required to put in place a registry to report annually on acquisition, holding, transfer, cancellation, withdrawal and carryover of assigned amount units, removal units, emission reduction units and certified emission reductions during the previous year. Since the submission of Australia's Initial Report under the Kyoto Protocol, Australia's National Registry has been developed and implemented by Perrin Quarles Associates, Inc. (PQA) (November and December 2008) for operation by the Department of Climate Change. A full description of Australia's registry system is presented in Annex 8 (Volume 2).

Following the successful initialisation testing of Australia's National Registry against the UNFCCC Secretariat's Data Exchange Standards, the registry went live with the UNFCCC Secretariat's International Transaction Log (ITL) system on 19 December 2008. There have been no changes to the national registry since this time, however a new system administrator has been appointed (see Annex 8 for details).

PQA developed the registry as a customised version of the Emissions and Allowance Tracking System (EATS), a software application for collecting, verifying, and managing emissions and tradable allowance data for state, regional, national, and international emissions trading programmes. The National Registry allows Australia to manage its obligations under the Kyoto Protocol as well as to participate in international emissions trading, including receiving credits based on Clean Development Mechanism (CDM) projects. While the registry has not yet been opened to users outside of the Australian Department of Climate Change, going live with the ITL represents a key step towards Australia's participation in emissions trading under the Kyoto Protocol. The registry will be further developed over 2009 to support Australia's Carbon Pollution Reduction Scheme, set for introduction in 2010.

Commitment Period Reserve

The Annex to Decision 11/CMP.1 (paragraph 6) specifies that: 'each Party included in Annex I shall maintain, in its national registry, a commitment period reserve which should not drop below 90 per cent of the Party's assigned amount calculated pursuant to Article 3, paragraphs 7 and 8 of the Kyoto Protocol, or 100 per cent of five times its most recently reviewed inventory, whichever is lowest'.

Australia's commitment period reserve is 2,661,821,229 tonnes CO₂ equivalent calculated as 90% of Australia's assigned amount.

1.3 Brief Description of the Process of 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 Submissions timelines and data availability. Steps 1-18 provide an overview of the general inventory cycle. The cycle commences with a review of emission estimation methods, the allocation of tasks and 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.
2. Preparation of *QA-QC* and *Inventory Improvement plans*, taking into account DCC review of methodologies, activity data and UNFCCC expert review recommendations.
3. Selection of expert consultants for preparation and review processes (May-June).
4. Development of investment and maintenance plan for the AGEIS (June).
5. Methodology development & review. Incorporation into AGEIS (June - October).

Data collection and entry

6. Activity data collection conducted annually by a panel of external consultants and by the DCC (June - October). Heavily reliant on published data from Australia's premier economic statistics agencies and subject to quality control checks.
7. Activity data entry into the AGEIS input database - by the DCC through predefined data entry templates (August - November).

Data verification

8. Activity data verification and quality control - the DCC 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.
9. A designated analyst (known as a Supervisory user) investigates anomalies and records an assessment of the quality of the activity data in the system.
10. The data quality is checked and internally audited by 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

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

Emission and report review

12. Emissions estimates verification – the DCC analysts repeat the range of tests on emissions estimates generated by the AGEIS to ensure time-series consistency and consistency across sectoral emissions estimates and accuracy of recalculations.
13. Checking and internal audit procedures on emission estimates by designated DCC staff to provide QC (DOM and the “Emissions Analysis Team Manager”).
14. The compiled inventory is circulated to Australian Government departments and the NNGI Committee of State and Territory government representatives for comment prior to public release (February).

Report publication

15. Automated population of reporting (CRF) tables (February).
16. The inventory is available for public release.
17. Release of Australia’s National Greenhouse Accounts and release of the AGEIS database of emission estimates and background data at www.climatechange.gov.au/inventory (April-May).
18. UNFCCC Expert Review of the National Inventory Report and CRF Tables (August-November).

1.4 Brief General Description of Methodologies and Data Sources

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 emission factors. Australia predominantly uses tier 2 approaches to estimate emissions.³ 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.

³ An explanation of the ‘Tier’ concept is provided in the Glossary

In general, *Australia's National Greenhouse Accounts* have been moving towards the adoption of enhanced estimation methods that incorporate:

- 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. For some sources, the location of the changes in activity can be important (examples include in agriculture, passenger vehicle transport, conversion to grassland and croplands and waste disposal). The inclusion of regional differences in emission processes and factors means that national emissions trends depend in part on the mix of regional trends.

The complexity also ensures that estimated emissions levels reflect past activity levels as well as current ones. The characterisation of capital stock structures in many of the estimation methodologies emphasises the link between current emission levels and past investment decisions in both the volume of capital stock and technology type (for example, in transport and household appliances). Similarly, in solid waste disposal, current emission levels depend more on past waste disposal actions than on current ones, so that the emissions profile changes only slowly.

A summary of key emission factors is provided each year in the DCC's National Greenhouse Account Factors Workbook which is available from the DCC website at www.climatechange.gov.au/inventory.

The inventory is prepared using a mix of sources for activity data including published data from national statistical agencies and DCC collections. The principal data sources are set out in Table 1.1.

Table 1.1: Principal data sources for the estimation of Australia's inventory

Category (UNFCCC sector)	Principal data sources
Energy sector (1A1, 1A2, 1A4, 1A5)	Australian Bureau of Agricultural and Resource Economics (ABARE), DCC collections
Energy sector (1A3)	ABARE, Australian Bureau of Statistics
Energy sector (1B)	Coal Services Pty Ltd, Australian Petroleum Exploration Association
Industrial processes (2) and solvents (3) HFCs	DCC collection, Australian Government Department of the Environment, Water, Heritage and the Arts
Agriculture (4)	Australian Bureau of Statistics
Land use, land use change and forestry (5)	National Carbon Accounting System DCC, ABARE,
Waste (6)	State and Territory government waste agencies

Reporting year

The Australian inventory is reported for Australian fiscal years as key data sources such as the national energy and agricultural statistics obtained from national statistical agencies (the Australian Bureau of Agricultural and Resource Economics and the Australian Bureau of Statistics) are published on this basis. The year 2007 refers to the Australian fiscal year from 1 July 2006 to 30 June 2007, and a similar format is used for other years. Time series consistency is maintained. The estimates of emissions and removals in the *land use, land use change and forestry* 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.

Treatment of confidentiality

Nearly all of the data necessary to compile the Australian inventory are publicly available. The main exception relates to the reporting of emissions from some *industrial processes* sources. Activity data for soda ash production and use, magnesia production, nitric acid production, ammonia production, acetylene use and N₂O use in aerosols and anaesthesia are commercial-in-confidence and, due to the direct relationship between activity and emissions, emissions estimates by gas species are also confidential. These emissions are aggregated and reported as CO₂-e emissions. For the next inventory report greater disaggregation of these categories will be possible following implementation of the National Greenhouse and Energy Reporting Act 2007.

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/CP.9. 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 *grassland remaining grassland*, *public electricity (solid fuel)* and *forest conversion to grasslands* as the most significant of the key categories (i.e. contributing more than 10% of the level or trend) in 2007. When the LULUCF sector is excluded from the analysis the most significant key categories in 2007 are *public electricity (solid fuel)*, *road transportation* and *enteric fermentation (sheep)*. More details are provided in Annex 1.

1.6 Information on the QA/QC Plan

Australia’s National Inventory Systems QA/QC processes are outlined in full in Australia’s *National Inventory Systems: Quality Assurance-Quality Control Plan 2008-09*. The Plan aims to conform with *IPCC Good Practice Guidance* and to contribute to the production of inventories that are accurate, where uncertainties are reduced to the extent practicable and where the inventories are transparent, documented, consistent over time, complete and internationally comparable. To this end, the DCC has established quality objectives for the national greenhouse account emission estimates and for the National Inventory Report itself. The quality indicators comprise a mix of self-assessment (ie by the DCC itself) and external assessment (in particular, by external consultants, the National Greenhouse Gas Inventory Committee and by the UNFCCC Expert Review Teams).

The key elements of the DCC quality control structures include:

- establishment of explicitly-defined quality objectives for the National Greenhouse Accounts;
- automated and systematised quality control processes built within the AGEIS for all data handling and emission estimation procedures, principally aimed at ensuring time series consistency and accuracy;
- prioritisation of quality control processes built within the AGEIS to ensure effort is principally directed toward key categories;
- separation of data handling and data approval roles within the DCC to improve accountability;
- auditability of QC controls to improve accountability;
- reconciliation checks for emissions data with reference to Australia’s national greenhouse accounts structure - national emission estimates are reconciled with the aggregation of State and territory emission estimates; and IPCC emission estimates are reconciled with economic sector classification estimates; and
- reconciliation checks for emissions data to ensure completeness of activity data for fossil fuels and carbonates.

Quality Control

Within the Department of Climate Change, quality control processes principally revolve around the central role of the AGEIS in the inventory preparation process. Key tier 1 QA/QC procedures for the inventory compilation process have been systematically built into the operation of the AGEIS. Systematic and 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. Tier 1 checks are also implemented during the pre-processing of input data. For this inventory and associated time-series, there are approximate 2.5 million data inputs in the non-LULUCF sectors.

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.

Implied emission factors are checked for time-series consistency prior to submission. International comparisons of Australia's implied emission factors with those of other Annex I parties are undertaken through a statistical analysis of differences in means.

A carbon balance has also been undertaken for all years. 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.

Category-specific QC (Tier 2) checks comprise emission factor and activity data review. These checks are described in detail in the QA/QC sections in the following chapters.

The inventory relies primarily upon official national statistics and 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 ABARE through its annual Fuel and Electricity Survey. The ABARE data was reviewed and 'benchmarked' by the ABS in its role of national statistics co-ordinator in 2004 (ABS 4648.0.55.001 Detailed Energy Statistics Australia). With respect to electricity, explicit reconciliations of energy data are undertaken by external consultants comparing data collected through DCC Programs and supplemented by survey and the estimates produced by ABARE, the Energy Supply Association of Australia and the National Electricity Market Management Company (NEMMCO) (which are all undertaken for slightly differing reasons and with slight differences in coverage).

Table 1.2: Australian implementation of tier 1 quality control checks

Tier 1 QC activity: Checks ^(a)	Implementation
Assumptions and criteria for the selection of activity data and EFs documented	Documented in the NIR and <i>Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks</i>
Transcription errors in data input and reference	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. Bibliographical data <i>references checked for correct citation.</i>
Emissions are calculated correctly	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	Extensive testing during AGEIS development phase and when new methods introduced. Selected dual estimation process using traditional spreadsheets.
Integrity of database files	Extensive verification/external acceptance testing during the AGEIS development phase. Selected dual estimation process using traditional spreadsheets. Database system and operation documentation updated and archived.
Consistency in data between source categories	Parameters (activity data, constants, EF) which are common to multiple sources are entered into global or general data tables so data is only entered once into database.
Movement of inventory data among processing steps is correct	Extensive testing during AGEIS development phase and when new methods introduced. Standard reconciliation reports are run to ensure correct aggregation of emission estimates
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	Where changes are made to methods or activity data the full time-series of emissions is recalculated, the AGEIS ensures consistent use of methods across time-series.
Completeness	Checked through CRF Reporter Tool. Mass balance checks undertaken for fuel, carbonates and biomass
Trend	Activity data, emissions and implied emissions factors are compared with previous years estimates and across time series through the AGEIS and CRF Reporter Tool
Review of internal documentation	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.

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

Quality Assurance

Australia's quality assurance systems utilises a mix of approaches which, when taken together, provide a powerful incentive structure for maintaining and enhancing the overall quality of the inventory. These quality assurance actions are principally undertaken by individuals not involved in the preparation of the inventory.

1. The national greenhouse inventory is reviewed each year by the National Greenhouse Gas Inventory Committee and by Australian Government departments prior to its release.
2. Specific reviews of sectoral methodologies are regularly performed by expert consultants that are not involved in the inventory preparation process. For example, in 2008/09, external consultants were contracted to review the waste mix and wood waste data.

3. A wide range of QA processes have been employed for the National Carbon Accounting System (see Volume 2).
5. The transparency of inventory emission estimates and methods published by the DCC ensures that the inventory is open to public review each year. Data are downloadable by the public through an email export function from the AGEIS. Industry and public feedback is encouraged through an email facility to the Inventory contact point ageis@climatechange.gov.au.
6. UNFCCC expert review team processes aim to review and improve the quality of all Annex I inventories in an open and facilitative manner on an annual basis. Australia's inventory has been reviewed by in-country teams in 2002, 2005 and 2008, with centralised reviews utilised in other years. Principal suggested modifications to the National Inventory Report and cross cutting issues raised by the review team reports published in 2009 are listed in Table 1.3.

Originally, expert working groups developed the Australian emission estimation methodologies. An important QA function is the ongoing review of estimation methodologies used to compile the Australian inventory undertaken in accordance with the DCC's Inventory Improvement Plan (and as outlined in chapter 10.4). This work focuses on key source categories, sectors where emissions have relatively higher uncertainties attached to them, and where the payoffs in terms of reduced uncertainty for the inventory overall might be expected to be greatest.

Table 1.3: Cross cutting issues for modification identified by the expert review team in recent review reports

Reference	Identified areas for inclusion ^{(a) (b)}	Response
General	Correct reporting of notation keys in a small number of cases in the industrial processes and agriculture sectors and ensure consistency between the CRFs and NIR	Implemented
Chapter 1	Establish additional QA checks in some areas, such as carbon balance for the iron and steel sector, and by systematically analysing fluctuations in IEFs	Implemented
Chapter 3	Reconcile the data used to compile the inventory with that provided by ABARE to the IEA	Project initiated
	Include additional information on emission allocation between the energy and the industrial processes sectors	Implemented
Chapter 4	Report the confidential emissions at a more disaggregated level	Greater disaggregation cannot be implemented at this time without revealing confidential data. The level of disaggregation will be reassessed once NGERS data becomes available in 2009
Chapter 6	Enhance the explanation of country specific parameters and trends in IEFs	Implemented
Chapter 7	Address issues regarding representation of land areas and provide annual land-use change matrices	Implemented
	Use annual data to estimate forest fires	<p>Climatic variability contributes large year-to-year variations in biomass burning in Australia. Consequently, to obtain a more representative value, emissions are reported as a 3-year moving average of individual annual estimates as recommend by the IPCC (1997, Volume 1, page 2.3).</p> <p>While IPCC (2003) provides methods for estimating annual emissions (as did the previous guidance), as an elaboration of the Revised 1996 IPCC Guidelines (IPCC 1997), they do not explicitly indicate that reporting three year averages is no longer good practice.</p>

	Provide results of verification efforts, sensitivity analyses for the most important parameters and assumptions and improved documentation on the selection of parameters	Implemented
Chapter 8	Validate the HWP model used to estimate the amount of wood and paper sent to landfill	Implemented
	Include information on country-specific data in the waste sector	Implemented
Annex 5	Enhance completeness by including estimates for forest land soils in the LULUCF sector and minor emissions from missing sources in the energy and industrial processes sectors,	Changes in forest soils will be reported when estimate for this category are made using the NCAS. Inclusion of other sources is under investigation
Annex 1	Review the disaggregation level used for the analysis of key categories	Planned for future submissions
Annex 4	Enhance the explanation of the differences between the reference and sectoral approaches	Implemented
Annex 7	Continue development of Tier 2 uncertainty estimates	Planned for future submissions

Source: a) UNFCCC 2009a, 'Report of the review of the initial report of Australia', <http://unfccc.int/resource/docs/2009/irr/aus.pdf>;
b) UNFCCC 2009b, 'Report of the individual review of the greenhouse gas inventory of Australia submitted in 2008', <http://unfccc.int/resource/docs/2009/arr/aus.pdf>

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* report 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* guidelines. These estimates have been subjected to an independent review by the CSIRO.

Emission estimate uncertainties typically are low for carbon dioxide from energy consumption as well as from some industrial process emissions ($\pm 4\text{--}5\%$). Uncertainty surrounding estimates of emissions are higher for agriculture, land use, land use change and forestry and synthetic gases. A medium band of uncertainty applies to estimates from fugitive emissions, most industrial processes and non-CO₂ 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 Report*.

At an aggregate level, using IPCC good practice methods (tier 1), the uncertainty surrounding the Australian inventory estimate levels overall for 2007 is estimated at $\pm 2.4\%$. The reported uncertainty for the trend in emissions is estimated to be $\pm 3\%$. The IPCC approach provides accurate estimates of uncertainty under certain restrictive assumptions that do not always hold for most countries' inventories. Consequently, the Department of Climate Change 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

Greenhouse gases emanate from a wide variety of sources and through a large range of processes. For the most part estimates are generated from published sources of activity data. This is true for the most significant component of the inventory—emissions from fossil fuel combustion—where data collection processes are well established for either energy policy or taxation reasons. Where published data are not readily available, such as for some industries in the industrial processes sector, the DCC conducts comprehensive surveys of industry in order to obtain the necessary data.

Tier 2 QA/QC checks were undertaken to ensure that activity data is complete in the use of fossil fuels and carbonate materials such as limestone. 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. The reconciliations are critical to providing assurance as to the completeness of the activity data used in the estimation of emissions for the inventory.

A few minor sources are not included within the inventory, due to either a lack of available information or methodology. These sources are considered to be insignificant, however, when compared with the inventory as a whole.

The assessment of completeness is used to help identify areas where methodologies can be developed, and where additional sources of data may be sought.

1.9 Geographical Coverage

The Australian inventory covers the six states (New South Wales, Victoria, Queensland, South Australia, Western Australia, Tasmania) and 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:

- Australian Antarctic Territory
- Norfolk Island
- Christmas Island
- Cocos Islands
- Heard and McDonald Islands.

The following external territories are also covered but are included in the state statistical territories by the Australian Bureau of Statistics:

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

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

- fuel combustion, waste and PFC emissions associated with refrigeration are estimated
- fugitive and industrial processes emissions are assumed to be not occurring
- agriculture and land use, land use change and forestry emissions and removals are not estimated but are likely to be negligible.

2. Trends in Greenhouse Gas Emissions

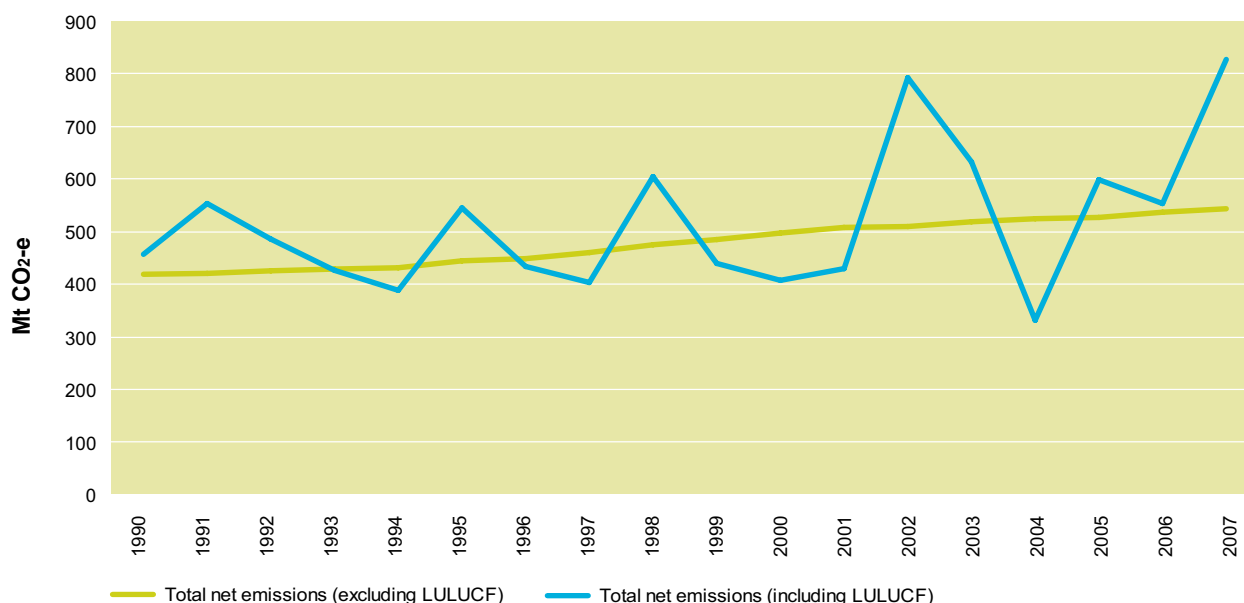
2.1 Emission Trends for Aggregated Greenhouse Gas Emissions

In 2007, Australia's total greenhouse gas emissions were 541.2 million tonnes (Mt), CO₂-equivalent (CO₂-e) excluding the LULUCF sector. This represents an increase of 6.7 Mt or 1.3 % on net emissions recorded in 2006 and an increase of 30.0% (125.0 Mt) above 1990 levels (Figure 2.1).

The combined *energy* subsectors (including stationary energy, transport and fugitive emissions) were the largest source of greenhouse gas emissions in 2007 comprising 75.4 % of emissions (Table 2.1) followed by the *agriculture* sector (16.3 %). The emissions from the *industrial processes* and *waste* sectors are relatively minor.

Carbon dioxide is the most important of the greenhouse gases in Australia's inventory with a share of 73.2 % (396.3 Mt) of the total CO₂-e emissions, followed by methane, which comprises 21.3% (115.3 Mt CO₂-e) (Figure 2.2). The remaining gases make up 5.5 % (29.6 Mt CO₂-e) of Australia's greenhouse gas emissions.

Figure 2.1: Australia's total net greenhouse gas emissions from 1990 to 2007



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 2007 were 825.9 Mt CO₂-e⁴. This represents an increase of 372.1 Mt or 82.0 % on net emissions recorded in 1990. From year to year the *LULUCF* sector may change from a net source to a net sink. In 2007, the *LULUCF* sector was a net source of 284.7 Mt. The trends in the *LULUCF* sector are primarily driven by inter-annual climate variability and natural disturbance, which masks other, underlying patterns in the sector directly associated with human activities.

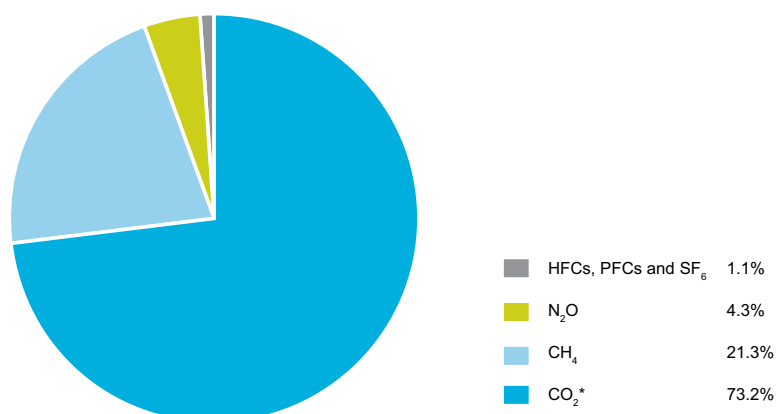
⁴ This total does not reflect Australia's emissions and removal under the Kyoto Protocol accounting framework as the inclusion of LULUCF emissions and removals are restricted to a subset of activities (ie Afforestation, Reforestation and Deforestation which have occurred since 1990).

Table 2.1: Australian net greenhouse gas emissions by sector, 2007

Sector and Subsector	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	Total	Share of total
	Mt CO ₂ -e							%
1 All energy (combustion + fugitive)	372.1	33.3	2.7	NA	NA	NA	408.2	75.4
Stationary energy	289.5	1.3	1.0	NA	NA	NA	291.7	53.9
Transport	76.5	0.6	1.7	NA	NA	NA	78.8	14.6
Fugitive emissions from fuel	6.2	31.5	0.0	NA	NA	NA	37.7	7.0
2 Industrial Processes	24.1 ^(a)	0.1	0.0	5.1	0.5	0.5	30.3	5.6
3 Solvent and other product use	NA	NA	IE	NA	NA	NA	IE	IE
4 Agriculture	NA	67.9	20.2	NA	NA	NA	88.1	16.3
6 Waste	0.0	13.9	0.6	NA	NA	NA	14.6	2.7
Total net emissions (excluding LULUCF)	396.4	115.3	23.5	5.1	0.5	0.5	541.2	100.0
5 Land use, land use change and forestry	278.7	4.5	1.6	NA	NA	NA	284.7	34.5
Total net emissions (including LULUCF)	674.9	119.8	25.0	5.1	0.5	0.5	825.9	100.0

Note: a) Includes confidential N₂O emissions from *industrial processes* and *solvent and other product use* reported as CO₂-e

Figure 2.2: Contribution to total net CO₂-e emissions (excluding LULUCF) by gas, 2007



*Includes confidential emissions from *industrial processes* and *solvent and other product use* reported as CO₂-e

2.2 Emission Trends by Gas

Of the individual greenhouse gases, emissions of carbon dioxide increased by 42.6% between 1990 and 2007. Methane emissions increased by 0.5%; nitrous oxide emissions increased by 29.6%; HFC emissions increased by 354.4%; PFC emissions fell by 87.3%. and SF₆ emissions from electrical equipment are assumed to be stable.

The *energy* sector is the major contributor to carbon dioxide emissions at 93.9 % (372.1 Mt). The growth in CO₂ represents the increased emissions from the *energy* sector particularly in energy generation and road transport.

Agriculture is the main contributor of methane (58.9 %, 67.9 Mt) and nitrous oxide (85.9 %, 20.2 Mt) emissions. However, the growth in these gases is driven by increasing emissions from the *energy* sector, road transport in particular. The growth in the N₂O emissions is also driven 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 and PFCs which contribute about 1 per cent of the total emissions, have undergone large relative changes between 1990 and 2007. Emissions of PFCs have decreased due to improvements in the aluminium smelting process. HFC emissions have increased because of the use of HFCs as a substitute for chlorofluorocarbons (CFCs) phased out under the Montreal Protocol.

Table 2.2: Change in total net CO₂-e emissions by gas (excluding the LULUCF sector), 1990–2007

Greenhouse gases	1990 Mt CO ₂ -e	2007 Mt CO ₂ -e	1990 % of Total	2007 % of Total	Changes Mt	% Change in emissions
CO ₂ ^(a)	277.8	396.3	66.8	73.2	118.5	42.6
CH ₄	114.7	115.3	27.6	21.3	0.6	0.5
N ₂ O	18.1	23.5	4.3	4.3	5.4	29.6
HFCs	1.1	5.1	0.3	0.9	4.0	354.4
PFCs	4.0	0.5	0.9	0.1	-3.4	-87.3
SF ₆	0.5	0.5	0.1	0.1	0.0	0.0
Total CO₂-e	416.2	541.1	100.0	100.0	124.9	30.0

Note: a) Includes confidential N₂O data from *industrial processes* and *solvent and other product use* reported as CO₂-e

2.3 Emission Trends by Source

Sectors with increasing emissions over the 1990 to 2007 period included *Stationary energy* (up 49.5%), *transport* (up 26.9%), *fugitive emissions from fossil fuels* (up 28.9 %), *industrial processes* (up 25.7%), *agriculture* (up 1.5%) and *land use, land use change and forestry* (up 657.6%). Waste decreased (down 22.5 %).

Figures 2.2 and 2.3 show the absolute annual change for each sector from 1990-2007. The principal drivers of these emission trends are as follows:

- *Energy*: The largest sectoral increase in greenhouse gas emissions over the 1990 to 2007 period, of 49.5% (96.6 Mt CO₂-e), occurred in the *stationary energy* sector, driven in part by increasing population, household incomes and export increases from the resources sector. The main driver for the increase in *transport* emissions is continuing growth in household incomes and numbers of vehicles. *Fugitive emissions* have increase due to increased production from gassy underground coal mines.
- *Industrial processes*: The increase in emissions since 1990 is primarily driven by the growth in emissions associated with HFCs and the chemical industries.
- *Agriculture*: Between 1990 and 2001 emissions from Agriculture increased due to increased fertiliser use and savanna burning. Since 2002, southern and eastern Australia has experienced widespread drought conditions which has contributed to reductions in animal populations, crop production and fertiliser use.
- *Waste*: The net emissions from waste have decreased as increases associated with growing populations and industrial production have been offset by increased methane recovery.
- *LULUCF*: The *LULUCF* sector changes between a net source and a net sink a number of times through the time-series. The trends in the *LULUCF* sector are primarily driven by inter-annual climate variability and natural disturbance. The trend in net emissions in the early 1990's is driven by the reduction in forest conversion emissions, however the shift from a net sink to net source in 1995, 1998 and 2002 and the large spike in 2007 are due to natural disturbances such as fires and extensive drought conditions which caused a loss of carbon from all pools.

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

Figure 2.3: Absolute annual change in CO₂-e emissions by sector, 1990-2007

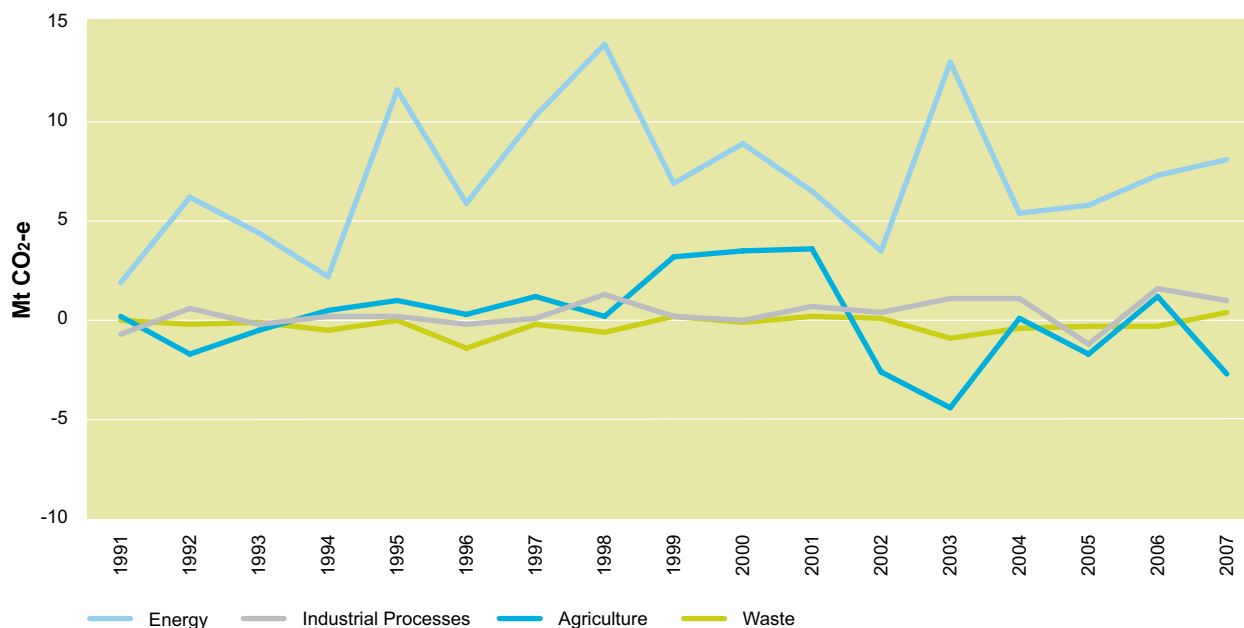
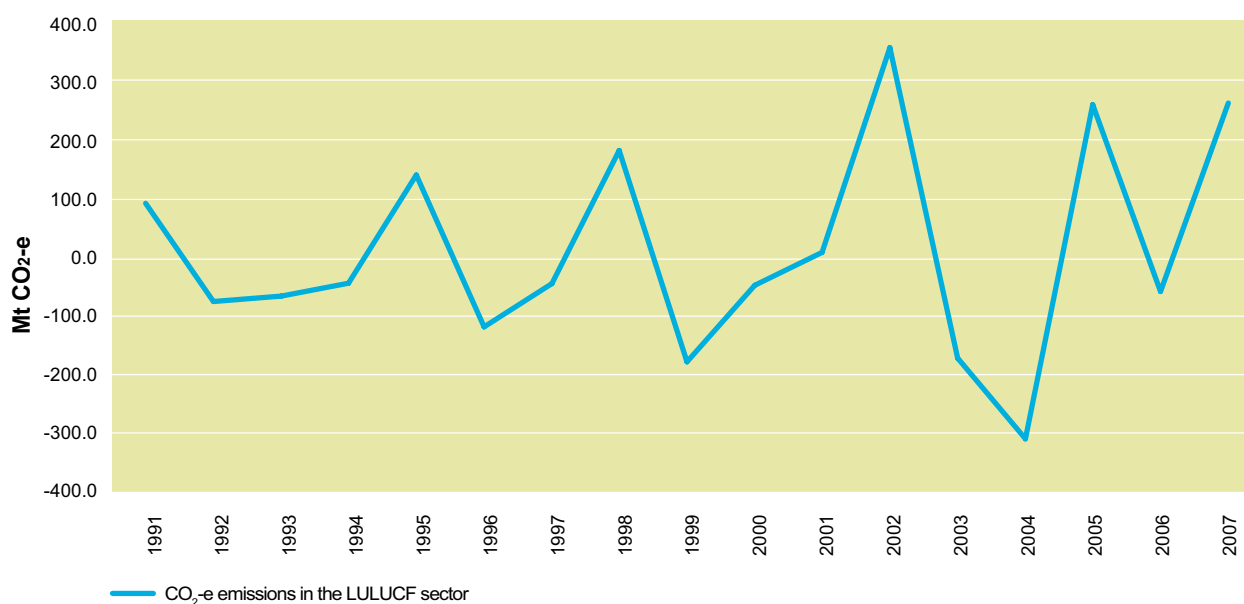


Figure 2.4: Absolute annual change in CO₂-e emissions in the LULUCF sector, 1990-2007



2.4 Emission Trends for Indirect Greenhouse Gases and SO₂

The indirect greenhouse gases NO_x, CO, NMVOC and SO₂ 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 and SO₂ and NMVOCs (Table 2.3).

The main source of NO_x is the *energy* sector, with the largest single source road transportation. 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 SO₂ occur in the *industrial processes* and *energy* sectors. The principal sources being other metal production (2.C5) (67.1 %) and electricity and heat production (1.A1.a) (24.7 %).

Table 2.3: Emissions of indirect greenhouse gases and SO₂ in 1990 and 2007

Greenhouse gas	1990	2007	Change from 1990 (Mt)	Change from 1990 (%)
NO _x	1.8	2.6	0.8	42.7
CO	20.8	25.3	4.5	21.5
NMVOC	2.2	2.4	0.1	6.2
SO ₂	1.6	2.5	0.9	56.2

Note: Including emissions from the LULUCF sector

3. Energy

3.1 Overview

Total emissions from the *energy* sector for 2007 were estimated to be 408.2 Mt CO₂-e (Table 3.1). *Energy industries* were the main contributor, accounting for 54.4% of emissions from the *energy* sector. Other significant contributors to total *energy* emissions were *transport* (19.3%), and *manufacturing industries and construction* (11.9%).

Energy sector emissions increased by 42.5% between 1990 and 2007. Emissions from the sector increased by 8.1 Mt (2.0%) from 400.1 Mt in 2006. The main contributor to the increase in emissions was *stationary energy*, which contributed an additional 4.6 Mt CO₂-e.

Table 3.1: Energy sector CO₂-e emissions, 2007

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)			
	CO ₂	CH ₄	N ₂ O	Total
1 ENERGY	372,138	33,320	2,705	408,163
A. Fuel combustion activities	365,978	1,853	2,679	370,510
1 Energy industries	220,972	234	638	221,844
a Electricity and heat production	198,747	195	603	199,545
b Petroleum refining	5,711	2	13	5,726
c Manufacture of solid fuels	16,514	37	22	16,573
2 Manufacturing industries and construction	48,347	53	261	48,661
3 Transport	76,482	589	1,703	78,773
a Civil aviation	5,292	1	51	5,344
b Road transportation	66,450	463	1,617	68,529
c Railways	1,917	2	17	1,936
d Navigation (domestic)	2,780	123	17	2,920
e Other transportation	44	0	0	45
4 Other sectors	18,629	975	68	19,672
5 Other	1,547	2	10	1,559
a Lubricants	454	NA	NA	454
b Mobile (military)	1,093	2	10	1,105
B. Fugitive emissions from fuels	6,160	31,467	26	37,653
1 Solid fuels	NE	26,832	NA	26,832
2 Oil and natural gas	6,160	4,635	26	10,821

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 291.7 Mt CO₂-e in 2007, equal to 53.9% 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.A1.a) contributed 199.5 Mt CO₂-e or 68.4% of *stationary energy* emissions in 2007. 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 22.3 Mt in 2007.

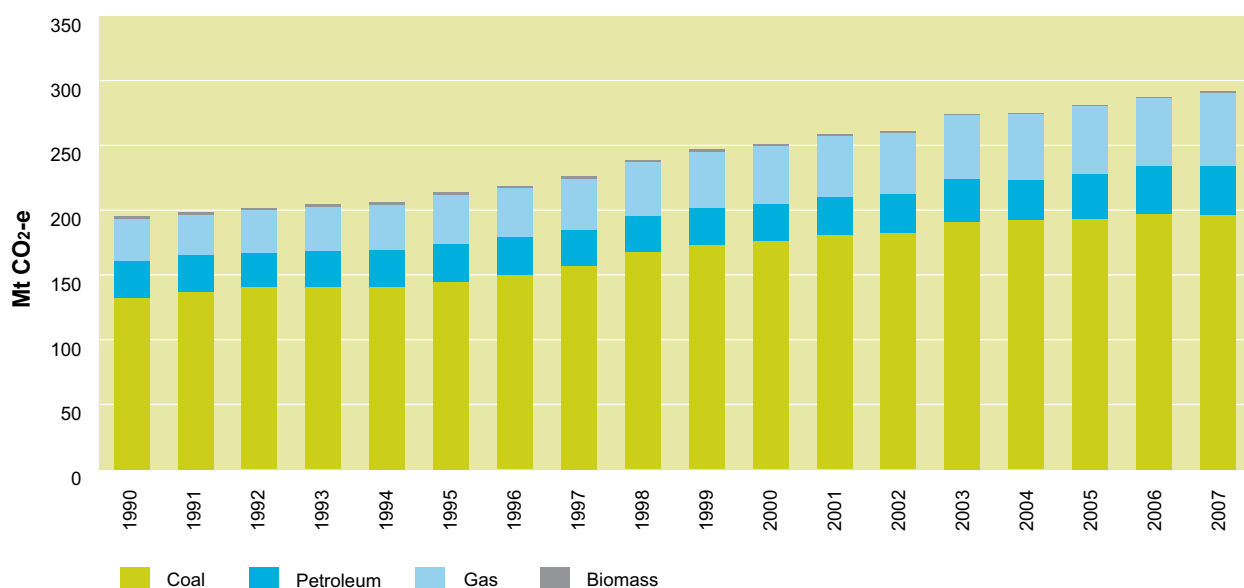
The *manufacturing industries and construction* subsector (1.A2) emissions were 48.7 Mt CO₂-e in 2007. This subsector includes direct emissions from fuel combustion in manufacturing industries, ferrous and non-ferrous metals production, plastics production, construction and non-energy mining. These calculations 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.A1.a).

Estimated emissions from *other sectors* (1.A4) were 19.7 Mt CO₂-e in 2007. 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.A1.a). *Other* (1.A5) includes emissions from *lubricants* (0.5 Mt) and *military transport* (1.1 Mt). Emissions from *lubricants* arise from the combustion of engine oil in vehicles.

Trends

Emissions from *stationary energy* increased by 49.5% (96.6 Mt) between 1990 and 2007, including an increase in emissions from coal combustion of 48.3% (63.9 Mt) in the same period (Figure 3.1). Although coal 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 72.9% (24.0 Mt) between 1990 and 2007. Emissions from liquid fossil fuels increased by 33.7% (9.4 Mt) in the same period. Biomass emissions decreased by 37.9% (0.7 Mt) between 1990 and 2007. Between 2006 and 2007, emissions from *stationary energy* increased by 1.6% (4.6 Mt).

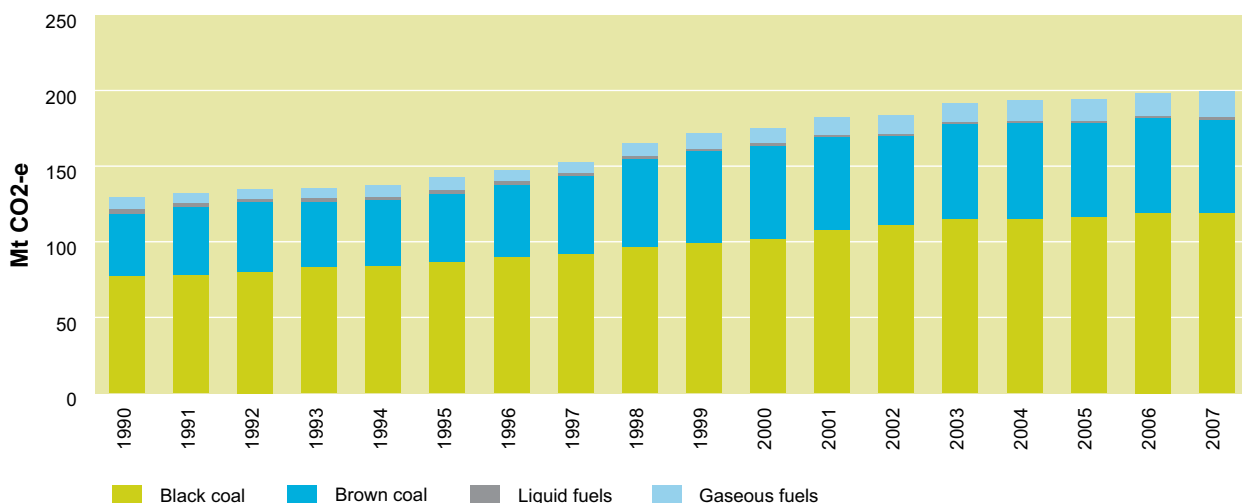
Figure 3.1: Total CO₂-e emissions from stationary energy combustion by fuel, 1990–2007



Electricity generation emissions increased by 1.6 Mt (0.8%) from 2006 to 2007, and by 70.1 Mt (54.1%) from 1990 to 2007 (Figure 3.2). The 2006 to 2007 electricity generation emissions increase (0.8%) was less than the increase in fuel use (2.1%). The black coal share of energy use decreased by 0.9% to 56.2% while the brown coal share also decreased by 0.9% to 28.2%. The share of fuel use contributed by gaseous fuels increased 2.0% to 14.5% while liquid fuels remained nearly the same at 1.1%.

Emissions from *stationary energy* subsectors, other than *electricity generation*, increased by 3.0 Mt (3.4%) between 2006 and 2007, and increased overall by 26.5 Mt (40.4%) from 1990 to 2007. Emissions from the *manufacturing industries and construction* subsector increased 2.8% (1.3 Mt) between 2006 and 2007 and increased by 34.1% (12.4 Mt) from 1990 to 2007.

Figure 3.2: CO₂-e emissions from electricity generation by fossil fuels, 1990-2007



3.1.2 Transport

In 2007 transport contributed 78.8 Mt CO₂-e or 14.6% of Australia's net emissions (excluding LULUCF).

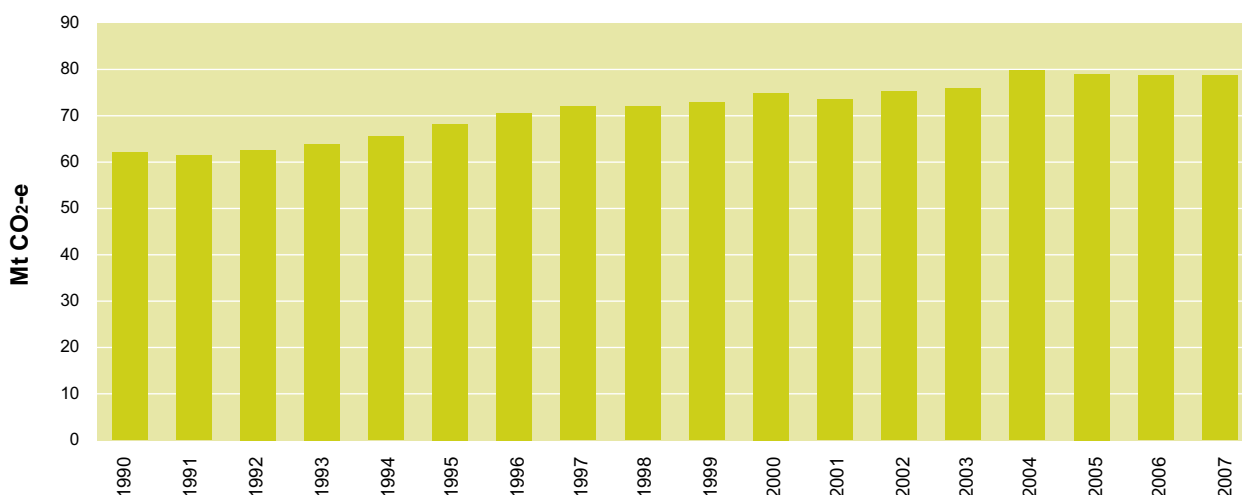
The major source of transport emissions in Australia is road transportation, which accounts for 87.0% (68.5 Mt) of transport emissions. This outcome is principally driven by the importance of motor vehicles as modes of transportation of passengers and freight in Australia. Passenger cars account for 41.9 Mt and trucks and buses 15.4 Mt. Other sources are far smaller: domestic aviation contributed 6.8% (5.3 Mt), domestic navigation 3.7% (2.9 Mt), and railways 2.5% (1.9 Mt).

Fuel used in *international transport* (*international aviation* and *marine 'bunkers'*) is by international agreement reported separately from the national total net emissions. In 2007, international bunker fuels generated 12.0 Mt of emissions.

Trends

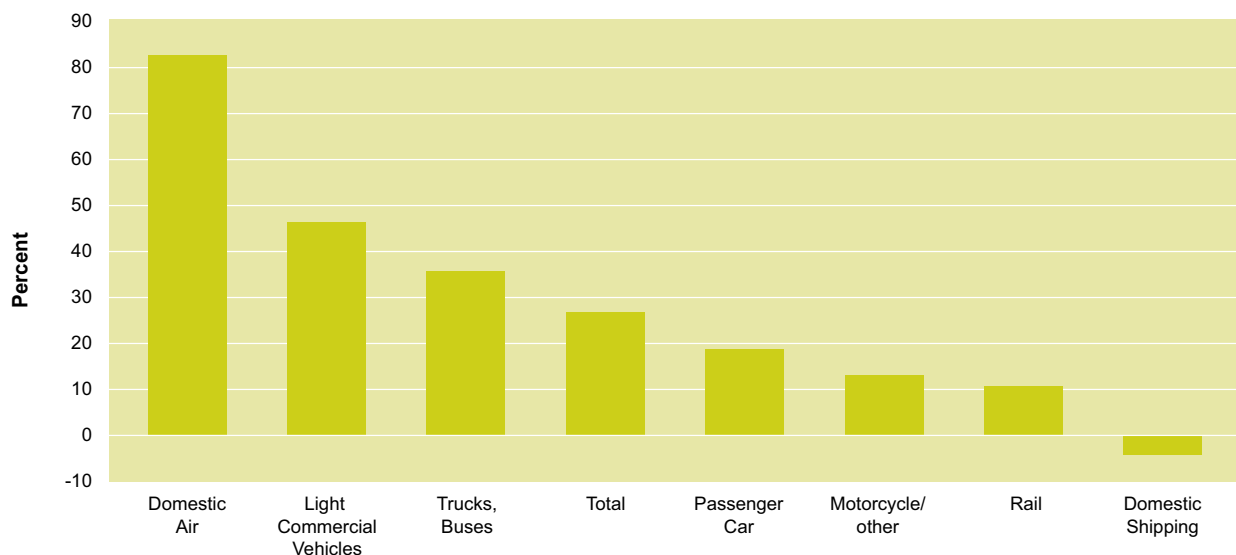
Transport emissions are one of the strongest sources of emissions growth in Australia. Emissions from this sector were 26.9% higher in 2007 than in 1990, and have increased by about 1.5% annually (Figure 3.3). Emissions from road transportation increased by 26.1% (14.2 Mt) between 1990 and 2007 (Figure 3.4). Emissions from passenger cars increased by 18.8% (6.6 Mt). Emissions from Light Commercial Vehicles (LCVs) and heavy duty trucks and buses have also grown strongly (46.3% and 35.7% respectively).

Figure 3.3: Total transport emissions, 1990-2007



Estimates of civil aviation (domestic air transport) emissions were 82.8% (2.4 Mt) higher than the 1990 level. Emissions have grown strongly in this sector, particularly in the early 1990s, although emissions in the 1990 base year were unusually low because of an extensive dispute with airline pilots in that year and this has contributed to the magnitude of the change. Emissions from rail have risen by 10.7% while domestic shipping emissions have fallen by 4.2%, reflecting improved productivity and changes in activity.

Figure 3.4: Comparison of growth in transport emissions by subcategory, 1990-2007



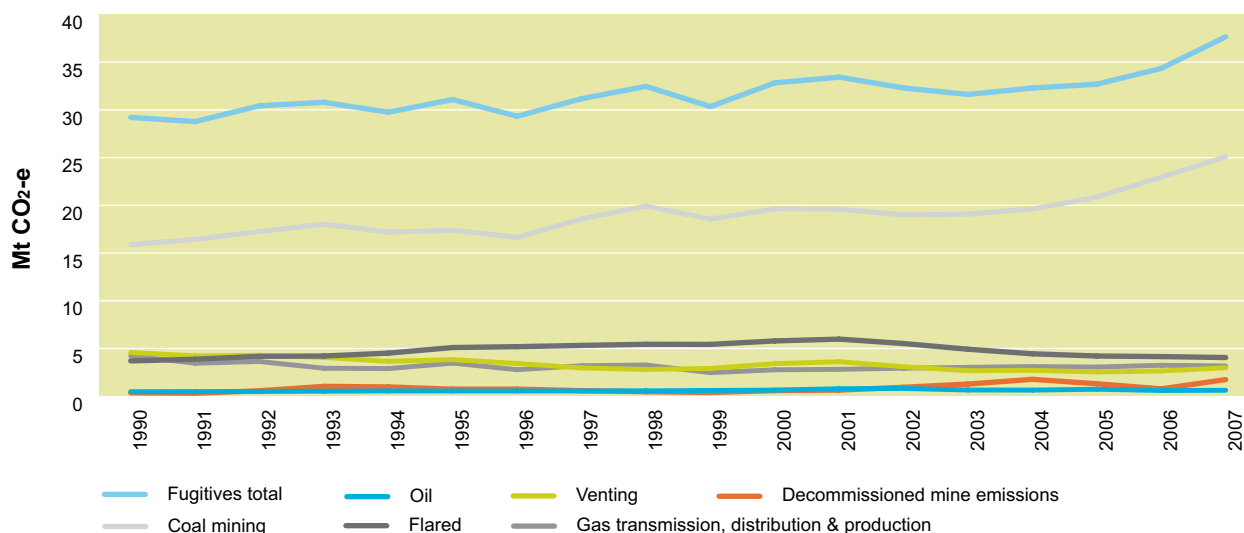
3.1.3 Fugitive Emissions

Total estimated *fugitive emissions* for 2007 were 37.7 Mt CO₂-e, representing 7.0% of net national emissions (excluding LULUCF). Net *solid fuel* emissions contributed 71.3% (26.8 Mt) of *fugitive* emissions. *Oil and natural gas production, processing and distribution* account for the remaining 28.7% (10.8 Mt) of *fugitive* emissions.

Trends

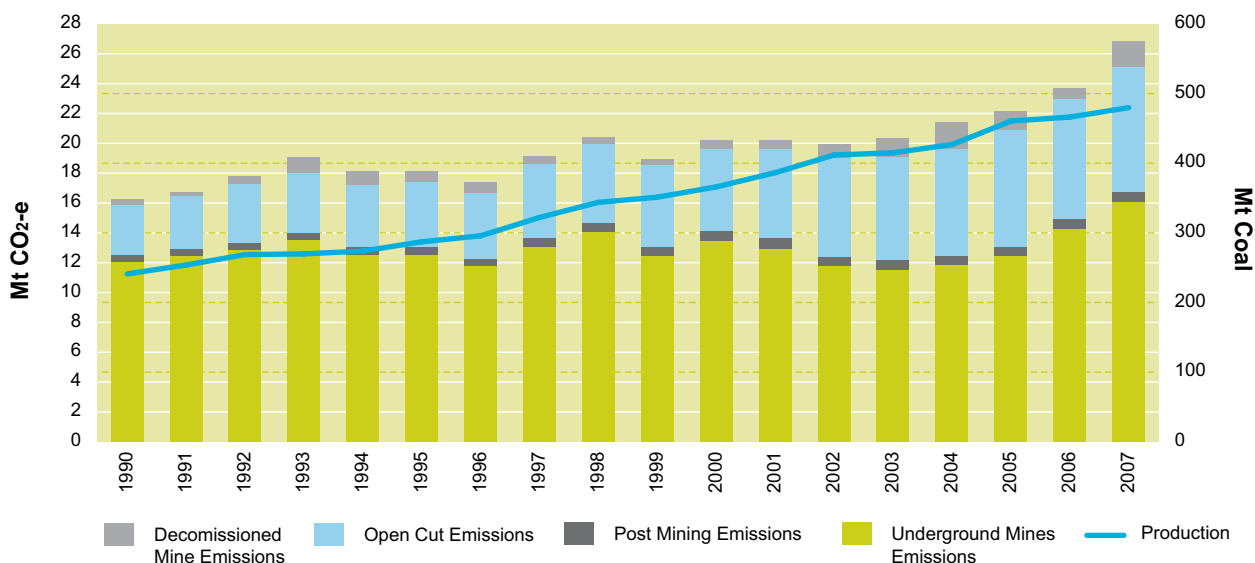
Overall *fugitive* emissions increased 28.9% (8.4 Mt) between 1990 and 2007, and increased by 9.6% (3.3 Mt) from 2006 to 2007 (Figure 3.5). From 1990 to 2007 fugitive emissions from *solid fuels* increased by 65.3% (10.6 Mt) and *oil and natural gas* emissions decreased by 16.6% (2.2 Mt).

Figure 3.5: CO₂-e fugitive emissions by category, 1990-2007



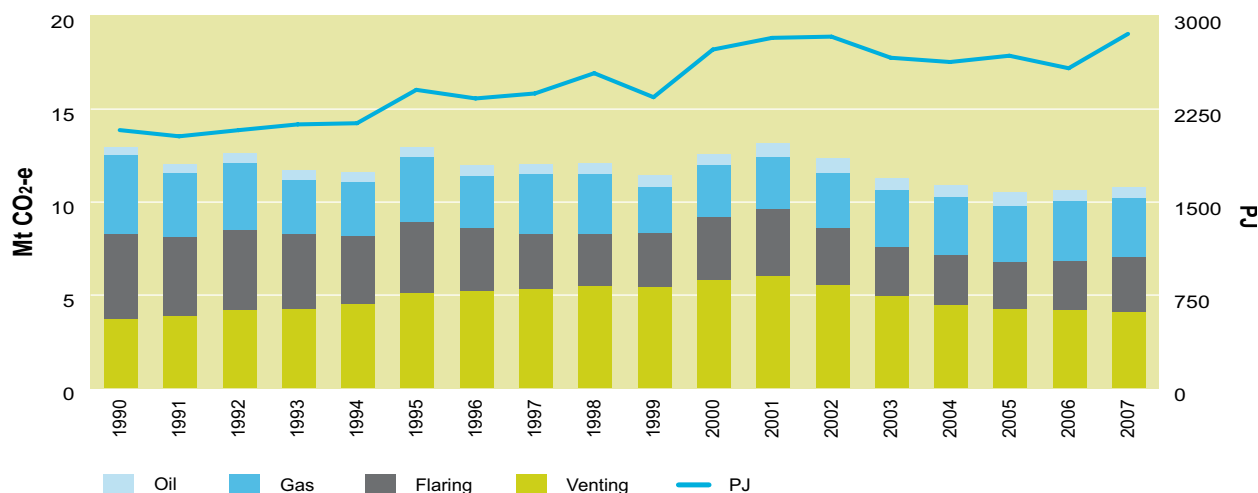
Solid fuel emissions increased by 13.1% (3.1 Mt) between 2006 and 2007, driven by an 8.5% increase in coal production from gassy underground mines. Emissions tend to fluctuate from year to year, depending on the volume of coal mined and the share of gassy underground mines in total production. Decommissioned mine emissions also contributed to the overall increase due to the closure of several large gassy mines. Mine production of coal has increased from 241 Mt in 1990 to 480.9 Mt in 2007, an increase of 99.5%. Since 1990, methane emissions have not grown as fast as activity principally because, since 1998, there has been a decreasing trend in activity from gassy mines while there has been growth in non-gassy mines and surface mines (Figure 3.6). In addition, technologies to recover and utilise or flare CH_4 have been increasingly adopted. Emissions from decommissioned mines have increased 1.4 Mt between 1990 and 2007.

Figure 3.6: Fugitive $\text{CO}_2\text{-e}$ emissions from coal mining activities, 1990-2007



Oil and natural gas fugitive emissions decreased by 16.6% (2.2 Mt) between 1990 and 2007 (Figure 3.7). This compares with a 37.4% 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 2006 and 2007, emissions from oil-related activities increased by 3.8% (0.02 Mt) and emissions from gas-related activities decreased by 2.2% (0.1 Mt). Emissions from venting decreased by 2.4% (0.1 Mt) from 2006 to 2007 although, compared with 1990, emissions were higher by 9.4% (0.3 Mt). Flaring-related emissions increased by 13.0% (0.3 Mt) from 2006 to 2007, although emissions in 2007 were lower than 1990 levels by 34.9% (1.6 Mt).

Figure 3.7: Fugitive $\text{CO}_2\text{-e}$ emissions from oil and gas production, 1990-2007



3.2 Overview of Source Category Description and Methodology – Energy

The *Energy* sector includes emissions from the combustion of fossil fuels (1.A1 *Energy Industries*; 1.A2 *Manufacturing Industries and Construction*; 1.A3 *Transport*; 1.A4 *Other sectors*; and 1.A5 *'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 emission factors. Emissions for the Transport sector have been estimated with a mix of Tier 1, 2 and Tier 3 approaches.

The Australian Bureau of Agricultural and Resource Economics (ABARE) compiles estimates of Australian energy consumption by fuel and economic sector for the purpose of meeting Australia's reporting commitments to the International Energy Agency. These estimates are compiled from an annual fuel and electricity survey conducted by the Bureau, supplemented by a variety of other sources of information. The statistics provide 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, ie. the coal, oil, gas and electricity industries.

3.2.1 CO₂ Emissions and Emission factors

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

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

Where: E_{hk} is the amount of CO₂ 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 CO₂ emission factor (in Gg CO₂/PJ) for fuel *k*;

P_k = the oxidation factor (in percent) of fuel *k*; and

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

Emission factors for CO₂ depend only on the chemical composition of the fossil fuel concerned under IPCC methods. For fuels having well defined and/or stable chemical composition, CO₂ emission factors 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).

Coal

Approximately 90% of all coal consumed in Australia is used by the electricity generation industry. CO₂ emission factors for coal used by the electricity industry are estimated for major individual power stations and are reported in Table 3.7. The variability of these emission factors is 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 CO₂ emission factor of 91.8 Gg/PJ for black coal used in iron/steel/coke production (L.Leung, BHP 2001, pers. comm). For other uses of coal, such as the steel industry, representative CO₂ emission factors are reported in Table 3.2.

Coke

The CO₂ emission factor 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 emission factor varies slightly from year to year depending on the balance of inputs and outputs, in a range between 105.9 and 108.8 Gg/PJ which is comparable to the IPCC default factor.

Coal By-Products

Wherever coal by-products are used as a fuel, except in the Basic Chemicals, Petroleum and Coal Products and Food, Beverages, Tobacco sectors (ANZSIC Codes 253, 252 and 21), it is assumed that the emission factor is the same as for coke oven gas. The coke oven gas emission factor has been advised by the steel industry to be 37 Gg/PJ (Deslandes and Kingston 1997). The steel industry has also advised that for its own inventory purposes it uses emission factors for coal tar and BTX (standing for Benzene, toluene, xylene) of 81.8 and 80.4 Gg/PJ respectively (Deslandes and Kingston 1997). In this inventory a value of 81.0 Gg/PJ is used for coal by-products used in the Basic Chemicals and the Petroleum and Coal Products sector. It should be noted that the effect of this factor is reduced due to the assumed sequestration of over 75% of the coal by-products listed as consumed by ABARE.

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 emission factors for marketable petroleum products for this inventory are taken from GHD 2006a, which reports the results of a review of Australian petroleum products. A representative value to be used for fuel oil, derived from IPCC 1997, was confirmed by discussion with Nabalco (J. Bawdin, pers. comm.), one of the largest industrial users of fuel oil in Australia, and Shell (J. Le Cornu, pers. comm.).

Other Petroleum Products

In the 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 emission factor for naphtha, (IPCC 1997), was therefore used in these sectors. For all other sectors in which petroleum products nec appears as a fuel type, an emission factor of 68.6 Gg CO₂/PJ, as advised by ABARE, was used. Recycled tyres are combusted for energy within Cement, Lime, Plaster and Concrete (ANZSIC Group 263). An emission factor of 81.6 Gg CO₂/PJ was sourced from the US Energy Information Administration (GHD 2006b).

Solvents, Lubricants, Greases and Bitumen

Australian information on CO₂ emission factors for these products is not available. Default IPCC values of 69.6 Gg/PJ for lubricants and greases; 80.7 Gg/PJ for bitumen and 69.7 Gg/PJ for solvents have therefore been used (IPCC 2006).

Natural Gas

A national emission factor 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 CO₂ emission factor 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 emission factor 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 emission factors, except for gas used for electricity generation, where factors are estimated for individual power stations. Emission factors for electricity generation are listed in Figure 3.8. Emission factors from coal seam gas are individually estimated for major individual power stations. When individual power station data are unavailable the national CO₂ emission factor for natural gas is used.

An additional adjustment is made for natural gas used by the chemical industry because this includes both natural gas and the separate ethane supply, used as feedstock. The CO₂ emission factor used for the inventory was derived based on data within the ASHRAE *Handbook Fundamentals* (2001) and is 56.5 Gg CO₂/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. In the absence of information about the composition and quantities of natural gas used by the chemical industry in each State, an Australian average emission factor is applied to all natural gas used by the basic chemicals sector.

Town Gas

Town gas, which is a minor source of emissions, is given the same emission factor as LPG, on the assumption that, in the manufacture of town gas, both carbon content and energy content is reduced in the same proportion, meaning that the carbon emission factor is unchanged.

Biomass Fuels

Emissions of CO₂ from biomass fuels are not included in the national inventory but are required to be reported as a Memo item. The CO₂ emission factors for bagasse and wood/woodwaste combusted in commercial and residential sectors are listed in Table 3.2. A detailed explanation of residential wood heater emission factors is provided in section 3.6.

Table 3.2: Emission factors for CO₂ 2007

Fuel Type	Fuel	CO ₂ emission factor (Gg CO ₂ /PJ)
Coal derived fuels	Coal used in public electricity generation ^a	84.0 - 96.4
	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	108.8
	Coal by-products (coke oven gas) ^b	37.0
	Coal by-products (coal tar and BTX) ^b	81.0
	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 ^d	68.6
	Fuel oil ^e	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) GWA 2008; b) Deslandes & Kingston 1997; c) GHD 2006a; d) ABARE; e) IPCC 2006; f) Australian Gas Association 2001; g) ASHRAE 2001; h) Todd 1993; i) Todd 2005; k) GHD 2006b; l) IPCC 1997; m) L.Leung BHP 2001; n) Derived from carbon balance within coke oven/iron & steel subsectors

Note: All emission factors expressed in terms of energy measured as gross calorific equivalents (GCV)

Oxidation Factors for CO₂

The oxidation factor is defined as the proportion of carbon contained in a fuel which is oxidised to CO₂. 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 CO₂ (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 factors listed for coal by-products are a result of the assumption that in all relevant sub-categories, other than Basic Chemicals and Petroleum and Coal Products nec, coal by-products are gaseous fuels. Hence consumption of coal by-products in these categories has an identical oxidation factor to that used for natural gas. Within the Basic Chemicals and Petroleum and Coal Products nec sub-categories the assumption is that the fuel is either BTX or coal tar and hence the IPCC default petroleum factor has been applied.

The oxidation factor for combustion of biomass for Residential is combined with the associated CO₂ emission factor, 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 & 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.

Oxidation factors for electricity generation (1.A1.a) are discussed in section 3.3.2.

3.2.2 Non-CO₂ Emissions

In addition to emissions of CO₂, the combustion of fuel in stationary sources results in the emission of CH₄, N₂O, NO_x, CO, and NMVOCs. Of these, methane and nitrous oxide account for around 1% of emissions on a carbon dioxide equivalent 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 and is therefore inherently more complex and more uncertain than estimates of CO₂ emissions.

For non-CO₂ 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 emission factor (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-CO₂ emissions generated by the combustion of fossil fuels. Consequently, emission factors for non-CO₂ 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-CO₂ factors are derived from IPCC 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 emission factors for uncontrolled fuel combustion sources, which must be used in the absence of reliable information on the equipment in use, means that the Australian inventories may overestimate some non-CO₂ emissions.

The emission factors for non-CO₂ greenhouse gases for various equipment types are summarised in Table 3.A4. In the absence of evidence to differentiate N₂O variations in measured N₂O concentrations between boilers (ie 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 N₂O emission factors 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, biomass) for the manufacturing industries, are provided by ABARE. These data are used to compile a set of weighted emission factors 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 emission factors 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.
- For Division E (Construction), mobile equipment emission factors are used.
- For Divisions F, H, I, J, K and L, it was assumed that all fuel combustion occurs in miscellaneous small combustion equipment.
- For sectors 65 and 67, 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.
- For the Residential sector, it was assumed that all combustion of coal, liquid fuels and gas occurs in miscellaneous residential combustion equipment.

In ANZSIC sector 361, public electricity generation, the respective electricity generation enterprises have provided relevant operating data for their respective power stations.

3.2.3 SO₂ Emissions

Data on emission factors was obtained from the following sources:

- for petroleum products Australian Institute of Petroleum and the National Pollutant Inventory
- for natural gas and LPG Australian Gas Association
- for coal (default values) Department of Primary Industries and Energy.

For the electricity industry specific SO₂ emission data have been obtained from power station operators. Within the petroleum refining sub-category the SO₂ emissions are not directly calculated but are sourced from the Australian National Pollutant Inventory Database. For other sectors, the emission factors 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: SO₂ 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, National Pollutant Inventory (petroleum refining), Department of Primary Industries and Energy (pers. comm. 1998) (for default coal values) and Australian Gas Association.

For both CO₂ and non-CO₂ gases, total national emissions are calculated by summing the estimated emissions from each fuel in each economic sector across all fuels and across all economic sectors.

3.2.4 Activity Data

The Australian Bureau of Agricultural and Resource Economics (ABARE), and predecessor organisations, have compiled statistics of Australian energy use by economic sector and fuel since the 1970s. These statistics are compiled from an annual fuel and electricity survey conducted by the Bureau supplemented by a variety of other sources of information. 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, ie the coal, oil, gas and electricity industries.

The data are presented in common energy units (PJ) on an individual State basis. ABARE also collects statistics of energy use by equipment (technology) type. These have been used to compile the technology weighted sectoral emission factors for non-CO₂ greenhouse gases. Several re-allocations to the ABARE statistics are required in order to:

- break down energy consumption into sub-sectors where this is required to match emission factor data, but is not done by ABARE;
- 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;
- eliminate double counting of gas leakage from the gas distribution system;
- allocation of fuel use to the industrial process sector for the estimation of emissions from the use of fuels as reductants.

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

Activity data for the time-series 1990 to 2007, reported by category level and fuel type, are available on the AGEIS website: <http://www.ageis.greenhouse.gov.au/GGIDMUserFunc/QueryAppendixTable/QueryAppendixTable.asp>

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.C1 Iron and Steel Production;
 - Black coal where used as a reductant in synthetic rutile production – reported in 2.B5 Chemical Industry - Other;
 - Petroleum coke where used as a reductant in titanium dioxide production – reported in 2.B5 Chemical Industry - Other;
 - Petroleum coke and coal tar used for anodes in aluminium production – reported in 2.C3 Aluminium Production;
 - Natural gas used in Ammonia production – reported in 2.G Other.
- Reported in *fugitive emissions from fuels*
 - Oil refinery flaring- reported in 1.B2.A Oil Refining/Storage;
 - Natural gas leakage – reported in 1.B2.b Natural Gas Distribution.

There were 13.8 Mt CO₂ emissions from non-energy fuel use reported in the *industrial processes* sector of the inventory. Coke used as a reductant within iron and steel production was the most significant non-energy use of fuel, resulting in the reporting of 7.5 Mt CO₂ within the *industrial processes* sector. There were also 0.9 Mt CO₂ emissions from petroleum refining flaring and natural gas leakage reported as *fugitive emissions*.

The use of ethane and petroleum products used as feedstocks within chemicals production resulted in the equivalent of 2.1 Mt CO₂ being stored in products such as plastics, and therefore were not included in the estimate of emissions from the *energy* sector. A further 4.7 Mt CO₂ was associated with non-energy 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. A separate carbon balance demonstrating the derivation of the coke emission factor for integrated coke/iron and steel sectors is also presented in Annex 6.

Comparison with international data

The ABARE publication, Australian Energy Statistics, is the common source of data both for the preparation of the national inventory and also 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 published by the IEA. A project is being undertaken to investigate further the reconciliation of ABARE data provided to the IEA with the inventory data. Outcomes will be reported in the next submission.

Reasons for differences uncovered by preliminary investigations include:

- The inventory utilises data sources additional to the ABARE energy statistics;

This includes the electricity generation category where data is obtained directly from individual generators and upstream natural gas production where industry data is obtained from the Australian Petroleum Production & Exploration Association.

- The process of submitting data to IEA by ABARE and subsequent IEA data conversions;

Energy conversion: ABARE has advised that it submits energy data on a gross calorific value basis. The IEA then convert into net calorific value equivalents.

Data year alignment: ABARE submit annual activity data for solid and gaseous fuels on an Australian financial year (July to June) basis, but liquid fuels data on a monthly basis. IEA publish data on a calendar year basis.

3.3 Source Category 1.A1 – 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. ABARE 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 3.5.

Table 3.5: Relationship between IPCC source categories and ANZSIC sectors – Energy Industries

IPCC Source Category	ANZSIC Subdivision/Group/Class			
	Division	Sub-division	Group/Class	Description
1.A1 Energy Industries				
a Electricity and heat production	D Electricity, Gas and Water Supply	36	361	Electricity supply
b Petroleum refining	C Manufacturing	25	251	Petroleum refining
c Solid fuel transformation and other energy industries	B Mining	11		Coal mining (incl. briquette production)
	B Mining	12		Oil and gas extraction (incl. gas processing and LNG production)
	C Manufacturing	27	2711 (part)	Coke ovens associated with Basic iron and steel manufacturing
	D Electricity, Gas and Water Supply	36	362	Gas supply
	I Transport and Storage	65	6501 (part)	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 co-generation occurs in the industry sector within which co-generation occurs. There is no public generation of distributed heat in Australia.

3.3.2 Methodology

In summary, emissions for the Energy Industries sector are estimated using Tier 2 approaches and country specific factors (Table 3.6).

Table 3.6: Summary of methods and emission factors – Energy Industries

Source Category	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A1a Public electricity	T2	CS, PS	T2	CS	T2	CS
1A1b Petroleum refining	T2	CS	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 Group 361) (1.A1.a)

Electricity generation includes power for supply to the grid (whether the power stations are owned by public or private corporations) and also the generation of electricity at mines, mineral processing and manufacturing sites, where data are available on the electricity generated and fuels consumed. Where it is not possible to identify the quantity of fuel consumed - 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.

A tier 2 approach is used for the key category of electricity generation in which emission factors 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. Emissions from each large power station (over about 0.5 PJ fuel use) are calculated separately, predominantly using specific activity data and specific emission factors estimated in accordance with the Generator Efficiency Standards – Technical Guidelines (AGO 2006).

There are around 50 such power stations in Australia at present (the number depends on how generating units at the same site are treated). Data on fuel use and emission factors are requested directly from operational organisations of major power stations connected to the main transmission grids and power stations not connected to the main transmission grids but operated by the same organisations. The energy use of the power stations for which data were not obtained directly are inferred from company annual reports, previously submitted power station data and the difference between the total of reported values and Australian Bureau of Agricultural and Resource Economics (ABARE) energy statistics for ANZSIC class 361. In 2007 the coverage of individual coal power station data was comprehensive and displaced the necessity of using the coal data in ABARE's energy statistics for ANZSIC class 361 in calculations. However, the calculation method of the difference between the total of reported values and ABARE energy statistics for ANZSIC class 361 was used for other liquid and gaseous fuel types.

Most large power stations use a main fuel (eg coal) and a secondary fuel that may be used only at start-up (eg fuel oil). Some large power stations use a third fuel type as well, to supplement the main fuel during normal operation. CO₂ emissions are calculated for the main fuel, and for the secondary and tertiary fuels (if present) using emission factors for individual power stations.

The oxidation factors and the emissions factors are linked in that some power station operators report CO₂ emission factors including the effects of oxidation based on analysis of ash contents and in accordance with Australian Greenhouse Office (2006). In such cases applying the default oxidation factor of 99% for electricity generation coal would double-count the effect of incomplete combustion, so an oxidation factor of 100% is reported.

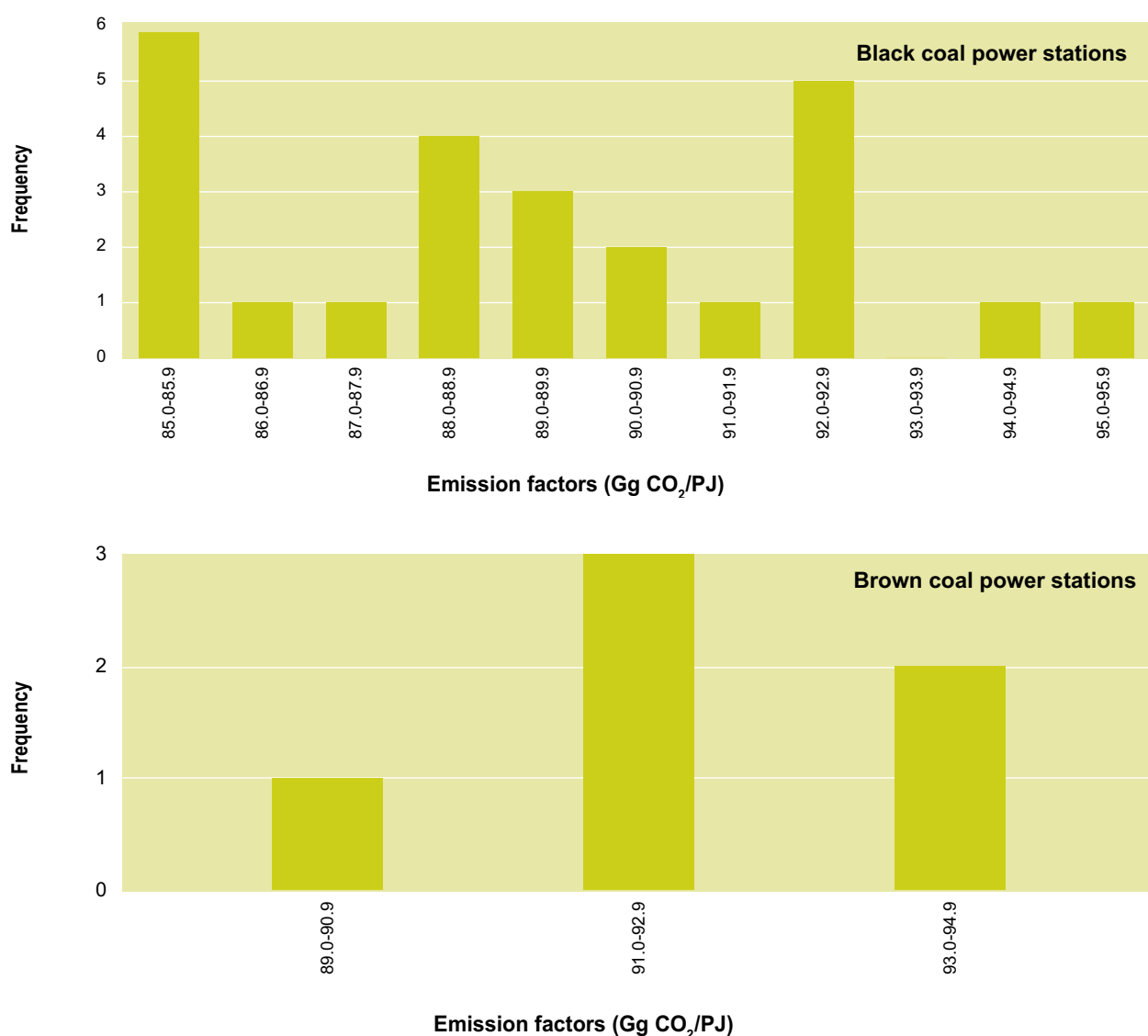
**Table 3.7: CO₂ and non-CO₂ emission factors and oxidation factors for major power stations
2006-2007**

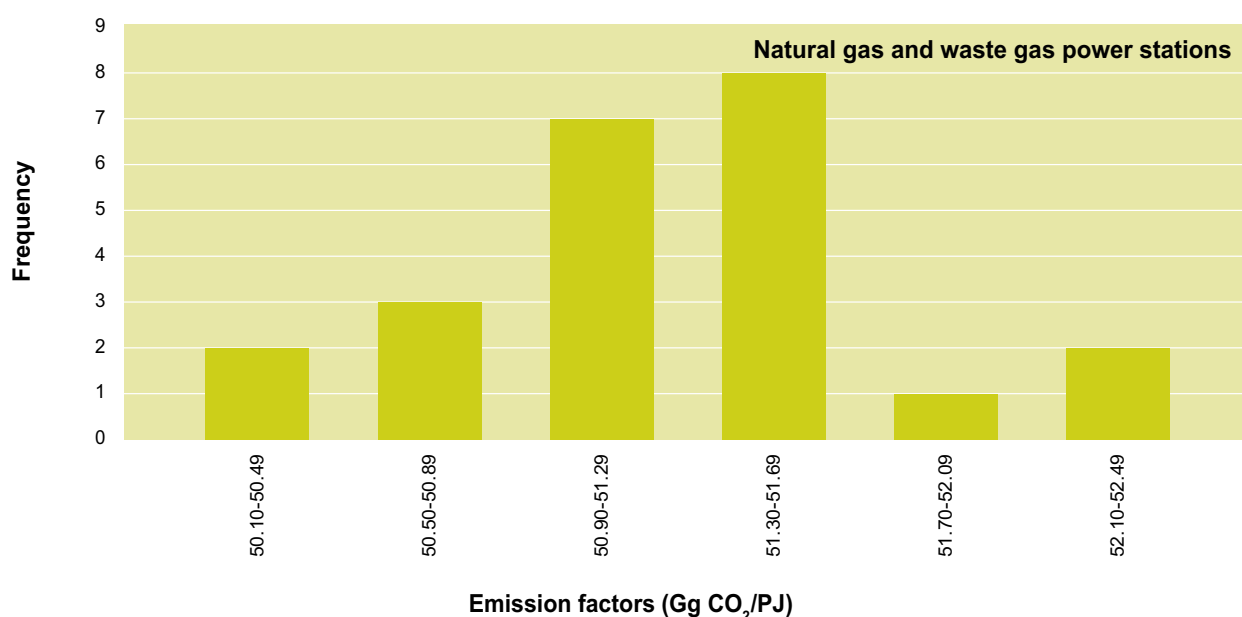
Power Station	Fuel	Gg CO ₂ /PJ		Emission Factor Mg/PJ						Oxidation Factor
		Main Fuel	Oil	CH ₄	N ₂ O	NO _x	CO	NM VOC	SO ₂	%
NSW										
Bayswater	BC	90.4	69.6	0.9	0.8	204	11	1.7	521	100
Eraring	BC	89.5	69.3	0.9	0.8	258	11	1.7	250	100
Mt Piper	BC	89.0	69.9	0.7	0.8	299	11	1.7	456	100
Liddell	BC	88.4	70.2	0.9	0.8	306	11	1.7	370	100
Munmorah	BC	89.1	69.7	0.7	0.8	206	11	1.7	267	100
Vales Point	BC	88.6	69.8	0.7	0.8	235	11	1.7	275	100
Wallerawang	BC	86.5	70.3	0.7	0.8	325	11	1.7	445	100
Appin/Tower	WG	51.7	-	240.0	0.1	834	340	80.0	2.3	99.5
Smithfield	NG	51.4	-	8.0	0.1	23	7	2.4	2.3	99.5
Redbank	BC	92.0	73.6	0.9	0.8	55	11	1.7	175	99
Victoria										
Hazelwood	BrC	93.9	-	0.5	1.4	136	17	1.7	70	99.7
Loy Yang A	BrC	91.6	-	0.9	0.8	167	21	1.7	310	99
Loy Yang B	BrC	92.0	-	0.5	1.4	136	2	1.7	270	100
Morwell	BrC	92.0	68.0	0.9	1.4	136	17	1.7	150	99.6
Yallourn	BrC	95.2	73.6	0.5	1.4	85	79	0.0	115	98.8
Anglesea	BrC	92.1	73.6	0.9	1.4	230	3	1.4	2547	99.9
Newport	NG	50.6	-	0.1	0.1	226	16	0.6	2.3	99.5
Jeeralang A & B	NG	50.6	-	8.0	0.1	190	46	2.4	2.3	99.5
Queensland										
Callide	BC	95.6	69.0	0.9	0.8	380	11	0.6	179	99.2
Gladstone	BC	88.6	70.1	0.9	0.8	523	11	1.7	370	99
Stanwell	BC	90.8	70.0	0.9	0.8	462	11	1.7	370	99
Swanbank	BC	85.0	69.0	0.9	0.8	245	5	0.6	393	98
Collinsville	BC	89.4	-	0.9	0.8	523	11	1.7	370	99
Tarong	BC	91.2	69.4	0.9	0.8	419	11	1.7	246	99
Millmerran	BC	84.0	73.0	0.9	0.8	462	11	1.7	370	99
Mica Creek	NG	52.1	69.9	4.0	0.6	280	6	2.4	66	99.5
Western Australia										
Muja A/B	BC	93.8	69.7	0.9	0.8	462	11	1.7	370	99
Muja C/D	BC	93.8	69.7	0.9	0.8	306	11	1.7	370	99
Cockburn	NG	51.8	69.7	8.0	0.1	39	10	2.4	2.3	99.5
Kwinana A	BC	93.8	-	0.9	0.8	462	11	1.7	370	99
Kwinana C	BC	93.8	69.7	0.9	0.8	306	11	1.7	370	99
Collie	BC	93.8	69.7	0.9	0.8	462	11	1.7	370	99
Kwinana B	NG	51.8	69.7	0.1	0.1	226	16	0.6	2.3	99.5
Kwinana GT	NG	51.8	-	8.0	0.1	190	46	2.4	2.3	99.5
Kalgoorlie	DO	69.9	-	4.0	0.6	1322	349	45	85	99
Mungarra	NG	52.5	-	8.0	0.1	190	46	2.4	2.3	99.5
Pinjar	NG	52.5	69.9	8.0	0.1	190	46	2.4	2.3	99.5
TiWest	NG	51.8	-	8.0	0.1	190	46	2.4	2.3	99.5
Worsley	NG	51.8	-	8.0	0.1	190	46	2.4	2.3	99.5

continued

Power Station	Fuel	Gg CO ₂ /PJ		Emission Factor Mg/PJ						Oxidation Factor
		Main Fuel	Oil	CH ₄	N ₂ O	NO _x	CO	NMVOC	SO ₂	%
South Australia										
Northern/ Playford	BC	96.4	73.6	0.9	1.4	136	17	1.7	150	99
Torrens Island	NG	51.4	73.6	0.1	0.0	226	16	0.6	2.3	99.5
Osborne	NG	50.8	-	8.0	0.1	190	46	2.4	2.3	99.5
Pelican Point	NG	53.1	-	8.0	0.1	190	46	2.4	2.3	99.5
Ladbroke Grove	NG	51.0	-	8.0	0.1	190	46	2.4	2.3	99.5
Tasmania										
Bell Bay	NG	51.8	-	0.1	0.1	226	16	0.6	3.9	99.5
Northern Territory										
Channel Island	NG	51.4	-	8.0	0.1	190	46	2.4	2.3	99.5
Notes: BC = Black Coal, BrC = Brown Coal, NG = Natural Gas, DO = Diesel, WG = Waste Gas. Source: GWA (2008)										

Figure 3.8: Emission factors for CO₂ in electricity generation, 2007





Notes: Values are the product of the respective CO₂ emission factors and oxidation factors
Source: GWA (2008)

Petroleum Refining (ANZSIC Group 251) (1.A1.b)

Estimated emissions are derived from equations 3.1 and 3.2 and the emission factors reported in Tables 3.2 and appendix Table 3.A1. There are only two fuel categories reported by ABARE for this sub-sector, those being Petroleum Products nec and Natural Gas. In the case of Petroleum Products nec, fuel that is flared and/or vented is accounted for in the Fugitive Fuel Emissions sector (see 3.2.1 for description of Petroleum Products nec fuel).

ABARE statistics for this sector show 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, 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.

ABARE statistics show the consumption of refinery fuel, which is specified as the fuel type 'Petroleum Products nec'. Some natural gas is also consumed in refineries, and separately reported in the ABARE statistics. The apparent consumption of petroleum energy is reduced by the quantity of energy flared and is set at 0.6% of refinery throughput (GHD 2006b). This adjustment is necessary to prevent double counting of emissions, since venting and flaring are accounted under 1.B *Fugitive Fuel Emissions*.

One of the functions of petroleum refining is processing to reduce or remove sulphur compounds contained in crude oil (termed desulphurisation). While most of the sulphur extracted is contained in by-products or solid waste products, some is emitted to the atmosphere as SO₂. All Australian oil refineries are required, by the environmental legislation of the States in which they operate, to monitor and report SO₂ emissions, though the precise form of reporting varies from State to State. Data on the quantities emitted, which depend on operational details at individual refineries, is currently obtained from the National Pollutant Inventory database (NPI)⁵. This methodology is only applicable from 1999 onward, as the data are not available from this source for earlier years. Prior to this methodology being applied the estimates were sourced from the Australian Institute of Petroleum.

⁵ Department of the Environment, Water, Heritage and the Arts, www.npi.gov.au

Manufacture of Solid Fuels and Other Energy Industries (1.A1.c)

The manufacturing of solid fuels and other energy industries sector, 1.A1c, comprises six ANZSIC sectors:

- Coke Oven Operation (ANZSIC Class 2711, part),
- Briquette Manufacture (ANZSIC Class 1102, part),
- Coal Mining (ANZSIC Subdivision 11, remainder),
- Oil and Gas Extraction (ANZSIC Subdivision 12),
- Other Transport, assumed to be gas pipeline transport (ANZSIC Subdivision 65),
- Gas Supply (ANZSIC Group 362).

Estimated emissions are derived from equations 3.1 and 3.2 and the emission factors reported in Tables 3.2 and 3.3 and Table 3.A1.

The *Coke Oven Operation (ANZSIC Class 2711, part)* sub-sector is effectively a subsidiary activity of the Iron & 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. An energy and carbon balance for coke oven and iron and subsectors is detailed in Annex 6.

The consumption of natural gas in the *Other Transport (Natural Gas Transmission) (ANZSIC Subdivision 65)* as listed by ABARE under ANZSIC Subdivisions 65–67 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 Group 362) sector is also one of the energy transformation industries, manufacturing town gas from both natural gas and LPG. Fuel consumption, as indicated by the *ABARE Energy Supply and Demand Statistics* 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,
- gas leakage.

The quantity of town gas produced is shown as an energy output of the sector in the *ABARE Energy Supply and Demand 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. In each year, this figure is roughly a quarter of total fuel consumption in the sector as shown in ABARE statistics.

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 carbon dioxide emission factors for coal burned in electricity generation.

Time series variability of GHG implied emission factors are likely to be influenced by changes in fuel mix within categories, and changes of actual fuel emission factors. Notable examples of where such variations occur in Energy 1.A1 are set out below:

1.A1.c Manufacture of Solid Fuels and Other Energy Industries – CO₂ from solid fuels: The implied emission factor (IEF) declines by 12% between 1990 and 1999. This can be explained by the relative rise of coal by-products—coke oven gas as a fuel (with a relatively low emission factor of 37 Gg/PJ) at the expense of black coal.

1.A1.a Public Electricity – CO₂ from biomass: Biomass combustion for electricity consists of a growing proportion of biogas from landfill. Biogas has a relatively low CO₂ emissions factor compared to other biomass fuel, hence Australia's CO₂ biomass IEF is relatively low.

No major deviations are evident in emission and activity data trends.

3.3.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in section 1.6. 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.A1.a Public Electricity are compiled by an external energy consultant based on DCC survey data, company annual reports and ABARE energy data. The resulting 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 National Electricity Market Management Company (NEMMCO). These comparisons confirm the consistency of the estimates to a high level of accuracy and show that all energy/carbon has been accounted for.

3.3.5 Recalculations Since The 2006 Inventory

Recalculations were made in response to changes to the ABARE national energy statistics for a number of years. In addition, for the electricity sector the carbon balance and associated quality assurance and quality control tools identified some minor errors in oxidation factors used in the emission calculations (resulting in changes of less than 20 Gg CO₂-e). An updated emission factor provided by an electricity generator resulted in a decrease of 120 Gg CO₂-e in 2006.

The impact of these recalculations is as follows:

- 2006 Inventory: 143,097 Gg CO₂-e in 1990, 219,457 Gg CO₂-e in 2006.
- 2007 Inventory: 143,097 Gg CO₂-e in 1990, 218,980 Gg CO₂-e in 2006.

Recalculations in the 2007 inventory resulted in a 476.8 Gg CO₂-e reduction to the 2006 estimate.

3.3.6 Planned Improvements

All relevant data are kept under constant review.

3.4 Source Category 1.A2 – 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.

ABARE 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 3.8.

Table 3.8 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		27	271	Iron and steel manufacturing (excl. Coke ovens)
B Non-Ferrous Metals		27	272	Basic non-ferrous metal manufacturing
C Chemicals		25	252	Petroleum and coal product manufacturing
		25	253	Basic chemical manufacturing
		25	254	Other chemical product manufacturing
		25	255	Rubber product manufacturing
		25	256	Plastic product manufacturing
D Pulp, Paper and Print		23		Wood and paper product manufacturing.
		24		Printing, publishing and recorded media
E Food Processing, Beverages and Tobacco	C Manufacturing	21		Food, beverages, tobacco manufacturing
F Other (part)	B Mining	13, 14, 15		Metal ore mining, Other mining, Services to mining
F Other (part) (all other manuf.)		22		Textiles, clothing , footwear and leather manufacturing
F Other (part) (non-metallic mineral products)		26	261	Glass and glass product manufacturing
F Other (part)		26	262	Ceramic product manufacturing
		26	263	Cement, lime, plaster and concrete product manufacturing
		26	264	Non-metallic mineral product manufacturing n.EC
F Other (part) (all other manuf.)		27	273, 274, 275, 276	All other metal product manufacturing
F Other (part)		28		Machinery and equipment manufacturing
		29		Other manufacturing
E Construction		41, 42		Construction

3.4.2 Methodology

The emissions for sector 1.A2 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 ABARE. CO₂ emission factors are country-specific and direct industry advice on the use of CO₂ emissions factors has been adopted for the use of coal by-products within 1.A2.c Chemicals, black coal within 1.A2.a Iron and Steel, and natural gas in general. Non-CO₂ emission factors have been calculated using a sectoral equipment-weighted average approach and are reported in Table 3.A2. More detail is provided for the metal and chemicals industries.

Table 3.9: Summary of methods and emission factors – Manufacturing and Construction

Category	CO ₂		CH ₄		N ₂ O	
	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 Group 271) (1.A2.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, BTX and naphthalene, all grouped as a single fuel type 'Coal By-Products', but each having quite different calorific values and emission factors. 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 CO₂ emissions, 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 CO₂, 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.C3 rather than the *energy* sector.
- Post 2001, steel producers have fed pulverised black coal direct into blast furnaces. This is currently counted as a fuel input within the Energy sector.

Although Coke Ovens (ANZSIC code 2711) 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.A1.C This separation is also required by the standard national energy balance tables used by the International Energy Agency; for Australia these tables are prepared by ABARE.

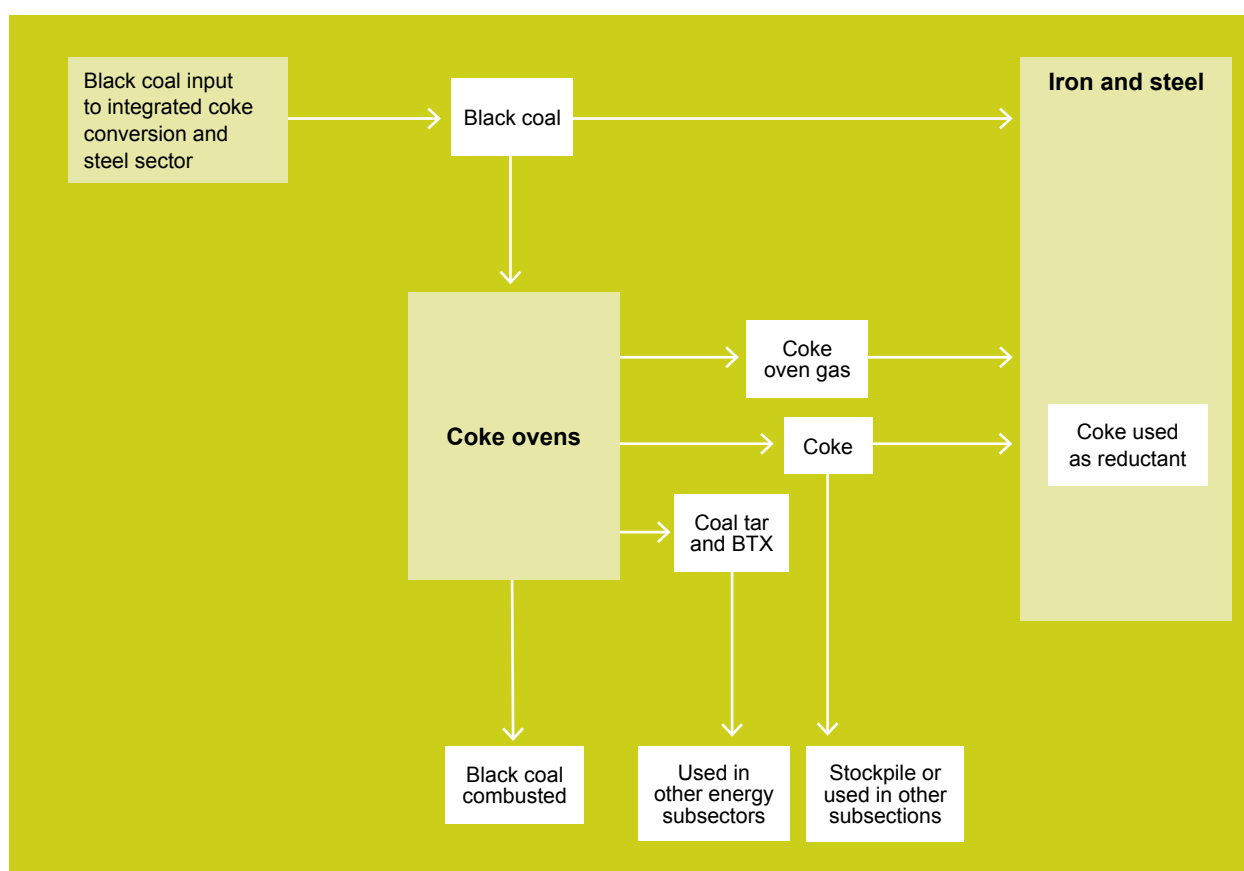
The statistics show that production of both coke and coal by-products exceed consumption within the sectors, i.e. the iron and steel industry as a whole is a net producer of coke and coal by-products. Only the net consumption is used to estimate emissions from the Iron and Steel sector. Some of the remaining 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.

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. It is assumed that exported coal by-products consist of coal tar and BTX, i.e. it is assumed that all coke oven gas is consumed within either the coke oven operation or the iron and steel sectors.

A schematic chart showing energy flows within the integrated coke oven/Iron and Steel subsectors is shown below 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 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.

A carbon and energy balance for the integrated coke oven/Iron and Steel subsectors are presented in Annex 6.

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



Non-Ferrous Metals (ANZSIC Group 272) (1.A2.b)

The consumption of petroleum products nec (meaning other, unspecified petroleum products ‘not elsewhere counted’) in this sector includes petroleum coke used to make carbon anodes for aluminium production. CO₂ emitted from oxidation of carbon anodes in aluminium smelters is accounted in UNFCCC category 2.C3. The quantity of petroleum coke consumed in this sector, as advised by industry each year, was therefore subtracted from total consumption of petroleum products nec, in order to eliminate double counting. It is assumed that the remaining consumption of Petroleum Products nec consists of naphtha. Likewise, the use of black coal in the production of synthetic rutile is also regarded as an industrial process, and is therefore deducted from ABARE black coal consumption.

Black coal used for non-energy purposes in the production of synthetic rutile is reported in UNFCCC category 2.B5.

Chemicals (ANZSIC Subdivision 25) (1.A2.c)

This sub-sector spans five ANZSIC classes:

- Petroleum and coal product manufacturing (ANZSIC Group 252),
- Basic chemical manufacturing (ANZSIC Group 253),
- Other chemical product manufacturing (ANZSIC Group 254),
- Rubber product manufacturing (ANZSIC Group 255),
- Plastic product manufacturing (ANZSIC Group 256).

The Chemicals sector (ANZSIC Subdivision 25) 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.

In ammonia production, emissions from the use of natural gas for its energy value are not able to be separated from its non-energy purposes and so, in order to prevent duplication, all emissions from the use of gas in ammonia production are included within the Industrial Processes sector. Non-energy use of petroleum coke for titanium dioxide production is 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 Petroleum and Coal Product Manufacturing (ANZSIC Group 252) and Chemical Manufacturing (ANZSIC Group 253) 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 *Petroleum and Coal Product Manufacturing* (ANZSIC Group 252) sector. It is assumed that these consist of coal tar and BTX 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 Manufacturing* (ANZSIC Group 253) 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 (methane), ethane, propane, butane, propylene and naphtha. The plastics and carbon black produced by this sub-category contain carbon derived from these feedstocks. Currently data is sourced annually on a commercial-in-confidence basis from companies in the industry.

Several feedstocks are used within this sub-category, these include natural gas (methane), ethane, LPG (propane and 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. ABARE statistics include ethane within the reported total natural gas consumption, after appropriately adjusting for the different energy content of ethane. They group propane and butane together as LPG and they group propylene and naphtha as petroleum products nec.

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

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

A third component, carbon black manufacture, uses relatively large quantities of fossil fuel as a source of carbon, but very little energy. A fourth, methanol, was not manufactured in Australia prior to 1996.

Synthetic Resins

Because 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, 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. Such 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. Actual production figures are provided by the companies making the products concerned. This is feasible, because the number of companies is relatively small. The analysis is nevertheless relatively complex, because most products are derived from several different feedstocks. The factors used in estimating the carbon sequestration are reported in Tables 3.10 and 3.11.

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 2007, 21.9 PJ of ethane and 14.5 PJ of petroleum product feedstocks resulted in the storage of 345 kt and 282 kt of carbon in long life products respectively. The emissions of ethane and petroleum products combusted as fuels are reported in the National inventory under 1.A2c Chemicals. In 2007 0.2 Mt of ethane emissions and 1.3 Mt of petroleum products emissions were reported.

Nitrogenous Products

The principal carbon containing products of this industry are urea and CO₂. In compiling the inventory it is assumed that the principal use of urea is as a fertiliser and that it is rapidly hydrolysed, following application. Similarly, it is assumed that uses of CO₂ result in it being quickly released to the atmosphere. Thus it is assumed for both products that the carbon is not stored, but rapidly released to the atmosphere as CO₂, and that no adjustment to fossil fuel consumption figures is needed for the inventory.

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 3.10: Feedstock assumptions in basic chemicals

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

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

Table 3.11: Product assumptions in basic chemicals

Product	Carbon Fraction
Polyethylene	0.86
Polypropylene	0.86
BR / SBR	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.

Time series variability of GHG implied emission factors are likely to be influenced by changes in fuel mix within categories, and changes of actual fuel emission factors. Notable examples of where such variations occur in Manufacturing Industries and Construction 1.A2 are set out below:

1.A2.a Iron and Steel - CO₂: 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, coke oven gas has a relatively low CO₂ emission factor of 37Gg/PJ. This acts to lower the overall CO₂ IEF for solid fuels. Likewise, the liquid fuels CO₂ IEF is also relatively low, being driven by the large and increasing use of LPG.

The IEF trend for solid fuels shows an increase in recent years. This is due largely to steel producers, post 2001, starting to feed pulverised black coal direct into blast furnaces.

1.A2.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 has changed 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 2006 Inventory

Recalculations were made in response to minor changes to ABARE national energy statistics for 2005 and 2006. In addition a small calculation error was uncovered by the carbon balance QC check relating to the application of the oxidation factor to chemical liquid and gas fuels. This error was fixed for all years. A summary of the impact of the recalculations follows:

- 2006 Inventory: 36,267 Gg CO₂-e in 1990, 47,245 Gg CO₂-e in 2006.
- 2007 Inventory: 36,280 Gg CO₂-e in 1990, 47,347 Gg CO₂-e in 2006.

Recalculations in the 2007 Inventory resulted in 1990 estimates increasing by 12 Gg CO₂-e and the 2006 estimate increasing by 102.0 Gg CO₂-e.

3.4.6 Planned Improvements

All relevant data are kept under constant review.

3.5 Source Category 1.A3 – 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 ABARE 2008a. 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.A2 and 1.A4. Emissions from mobile utility engines (such as lawn-mowers, chain-saws, portable generators and mobile compressors) and military transport are reported in sectors 1.A4 and 1.A5 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.A3.

3.5.2 Methodology

Like other energy sub-sectors, the methodology for 1.A3 is based on the application of ‘bottom up’ approaches to the estimation of emissions. Tier 2 approaches are employed for the estimation of non-CO₂ emissions from civil aviation, which takes account of fuel consumed, landing and take off cycles and Australian fleet characteristics. The estimation of non-CO₂ emissions from passenger and light commercial vehicles utilises a Tier 3 approach that depend on data on vehicle kilometres travelled, vehicle fleet characteristics and vehicle operating modes.

Table 3.12: Summary of methods and emission factors – Transport

Source Category	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A3a Civil Aviation	T2	CS	T2	CS/D	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
1A4 Other sectors	T2	CS	T2	D	T2	D
1A5b Military	T2	CS/D	T2	CS	T2	CS

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

General Methodology

The emission level 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 emission factor, in units of grams of gas l emitted per megajoule of energy use (g/MJ) for CO₂ and SO₂, and grams of gas l emitted per kilometre travelled (g/km) for other non-CO₂ gases

Fuel consumption data for the *transport* sector are taken from ABARE 2008a. The main assumptions applied to ABARE energy consumption data allocate petrol to off-road and military fuel uses (reported in Table 3.A12).

Civil Aviation (1.A3a)

The estimation of carbon dioxide emissions from civil aviation is undertaken using a Tier 2 methodology and emission factors given in Tables 3.2 and 3.3. Non-carbon dioxide emissions from domestic civil aviation from fuel use are estimated using a Tier 2 methodology. Emissions are calculated as a function of both the landing/takeoff cycles (LTOs) and of cruise emissions for both domestic and international aircraft.

The estimation of emissions from landing and takeoff cycles requires data on the number of LTO cycles at Australian airports; data on the profile of the Australian aviation capital stock or fleet; and emission factors by type of aircraft. The data required for the total yearly LTO for the domestic and international aircraft are available from Avstats, Department of Transport and Regional Services. The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority (Table 3.13). Emission factors for each aircraft type are taken from IPCC 2006 and are used to estimate weighted average LTO cycle emission factors for the domestic/interstate, regional and international aviation fleets (Table 3.14).

The estimation of cruise emissions is a function of fuel use, after deduction of fuel consumption required for the LTO cycles, and cruise emission factors. Data on the yearly fuel consumption for domestic and international activity are available from ABARE 2008a. Cruise emission factors are taken from IPCC (1997) (Table 3.15).

The methodology is applied to each of the eight Australian States and Territories. 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 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.

Emissions from international aviation are also estimated, but are reported as a Memo item only by international agreement. Activity data for international bunkers are derived from customs data (as the tax regime distinguishes between domestic and international activity) and reported in ABARE 2008a.⁶

Table 3.13: The Australian aircraft fleet, 2007, and emission factors by type of aircraft

Type of aircraft	Number	Emission Factors				
		CH ₄	N ₂ O	NO _x	CO	NM VOC
		kg/LTO	kg/LTO	kg/LTO	kg/LTO	kg/LTO
Major inter-state						
DHC-8-100	31	0.00	0.02	1.51	2.24	0.00
DHC-8-200	12	0.00	0.02	1.51	2.24	0.00
A320	35	0.06	0.10	9.01	6.19	0.51
A330–200/300	21	0.13	0.20	35.57	16.20	1.15
BAE 146	34	0.14	0.00	4.07	11.18	1.27
B717	14	0.01	0.10	10.96	6.78	0.05
B737–300/400/500	27	0.08	0.10	7.19	13.03	0.75
B737–700	22	0.09	0.10	9.12	8.00	0.78
B737–800	67	0.07	0.10	12.30	7.07	0.65
B767–200	0	0.33	0.10	23.76	14.80	2.99
B767–300	29	0.10	0.20	28.19	14.47	1.07
Regional						
SAAB 340	44	0.00	0.02	1.51	2.24	0.00
SA227	54	0.00	0.02	1.51	2.24	0.00
SA226	12	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	27	0.14	0.10	5.63	8.88	1.23
EMB 110	14	0.06	0.01	0.30	2.97	0.58
EMB 120	22	0.00	0.02	1.51	2.24	0.00
Cessna 525	11	0.33	0.03	0.74	34.07	3.01
Beech 200	107	0.06	0.01	0.30	2.97	0.58
F27	96	0.03	0.02	1.82	2.33	0.26
International						
747–300	4	0.27	0.40	65.00	17.84	2.46
747–400	30	0.22	0.30	42.88	26.72	2.02

Source: CASA Civil Aircraft Register (2006), International Civil Aviation Organisation, Engine Exhaust Emissions Databank (2004)

⁶ As the fuel consumption split between international and domestic uses published by ABARE did not match trends in Australian aircraft activity published in alternative sources, the 2006 activity data for these sources were derived as the average of 2005 and 2007 for domestic and international activity data. The 2007 activity data was verified against the Australian Petroleum Statistics (DRET 2009).

Table 3.14: Weighted average emissions factors per Landing and Take Off cycle

Fleet	CH ₄ (kg)	N ₂ O (kg)	NO _x (kg)	CO (kg)	NMVOC (kg)
Domestic/Interstate Fleet	0.08	0.09	11.84	8.98	0.77
Regional Fleet	0.05	0.02	1.47	3.86	0.42
International Fleet	0.23	0.31	45.48	25.68	2.07

Source: DCC estimates

Table 3.15: Aviation cruise emission factors (grams per tonne of fuel consumed)

Fleet	CH ₄ (g/t)	N ₂ O (g/t)	NO _x (g/t)	CO (g/t)	NMVOC (g/t)
Domestic and Regional Fleets	0	0.1	11	7	0.7
International Fleet	0	0.1	17	5	2.7

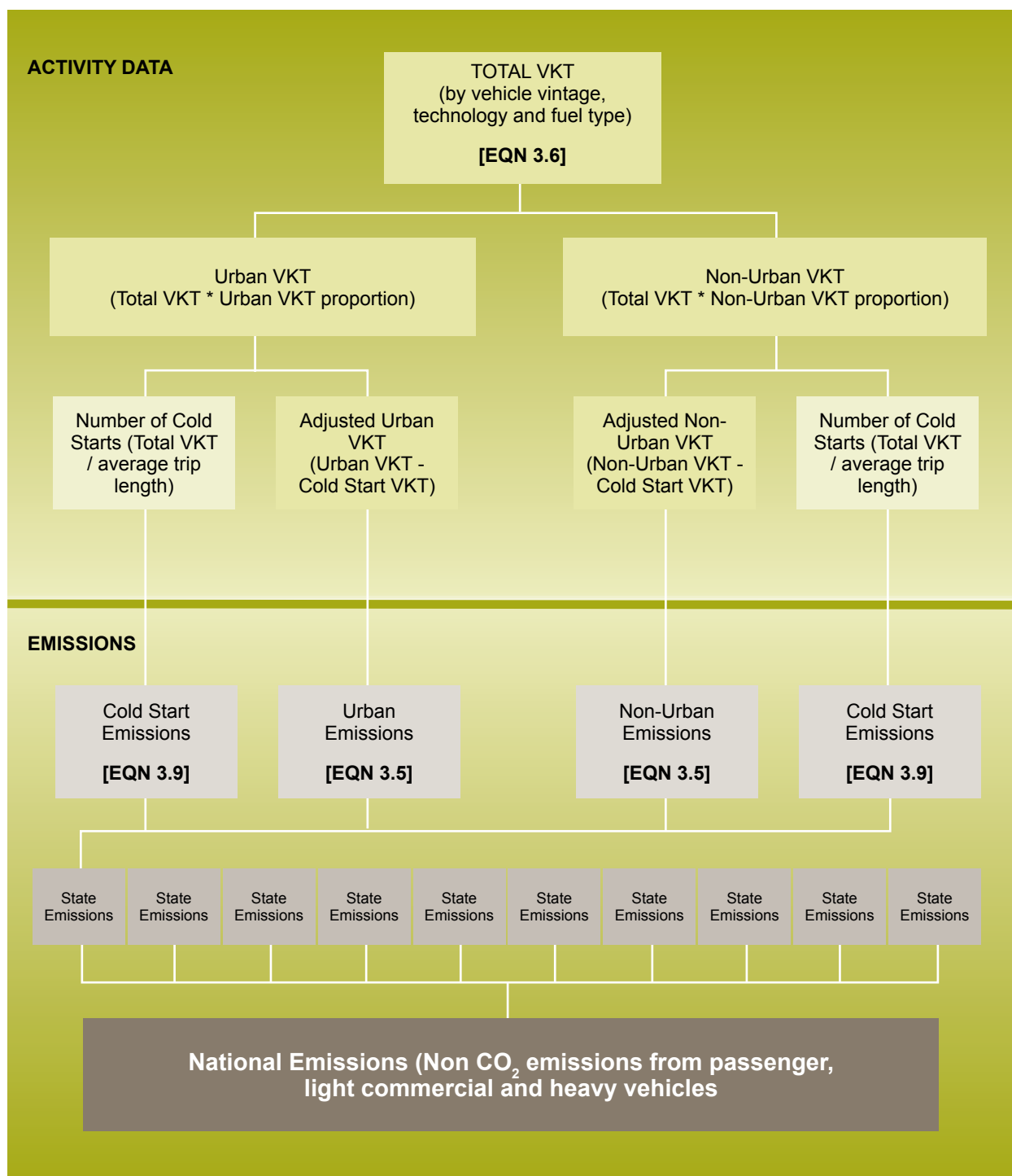
Source: IPCC (1997)

The estimated weighted emission factors have been held constant throughout the time series 1990–2004, and are adjusted in line with changes in the aviation capital stock from 2004 onwards.

Road Transportation (1.A3.b)

Like the aviation sector, the estimation of carbon dioxide emissions from the road transport sector is based on a Tier 2 method with emission factors given in Table 3.2. The estimation of non-carbon dioxide 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 emission factors are expressed in terms of g/km. The methodology is applied to each of the eight Australian States and Territories. Differences in emission estimates across the States principally reflect differences in fuel consumption and the impacts on non-CO₂ emission estimates of differentials in the age distribution of each State's vehicle fleet. National emissions are estimated as the sum of the State and Territory emissions (see Box).

Methodology for the estimation of non-CO₂ emissions from passenger and light commercial vehicles



Passenger and Light Commercial Vehicles, Heavy Vehicles and Buses (1.A3.bi-v)

Carbon dioxide emissions from all vehicle fuel sources have been estimated based on the quantity of fuel consumed by the CO₂ emission factor specific to that fuel and the proportion of that fuel which is completely oxidised.

$$E_{ijk} = A_{ijk}^{u=1} \cdot (F(l)_k \cdot P_k) \quad (3.4)$$

Where: $F(l)_k$ is the CO₂ emission factor (for fuel type k) applicable to complete oxidation of fuel carbon content; P_k is the proportion of fuel that is completely oxidised upon combustion; and $A_{ijk}^{u=1}$ 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)
For $l=CO_2$ and $k=petrol, diesel$ and LPG .

The CO₂ emission factors 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 non-CO₂ emissions for each age class are estimated based on vehicle kilometres travelled 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 emission factors.

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 of 10km (based on data cited in VicHealth (1999), QLD Transport (2001), and EPA NSW (2000)). 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.

Emission factors 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 based on data in Apelbaum Consulting Group 2006.

Vehicles using automotive gasoline, ethanol, diesel and LPG are further classified by age of vehicle (using data contained in ABS 2009). 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. 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. For diesel vehicles, this age band structure has been implemented to preserve internal consistency although no exhaust control distinction is made in the emission factors used.

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

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

Where: l = non-CO₂ gases; $A_{ijk}^{u=2}$ for vehicle kilometres travelled & k = automotive gasoline, diesel, and LPG;
 $EF(l)_{ijk}$ is the exhaust emission factor 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.

where vehicle distances travelled during the hot-engine phase of operation are related to energy consumption levels using:

$$A_{ijk}^{u=2} = A_{ijk}^{u=1} / R_{ik} \cdot D_k \quad (3.6)$$

Where: $A_{ijk}^{u=2}$ is the distance travelled for vehicle type i and age class j , using fuel type k = automotive gasoline, diesel, and LPG;
 R_{ik} is the average rate of fuel consumption (in l/km, given in Tables 3.A12-3.A14) 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

$$EF(I)_{ijk} = (ZKL_{ijk} + DR_{ijk} \cdot \text{CumVKT}_{ijk}) \quad (3.7)$$

Where: $EF(I)_{ijk}$ is the emission factor for gas I 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 I 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

$$\text{CumVKT}(I)_{ijk} = \sum_{t=1-n} A_{ijk}^{u=2} \quad (3.8)$$

Where: $A_{ijk}^{u=2}$ 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; and
 EF_{ijk} is the cold start emission factor (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 ABARE 2008a and ABS (2008a and various issues). The data on fuel consumption rates are taken from ABS (2008a, and various issues). The profile and age of the passenger vehicle stock in each State required for equation 3.7 is taken from ABS (2009, and various issues). Data required to estimate VKT for individual vehicle and age classes for 2004 are given in Tables 3.A13 to 3.A17.

Emissions of CH_4 from motor-vehicles are a function of the emission and combustion control technologies present as well as vehicle operating conditions. Emission factors 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 Table 3.18). The use of disaggregated, country-specific emission factors expressed in terms of emissions per kilometre travelled is consistent with the IPCC tier-3 methodology. Where country-specific emission factors were not available IPCC 2006 has been used as a source.

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 from 2004 in light duty vehicles and, since, 1996 in heavy duty vehicles. Therefore the IPCC default factors used for post 2004 vintage light duty vehicles and post 1995 heavy duty vehicles are based on European data (COPERT IV). 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 tables 3.16 and 3.17. 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 3.16: Australian petrol passenger car exhaust emission standards

Australian Standard	Year introduced	Source standard
ADR 79/00	2004	Euro 2
ADR 79/01	2006	Euro 3
ADR 79/02	2010	Euro 4

Source: Department of Transport and Regional Services

Table 3.17: Australian heavy duty diesel exhaust emission standards

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: Department of Transport and Regional Services

Table 3.18: Country specific CH₄ passenger vehicle emission factors

Vintage	Carnovale ¹ 1991				FORS ² 1996	BTRE ³ 2002
	g/km				g/km	g/km
	Congested	Residential	Arterial	Freeway		
1990's						0.06
1986-91					0.112	0.1
1985	0.0512	0.0816	0.032	0.04	0.144	0.15
1981-85	0.1254	0.1056	0.0822	0.0648		
1976-80	0.1332			0.1116		0.21

Sources: 1. Carnovale et al (1991) – derived from total hydrocarbon emission factors – assuming 6% of 1980 to 85 (ADR-27) vehicles HC emissions and 16% of post 1985 (ADR 37/00) vehicles HC emissions are CH₄

2. Federal Office of Road Safety (FORS) 1996 – derived from total hydrocarbon emission factors – assuming 6% of 1980 to 85 (ADR-27) vehicles HC emissions and 16% of post 1985 (ADR 37/00) vehicles HC emissions are CH₄

3. Bureau of Transport and Regional Economics 2002 - based on NISE study 1 (FORS 1996), MAQS Emissions Inventory (EPA NSW 1995), NGGIC (1996), Air emissions inventory Port Phillip Bay Control Region (Carnovale et al. 1991).

In some cases, CH₄ emission factors presented below have been derived from total hydrocarbon emission factors presented in the reports.

The Federal Office of Road Safety (FORS) 1996 - National In-Service Emissions study 1 - was a comprehensive testing program which looked specifically at the emissions performance of Australia's passenger car fleet and the effects of tuning and emissions control deterioration. Tests were performed on a total of 640 passenger cars. Emissions measured were limited to hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NO_x). Methane was not specifically identified in the study. However, it is possible to derive CH₄ emissions from HC emissions using standard assumptions about HC speciation. Methane emission factors by road type are presented in Carnovale 1991. Approximately 10 vehicles of vintage ranging from 1976 to post 85 were tested in this study. As with FORS 1996, methane emissions were not reported directly. The Bureau of Transport and Regional Economics 2002 also provides CH₄ emission factors for a range vehicle age cohorts. These emission factors are based on those presented in Carnovale et al. (1991) and FORS (1996).

As the emission factors cited in the above reports are most applicable to vehicles in the 2-way catalyst and pre catalyst technology categories, Carnovale et al. (1991) emission factors were used for urban (congested) and non-urban (freeway) roads in the pre-1976 and 1976-1985 age cohorts and FORS (1996) emission factors were used for urban roads in the 1985-1997 (2 way catalyst) vehicle class.

For vehicles fitted with 3-way catalyst technology (1985-97, 1998-2005 and post-2005), US EPA emission factors have been chosen and adjusted for urban, non-urban roads (based on IPCC 2006 (COPERT IV) proportions). IPCC default cold start emission factors (US EPA) are used for all passenger and light commercial vehicle age and technology classes.

There are no country-specific CH₄ emission factors available for heavy-duty vehicles. These emission factors have been taken from USEPA 1989 and IPCC 2006 as indicated in Appendix 3.A6. Methane emission factors for post-2005 vintage vehicles (Euro 3) have been derived based on the Euro 1 COPERT IV emission factor and an emission reduction factor over heavy Euro 1 diesel vehicles of 44% taken from Ntziachristos and Kuuridis 2007.

A summary of the emission factors used to estimate CH₄ 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.A5.

Emissions of non-CO₂ 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.

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 (ie new car) emissions for the two States' combined fleet. The general trend is for hydrocarbon emissions to increase as the cumulative VKT increases. The deterioration rates used to derive emission factors for the passenger and light commercial vehicle fleet are shown in appendix Table 3.A10.

N₂O Emission factors 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. Emission factors for the 2004-2005 and post 2005 age class are taken from IPCC (2006). The emission factors in Weeks et al are comparable to those reported in IPCC (2000) and by the US EPA and COPERT IV. IPCC default cold start emission factors (US EPA) are used for all passenger and light commercial vehicle age and technology classes.

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 equivalent to Euro II (ADR 79/00) were introduced in Australia in 2004. 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. Further empirical research is planned which will enable emission factors to be developed for the more advanced forms of catalyst technology as new, more stringent emission factors enter into force.

The emission factors used to estimate N₂O 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.A7.

There are no country-specific N₂O emission factors available for heavy-duty vehicles. These emission factors have been taken from USEPA 1989 and IPCC 2006 as indicated in appendix Table 3.A8.

Motorcycles (1.A3.Bvi)

More generally, the estimation of emissions for motorcycles is given by equations 3.4 and 3.5. Fleet average emission factors for motorcycles are provided in appendix Table 3.A11.

Evaporative Fuel Emissions (1.A3.Bv)

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.
- 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).

Emission factors 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.A18.

Railways (1.A3c)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. Carbon dioxide emission factors are reported in Table 3.2 and non-carbon dioxide emission factors are reported in Table 3.19. Given data on the composition and engine types in the local fleet, an average fleet emission factor has been calculated using the individual engine emission factors in USEPA (1992). Data on fuel consumption is taken from ABARE 2008a.

Table 3.19: Non-CO₂ emission factors for non-road sources

Source Category		CH ₄	N ₂ O	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	Ferries	0.004	0.002	1.105	0.246	0.075
	Fishing	0.004	0.002	1.105	0.246	0.075
	Shipping	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
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 (1995, and previous issue)

Navigation (1.A3d)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. Carbon dioxide emission factors are reported in Table 3.2 and non-carbon dioxide emission factors are taken from Lloyds 1995 and are reported in Table 3.19.

Emissions from international bunker fuels are also estimated, but are excluded from national emission inventory aggregates by international agreement. Activity data for international bunkers are derived from customs data and reported in ABARE 2008a.⁷

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 use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

⁷ As the fuel consumption split between international and domestic uses published by ABARE did not match trends in sea freight data published in alternative sources, the 2006 activity data for these sources were derived as the average of 2005 and 2007 for domestic and international activity data.

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.

Tier 2 quality control checks were completed for the passenger and light commercial vehicle sector. The primary sources of activity data for this sector are the Australian Bureau of Agricultural and Resource Economics (ABARE) 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. Consequently, the Department of Climate Change was able to conduct cross checks of the quality of ABS estimates of fuel consumption rates and VKT based on analyses undertaken by the Bureau of Transport Research Economics (BTRE 2000a) and data produced by Apelbaum Consulting Group (2006). ABARE estimates of fuel consumption, based on surveys of fuel suppliers, were also assessed and cross checked against data on fuel consumption reported by the ABS, based on surveys of motor vehicle usage.

The selection of emission factors was undertaken following a critical review of the existing empirical literature and international practice, and after consideration of the views of experts in the field (BTRE 2000b).

International comparison of implied emission factors was also undertaken.

3.5.5 Recalculations Since the 2006 Inventory

Standard quality assurance and quality control checks identified minor transcription errors in the activity data used in the *transport* calculations. These corrections resulted in recalculations of less than 4 Gg CO₂-e for all years except 1991 and 2004 where the corrections resulted in emission reductions of 399 Gg CO₂-e and 23 Gg CO₂-e respectively.

Additional recalculations resulted from the inclusion of updated fuel consumption data from ABARE for 2005 and 2006. The impact of all the recalculations is as follows:

- 2006 Inventory – 62,092 Gg CO₂-e in 1990, 79,079 Gg CO₂-e in 2006.
- 2007 Inventory – 62,092 Gg CO₂-e in 1990, 78,643 Gg CO₂-e in 2006.

3.5.6 Planned Improvements

All relevant data are kept under constant review.

3.6 Source Category 1.A4 – Other Sectors

3.6.1 Source Category Description

The source category—*1.A4 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.
- Agriculture, forestry and fisheries—emissions from fixed and mobile equipment.

ABARE 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 3.20.

Only the petroleum from sub-divisions 65–67 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 62 Railway Transport is included in this category. Any other fuel consumption within sub-category 62 is assumed to be accounted for within sector 1.A3.

3.6.2 Methodology

The methodology for this sector consists of a mix of tier 1 and 2 approaches. CO₂ emission factors consist of defaults and country-specific factors where they are more accurate than the IPCC defaults. Non- CO₂ emission factors have been calculated using a sectoral equipment-weighted average approach.

CO₂ emission and oxidation factors are reported in Tables 3.2 and 3.3. Activity data are taken from ABARE 2008a. Non- CO₂ emission factors for this sector, by ANZSIC Division, are reported in appendix Table 3.A3.

Table 3.20: Relationship between IPCC source categories and ANZSIC sectors – Other Sectors

IPCC Source Category	ANZSIC Category		
	Division	Sub-division	Description
4. Other Sectors			
A Commercial, Institutional	Division D	37	Water supply, sewerage and drainage services
	Division F	45, 46, 47	Wholesale trade
	Division G	51, 52, 53	Retail trade
	Division H	57	Accommodation, cafes and restaurants
	Division I Transport and Storage	66	Services to transport
	Division I Transport and Storage	67	Storage
	Division J	71	Communication services
	Division K	73, 74, 75	Finance and insurance
	Division L	77, 78	Property and business services
	Division M	81, 82	Government administration and defence
	Division N	84	Education
	Division O	86, 87	Health and community services
	Division P	91, 92, 93	Cultural and recreational services
	Division Q	95, 96	Personal and other services
B Residential	Residential		Residential
C Agriculture, forestry, and fishing	Division A	01	Agriculture
	Division A	02	Services to agriculture, hunting and trapping
	Division A	03	Forestry and logging
	Division A	04	Commercial fishing

Table 3.21: Summary of methods and emission factors – 1.A4 Other Sectors

Source Category	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A4a Commercial/Institutional	T2	CS	T2	CS	T2	CS
1A4b Residential	T1, 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.A4)

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 woodheaters. 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 (see Todd 2003, and updated with Todd 2005), and 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 3.10, and is also summarised in the algorithm below:

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

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 emission factor for gas k to the particulate emission factor.
- PEF_n = weighted particulate emission factor 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 woodheater correctly operated
- $l(2)$ certified woodheater carelessly operated
- $l(3)$ certified woodheater very badly operated
- $l(4)$ non-certified woodheater correctly operated
- $l(5)$ non-certified woodheater carelessly operated
- $l(6)$ non-certified woodheater 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 methane emission factor for certified woodheaters 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 methane emission factor of 461.3 Mg/PJ has been applied to non-certified heaters, through the application of a factor of 1.77 to the certified woodheater emission factor. 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) (US EPA 1996). The Australian emission test for woodheaters 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 the 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 woodheaters accounted for 30.6% of all wood-burning appliances in 2000. The population of certified woodheaters has been decreased linearly to 1994, where it is zero (Todd 2005).

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 emission factors 1.5 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 woodheaters are in this category. The increase in emissions compared to a well-operated heater has been set at a factor of 4 based on a small number of laboratory tests (Todd 2005).

Proportion of well/poorly operated woodheaters

The proportion of good, careless and very poor woodheater operators for 2000 was set by Todd (2005) at 0.4/0.5/0.1 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 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, suggest 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.

Open fireplaces

- Emission factors

No emission testing of masonry open fireplaces has been carried out in Australia. The US (US EPA 1996) value for the particulate emission factor for masonry open fireplaces (17.3g/kg) has been used by Todd (2005) to derive a base methane emission factor 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 emission factors. The CSIRO tests provide particulate emission factor 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 methane emission factor 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 a 1999 ABS survey (Todd 2005).

Softwood fuel and wet wood

- Emission factors

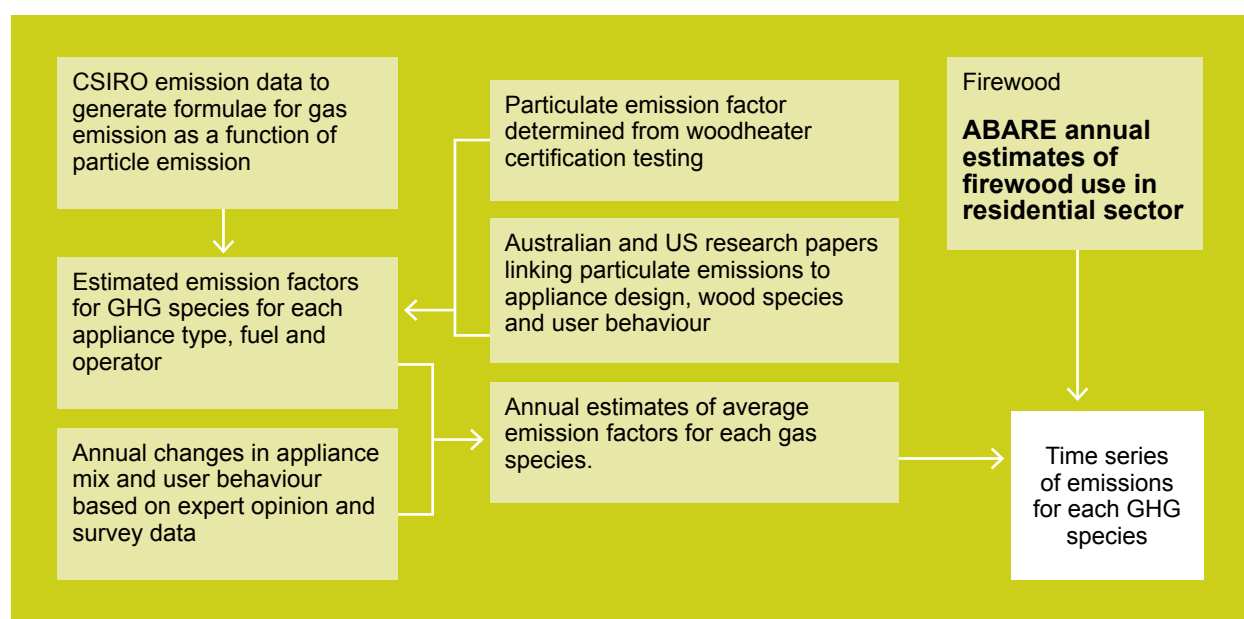
The use of wet firewood is often cited as one of the main reasons for high emissions from woodheaters. However, the CSIRO study, and other Australian studies (e.g. Todd et al. 1989a) have consistently shown that only very wet wood (i.e. unseasoned) influences emissions. High burn-rate tests carried out 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 4% proportion of households using very wet wood (>30% moisture, wet weight basis) is taken from a Hobart survey (Todd 2001). 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 3.10: Schematic diagram of the methodology process for estimation of emissions from woodheaters



The resulting emissions factor trends are shown below in Table 3.22. With Australian standards for woodheater 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 CO₂ emission factor (ie more carbon is oxidised under improved combustion conditions) and decreasing methane emission factor. As a result, the implied methane emission factor varies between 1100 Mg/PJ in 1990 and 714 Mg/PJ in 2007. This range is consistent with the 2006 IPCC defaults for residential methane emission factors for woodstoves (IPCC 2006, Vol 2, Table 2.9), taking in account the inherent uncertainty of residential combustion methane emission factors of 50 to 150% (IPCC 2006, Vol 2, Table 2.12).

Table 3.22: Residential biomass emission factors

Inventory Year	Greenhouse Gas Emission Factor (Mg/PJ)						
	CO ₂	CH ₄	N ₂ O	CO	NO _x	NM VOC	SO ₂
1990	70 374	1100.1	2.3	11751.6	16.9	1393.5	1.1
2000	76 245	782.4	1.9	9421.7	21.1	991.0	1.1
2001	76 561	765.2	1.9	9296.0	21.4	969.3	1.1
2002	76 877	748.2	1.9	9170.7	21.6	947.7	1.1
2003	77 191	731.1	1.9	9045.9	21.8	926.1	1.1
2004	77 505	714.2	1.9	8921.6	22.1	904.6	1.1
2005	77 505	714.2	1.9	8921.6	22.1	904.6	1.1
2006	77 505	714.2	1.9	8921.6	22.1	904.6	1.1
2007	77 505	714.2	1.9	8921.6	22.1	904.6	1.1

Emissions from lawnmowers are estimated using Tier 1 methods described by equation (3.1). Carbon dioxide emission factors are reported in Table 3.2 and non-carbon dioxide emission factors are reported in Table 3.23. 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.A4.c Agriculture, Forestry & Fisheries sector*, ABARE 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 emission factors for non-CO₂ 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 emission factors for the different types of diesel engines used in the types of equipment typical of the three sectors, to estimate weighted sectoral emission factors (Table 3.23).

Table 3.23: Non-CO₂ emission factors for non-road mobile sources

	CH ₄	N ₂ O	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 personal communication, 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.

Time series variability of GHG implied emission factors are likely to be influenced by changes in fuel mix within categories, and changes of actual fuel emission factors.

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 2006 Inventory

Recalculations were made in response to minor changes to ABARE national energy statistics for 2005 and 2006. A summary of the impact of the recalculations follows:

- 2006 Inventory: 14,744 Gg CO₂-e in 1990, 19,414 Gg CO₂-e in 2006.
- 2007 Inventory: 14,744 Gg CO₂-e in 1990, 19,414 Gg CO₂-e in 2006.

Recalculations in the 2007 Inventory resulted in a reduction of 0.1 Gg CO₂-e to the 2006 estimate.

3.6.6 Planned Improvements

All relevant data are kept under constant review.

3.7 Source Category 1.A5 – Other (Not Elsewhere Classified)

Emissions from the ‘Other’ sector are estimated using a mix of Tier 1 and Tier 2 approaches using emission factors set out in Tables 3.2 and 3.3.

Table 3.24: Summary of methods and emission factors: Other (Not Elsewhere Classified)

Source category	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A5 Other	T1, T2	CS	T2	CS	T2	CS

Notes: T1 = Tier 1, T2 = Tier2, CS= Country-specific.

3.7.1 Source Category Description

The source category *Other 1.A5* 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 CO₂ 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 ABARE 2008a. It is assumed that 60% of lubricants are not oxidised during engine operation, i.e. not actually combusted (Australian Institute of Petroleum, pers. comm.). Therefore the stated ABARE consumption of lubricants and greases is reduced by 60% before emissions are estimated. Emissions of gases other than CO₂ 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. Carbon dioxide emission factors are reported in Table 3.2 and non-carbon dioxide emission factors are reported in appendix Table 3.A11.

It is assumed that solvents are either emitted not oxidised, i.e. as NMVOC, in which case they are reported in the Solvents sector of the National Inventory Report, or as CO₂, 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 2006 Inventory

There has been a minor recalculation to the 2006 military transport emission estimates due to changes to the navigation and aviation fuel consumption data as described in section 1.A3. The impact of the recalculation was an increase of 129 Gg CO₂-e to the 2006 emission estimate.

3.7.6 Planned Improvements

All relevant data are kept under constant review.

3.8 Source Category 1.B1 – 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.

Most of Australia's resources and production of black coal are located in New South Wales and Queensland. There is also a very small quantity of bituminous black coal mined in Tasmania. In Victoria, large quantities of brown coal are mined in open cut operations. The CH₄ content of this coal is regarded as very low. Sub-bituminous coal is mined in Western Australia, while a low rank sub-bituminous coal is mined in South Australia.

A Tier 3 approach using directly measured mine methane emissions obtained from coal mining companies, are included for a number of mines. For mines where measured data is not available, methane emissions are based on a country-specific tier 2 approach where the emission factors (m³ CH₄/tonne coal produced) are based on measurement from Australian mines. Estimation of emissions is based on grouping Australian mines into a small number of categories of broadly similar mines. Emission factors or, in some cases, emission equations have been developed for each mine category based on the available empirical data, ie. actual measurements of emissions from representative mines in each category.

Table 3.25: Summary of methods and emission factors – 1.B1 Solid Fuels

Greenhouse Gas Source and Sink Categories	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1.B1 Solid Fuels	-	-	T2, T3	CS, PS	-	-

Notes: T2 = Tier2, T3 = Tier3, CS= Country-specific.

Data Sources

Principal data sources include Coal Services Pty Ltd, coal mining companies (BHP Billiton and Anglo Coal), the Australian Petroleum Production and Exploration Association, the Australian Gas Association, the Energy Supply Association of Australia and the Australian Bureau of Agricultural and Resource Economics.

Underground Mining (1.B1ai)

Mine methane concentrations within underground mines are monitored by mining companies as part of their operational procedures. Where available, mine emissions derived from direct measurement are included in the inventory. Emissions derived from direct measurement account for the majority of emissions from underground mines reported in the inventory. For mines where measured data is not available, an empirical default approach is taken. Emissions from underground coal mining in Queensland and New South Wales in 1990 and 1994 respectively were estimated in Williams et al. (1992) and Williams, Lama and Saghabi (1996). Both reports divide mines into two groups, having significantly different levels of CH₄ emissions. The two groups are designated Class A ('gassy') and Class B ('non-gassy'). From 2010, all underground mines are to report emission estimates using direct measurement under the National Greenhouse and Energy Reporting Regulations.

Production Data

The production data for each mine are published annually in the statistical publications of the Joint Coal Board, the New South Wales Department of Minerals, and the Queensland Coal Board. In January 2002 the Joint Coal Board merged with the Mines Rescue Board to form Coal Services Pty Ltd.

Measured Emissions from Underground Mines

Mine methane concentrations within underground mines are monitored by mining companies as part of their operational procedures. Where available, mine emissions derived from direct measurement are included in the inventory. Direct measurement now accounts for the majority of underground mine emissions. Where direct emission mine data have been obtained for later years only, then an emission factor is derived using the measured emissions and the corresponding mine production, with the emission factor then applied to the historical time series using the known mine production activity data.

Emissions from Underground Class A Mines

Emissions are estimated as the average of the results from the application of two empirical models (Williams et al (1992) and Williams, Lama and Saghaifi (1996)). In the first study, analysis of data provided by individual mines on CH₄ concentrations in ventilation exhaust, ventilation flow rate, in-situ CH₄ concentration and coal production rate enabled the annual CH₄ release to be calculated for 24 Class A mines, which accounted for about three quarters of total Class A production. Statistical analysis of the data showed a correlation between CH₄ emissions, in-situ gas content of the coal and production for the mines where measurements were taken.

The equation estimates emissions, E_{a1} as the average of the relationships identified in these two empirical studies, based on the quantity of production in Class A mines, QTY_a and the volume to mass conversion factor (C_a , equal to 0.616):

$$E_{a1} = (23.5975 \cdot QTY_a + 2.79) \cdot C_a \quad (1B1_1)$$

Algorithm (1B1_1) expresses the relationship between raw coal production, in-situ gas content and mining CH₄ emissions for the entire *group* of Class A mines in Australia. It does not apply to any *specific* mine, although the relationship can be manipulated to exclude mines where directly measured data is available.

Emissions from Underground Class B Mines

Similarly to Class A mines, measurements have also been made of emissions Class B mines (Williams et al. 1992 and Williams, Lama and Saghaifi (1996)). The relationship established between coal production, QTY_b , and CH₄ emissions from mining for the entire *group* of Class B mines in Australia, E_b is described by algorithm (1B1_2).

$$E_b = (0.66 \cdot QTY_b + 0.28) \cdot C_a \quad (1B1_2)$$

Total Emissions from Underground Mines

Total emissions of CH₄ from underground coal mines in Australia E_u are estimated as the sum of emissions from Class A, E_a , and Class B mines, E_b , and measured mine emissions, E_m . A correction has to be made to allow for gas which is extracted from mines in advance of mining E_{ef} , and used as fuel at the mine site. Although this may occur at any mine, in practice it only occurs at Class A underground mines. Total emissions from underground mines are estimated by:

$$E_u = E_m + (E_a + E_b - E_{ef}) \quad (1B1_3)$$

Surface Mining (1.B1a)ii)

Black coal mine production

Measurements have also been made of CH₄ emissions from open cut coal mines in New South Wales and Queensland (Williams et al. 1993). The experimental results were used to estimate emission factors (in m³/tonne raw coal) applicable to open cut black coal mining in each State, and these are shown in Table 3.26.

Brown coal (lignite) mine production

Open cut mining of brown coal occurs in Victoria for combustion in electricity generation. Emissions are regarded as very low, however no national emission factor data is available. A default methane emission factor of 0.05 m³/t for open cut brown coal mining, as used in the *IEA, Coal Industry Advisory Board, 1992* is used to estimate surface mined methane emissions of lignite/brown coal for Australia.

Open cut sub-bituminous coal mining in Western Australia

Coal mined in Western Australia is regarded as sub-bituminous. In the absence of mine specific factors, the 2006 IPCC Guideline default methane emission factor for surface mining of 1.2m³/tonne is applied.

Open cut sub-bituminous coal mining in South Australia

Open cut 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 emission factor from open cut brown coal mining of 0.05 m³/t (as used for Victorian brown coal) has been applied.

Table 3.26: CH₄ emission factors for open cut coal 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
Queensland	1.2 ^(a)	0.6767
Tasmania	1.0 ^(b)	0.6767
Western Australia	1.2 ^(d)	0.6767
South Australia	0.05 ^(e)	0.6767
Victoria	0.05 ^(e)	0.6767

Sources: a) Williams et al. (1993) and confirmed by Australian Coal Association; b) D Cain, Australian Coal Association, pers. comm. (1993);
c) These factors are derived by treating CH₄ as an ideal gas, ie 16 g (1 gmole) occupies 23.645 at 15 °C and 1 atmosphere; d) IPCC 2006;
e) IEA 1992.

Total emissions from open cut mines are then estimated by the following algorithm:

$$E_o = (QTY_{state\ i} \cdot EF_{state\ i}) \cdot C_{oc} \quad (1B1_4)$$

Post Mining Activities

Williams et al. (1993) measured the amount of gas retained in coal from gassy underground (ie Class A) mines in NSW and Queensland, once the coal reached the surface. Most of this gas is likely to desorb from the coal before combustion – during preparation, transportation, storage or crushing – and can therefore be classified as fugitive emissions from post mining activities. Williams et al. (1993) found that the amount of gas retained was quite variable, but adopted an average gas emission factor of 1.7 m³/t raw coal, of which 75% is CH₄ and 25% CO₂. The volume-to-mass conversion factor is 0.6767 kg/m³.

Emissions from post mining activities reflect the fugitive escape of gases from the coal before combustion—during preparation, transportation, storage or crushing—and are based on the measurements of Williams et al. (1993) and Williams, Lama and Saghaifi (1996). These studies related emissions E_{pm} to the quantity of black coal from underground Class A 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/m³:

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

The emission factor is the average of the results of the two empirical studies. Williams et al. (1993) found that the amount of gas retained was quite variable, but adopted an average gas emission factor of 1.7 m³/t raw coal, of which 75% is CH₄ and 25% CO₂. Williams, Lama and Saghaifi (1996) estimated an emission factor equal to 20% of the in-situ methane content of coal (6.78m³/tonne in this case).

It is assumed that post mining emissions are associated only with black coal mined in underground Class A (gassy) mines, and not with black coal mined in underground Class B mines, or with brown coal.

Total Emissions from Coal Mining

Total emissions from coal mining in Australia E_{cm} are estimated by summing emissions from underground black coal mining E_u , open cut black coal mining E_o and post-mining activities E_{pm} . This is expressed by the following algorithm:

$$E_{cm} = E_u + E_o + E_{pm} \quad (1B1_6)$$

Decommissioned Mine Emissions (1.B1.c)

Methane emissions are also known to occur under certain conditions following closure/abandonment of coal mines - leaking to the atmosphere through fractured rock strata, open vents and seals over daily to decades 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
- Mine water inflow rates.

The approach seeks to maximise the use of publicly available data and is best described as a high tier 2/3 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 methane emissions from decommissioned mines can be described as:

$$E_{dm} = (E_{tdm} \cdot EF_{dm} \cdot F_{dm}) - E_{rec} \quad (1B1_7)$$

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 emission factor 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 emission decay curve (EDC) describes the decline in fugitive methane 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, Lunarzewski and Creedy (2006). The EDCs are shown in Figure 3.10, and are described in the following formulae:

Gassy mines

$$EF_{dm} = (1 + A * T)^b - C \quad (1B1_8)$$

Non-gassy mines

$$EF_{dm} = (1 + A * T)^b - C \quad (1B1_9)$$

Where: EF_{dm} is the emission factor for a mine at any point in time since decommissioning (the emission factor is dimensionless).

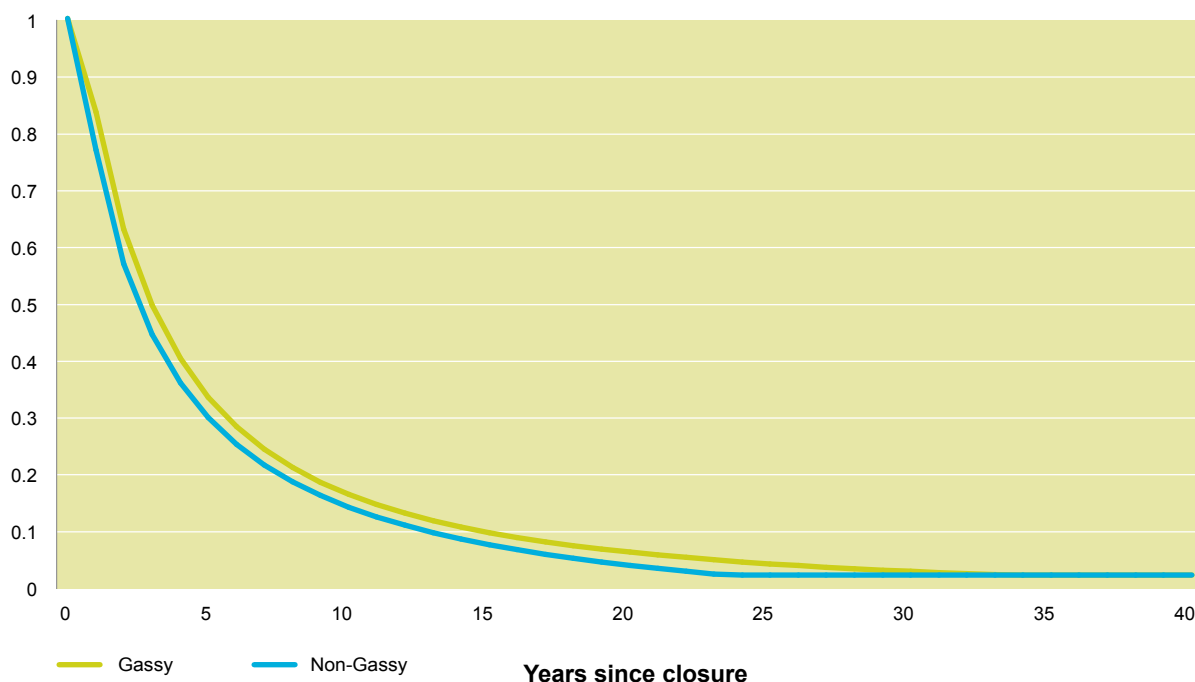
T is the time elapsed since decommissioning of mine.

A , b and C are coefficients unique to the decline curves (see table 3.27).

Table 3.27: 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 3.11: Emission decline curves for gassy and non-gassy Australian decommissioned coal mines



Mine Production Data

Mine production data are obtained from:

- Coal Services Pty Ltd (formerly the Joint Coal Board) for NSW mines from 1972 to 2007, and
- Queensland Department of Natural Resources, Mines and Energy, from 1979 to 2007.

In both datasets, details were obtained for mine type (underground/opencut), annual run-of-mine production and time of closure. Only underground mines were included in the study. Opencut mines were not included in the study as they are associated with relatively low methane emissions. This approach is consistent with that 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

A total of 117 underground mine closures (Class A-gassy and B-non gassy) back to 1972 were identified in New South Wales, while 97 mines back to 1979 were identified in Queensland.

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, that is, emissions at the point prior to closure. The approach used is consistent with that used to estimate methane emissions from active underground coal mines (see 1.B1ai). 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 methane, 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
- 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 then calculated. The Southern NSW region contained mine water production rates ranging between 1 – 5.0 ML/Day and an average value of 2.5ML/day. The Central NSW region ranged between 0.4 and 3ML/Day and an average value of 1.2ML/Day and Queensland

ranged between 0.1 and 0.4ML/Day and an average value of 0.2ML/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
3. Methane is produced evenly throughout the mine and flooding reduces the emissions proportionately to the void volume flooded

Fully Flooded Mine Emissions

Once a goaf 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 to 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).

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.

Time series variability of methane implied emission factors from coal mining activities are influenced by changes in the mix of production between gassy and non-gassy underground mines, open cut and underground mines, and the quantity of methane recovered. This is evident in a declining trend of the methane IEF for underground mines which reflects increased production from non-gassy mines and falling production from gassy mines. The implied emission factor 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 data is variable over time, reflecting the effects of opening and closure of large mines, commodity prices and global demand.

3.8.4 Source Specific QA/QC

3.8.4.1 Activity Data

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

3.8.4.2 Implied Emission Factors

As Australia uses country specific methods for estimating methane emissions, Australia's implied methane emission factors have been compared against emission factors reported by other countries. Overall, Australia's implied emission factors are not significantly different to the means of the implied emission factors of all other reporting parties.

In 2004, Australia's implied emission factor for underground mines was 6.65 compared to 10.11 (n = 24) for the mean of countries. The result of a T-Test comparison of the means accepted the hypothesis that Australia's CH₄ from underground mining is not significantly different to that of the mean for all countries.

Australia's implied emission factor for surface mining, in 2004, was 1.24 compared to 0.62 (n = 22) for the 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 CH₄ from surface mining is not significantly different to that of the mean for all reporting parties.

3.8.5 Recalculations Since The 2006 Inventory

Recalculations were made as a result the following changes:

- a change in the gassy classification of one underground mine;
- inclusion of additional methane recovery data for an underground mine;
- correction to the opening and closure dates for several mines.

A summary of the impact of the recalculations follows:

- 2006 Inventory – 16,229 Gg CO₂-e in 1990, 23,865 Gg CO₂-e in 2006.
- 2007 Inventory – 16,230 Gg CO₂-e in 1990, 23,720 Gg CO₂-e in 2006.

Recalculations in the 2007 Inventory resulted in an increase of 0.8 Gg CO₂-e to the 1990 estimate and a reduction of 145.4 Gg CO₂-e to the 2006 estimate.

3.8.6 Planned Improvements

Scope exists for further refining of the methodology in order to make it more relevant to Australian circumstances. Factors targeted for improvement include the use of actual measured mine emissions at time of mine closure, where available.

From 2010, under the National Greenhouse and Energy Reporting system, all underground mines will be required to report direct measurement emission data.

3.9 Source Category 1.B2 – Oil and Natural Gas

3.9.1 Source Category Description

The IPCC guidelines define a two 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)
- 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 accidental releases, ie uncontrolled sources. Emissions from venting and flaring are activities that are managed as part of normal operations at field processing facilities and oil refineries.

Emissions of CH₄ and NMVOCs may occur during *natural gas* production, including both production and field processing, from the same causes as the corresponding emissions from crude oil production, ie leakage, accidents and controlled releases for safety purposes and during some maintenance operations.

In Australia, most onshore exploration wells are drilled to delineate new reserves in established gas fields or in the expectation of discovering new gas fields rather than the expectation of finding oil. Therefore in Australia's inventory, oil and gas exploration emissions are treated as a single category, which should be seen as related to subsequent production and consumption of both oil and gas.

In the case of natural gas, field processing is typically a considerably more complex process than in the case of crude oil production. Natural gas processing includes some of the same types of processes which, in the case of oil, occur at the refinery, eg separation into product streams, such as ethane, LPG and condensate, and removal of undesirable components of the raw gas stream, such as CO₂ and sulphur compounds.

Liquefaction of natural gas for export, which takes place at the North West Shelf liquefied natural gas (LNG) plant near Dampier in Western Australia, is more complex again; this is one of the largest process plants in Australia.

Venting of CO₂ extracted from raw gas and flaring of unusable gas produced at various stages of processing are separately accounted for under venting and flaring.

Other than at the Dampier LNG plant, storage and loading are not activities which occur with natural gas, since the gas moves directly from the processing facility into the transmission pipeline. Some losses of CH₄ may occur in association with the loading of LNG onto ships.

Reported emissions are based on estimates published by the Australian Petroleum Production and Exploration Association (APPEA). APPEA estimate flaring emissions using country-specific emission factors applied to a measured activity parameter (volume flared). Venting emissions are reported from measured data (tier 3). Emissions from Natural Gas Distribution and Transmission are based on country-specific emission factors and activity data derived from statistics published by the Australian Gas Association. Oil and natural gas production activity data are obtained from the Department of Resources, Energy and Tourism monthly series, *Australian Petroleum Statistics*.

The relationship between the National Inventory subcategories and the corresponding relationship with APPEA source categories are shown in Table 3.29.

Table 3.28: Relationship between the National Inventory Report and APPEA source sub-categories

Inventory category	APPEA category	
Oil	Exploration (for both oil and gas)	Production Testing: Gas Flared, Oil Flared
	Crude oil production	Loading Losses: Rail/Truck, Shiploading
Natural gas	Production and processing	Fugitive Emissions
Venting and Flaring	Venting	Gas Venting
	Flaring	Flares

3.9.2 Methodology

Oil (1.B2a)

Oil (and Gas) Exploration (1.B2ai)

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. If a well is production tested and permanent facilities are not connected, CO₂, some unburnt CH₄ and NMVOCs are released as a result of the flaring of oil or the flaring or venting of gas. Emissions of CH₄ and NMVOCs may also occur as a result of leakages and accidental releases such as blowouts. Emissions are estimated using the emission factors reported in Table 3.29.

Table 3.29: Oil exploration and production fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO ₂	CH ₄	NMVOC	N ₂ O	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
Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO ₂	CH ₄	NMVOC	N ₂ O	NO _x	CO
Crude oil production	- Internal Floating tank		0.00004	0.0002	0	0	0
	- Fixed roof tank		0.0002	0.112	0	0	0
	- Floating tank		0.0002	0.0009	0	0	0
	Loading Losses:						
	- Rail/Truck		0.018	0.1	0	0	0
	- Shiploading		0.58	0.33	0	0	0

Source: APPEA 2005 and E and P Forum 1994

Crude Oil Production (other than venting and flaring) (1.B2a ii)

Emissions of CH₄ 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
- accidental events
- storage tanks and venting of gases during oil production
- controlled releases of pressurised pipe and component contents (blowdown) during routine maintenance activities, including well workovers, pipeline testing, process equipment maintenance etc

All other things being equal, emissions will tend to be greater from fields with a higher solution gas/oil ratio than from fields with a low solution gas/oil ratio. Emissions of CH₄ and NMVOCs may also occur while crude oil is in storage at production facilities, awaiting transportation, if vapour recovery is not employed.

Emissions are reported directly from the APPEA greenhouse gas emission inventory, corresponding to the subcategories - Loading losses plus Fugitive Emissions: tank losses (all categories except general leaks). Emission factors used for the APPEA inventory are reported in Table 3.29.

Crude Oil Transport (1.B2a iii)

The marine (or road/rail) transport of crude oil results in the emissions of NMVOCs, CH₄ and dissolved CO₂. The extent of emissions depends on the gas control technology employed during transfer operations, fuel properties, eg 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 USEPA data, it is estimated that 745 kg CH₄ is emitted per PJ of oil tankered (IPCC, 1997, Volume 3). Using the USEPA finding that CH₄ makes up 15% of the mass of total organic emissions (USEPA, 1995a), the NMVOC emission factor 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 petroleum product consumption in Victoria (where the great majority of the crude oil processed at Victorian refineries is transported via pipeline from the Bass Strait oil fields). Bass Strait oil is transported to other Australian refineries by ship, as is most of the oil from other Australian oil fields used by Australian refineries.

Crude Oil Refining and Storage (1.B2a iv)

Crude oil is refined to numerous products via a wide variety of physical and chemical processes. During such processing, fugitive emissions of NMVOCs and CH₄ 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 CH₄ 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 CH₄ emissions from crude oil refining and storage may be calculated using default emission factors according to IPCC guidelines (1997). The mid range IPCC default emission factors are adopted for crude oil refining and storage, ie 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 emission factor associated with fugitive and tank storage/loading is 20,000 kg/PJ of oil refined.

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 workbook the composition of refinery gas directed to flares is assumed to be 30% CH₄, 30% NMVOCs and 40% H₂ (by volume). An average flare combustion efficiency of 98% is used based on studies by USEPA (1995a).

In previous years, information on the quantity of gas flared at Australian refineries has been determined using the single national figure provided in the national energy consumption statistics (ABARE 2008a). The methodology has been reviewed by GHD (2006b) and the quantity of gas flared is now calculated as a 0.6 percent of the total ABARE annual refinery feedstock. The review considered the range and age of technologies of the Australian refining industry, and publicly available information on annual flaring emissions from Australian facilities. Emission factors, expressed in terms of gross calorific values of each flare gas component, are shown in Table 3.30.

Table 3.30: Emission factors for flaring of gas at oil refineries

Unit	CO ₂	CH ₄	N ₂ O	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: DCC estimates, following methodology of E&P Forum (1994)

Petroleum Product Distribution (1.B2av)

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 and tank filling losses and refuelling of aircraft and other mobile sources.

Emission factors for fuel storage tanks are a complex function of a number of variables. These emission factors are calculated from a weighted average analysis of fuel transfer and storage regulations in different regions of Australia.

Natural Gas (1.B2b)

Natural Gas Production and Processing (other than venting and flaring) (1.B2bi)

Fugitive emissions from natural gas production and processing are reported directly by APPEA, corresponding to the category fugitive emissions - general leaks. Emissions from the combustion of gas at processing plants are reported under category 1.A1. Emission factors are reported in 3.31.

Table 3.31: Fugitive emission factors for natural gas

Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO ₂	CH ₄	NMVOC	N ₂ O	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 2005 and E and P Forum 1994. M = directly measured emissions

Natural Gas Transmission and Distribution (1.B2bii)

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 3.32. Throughput data are obtained from the Australian Gas Association (AGA). *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 (eg 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
- 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
- leakage when intermittently operated appliances (eg 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 (NGGI C 1994), 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*.
- annual gas utility sales in each State and Territory, published in the Energy Supply Association of Australia series; *Electricity, Gas Australia*; 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.
- the composition of pipeline gas supplied in each State and Territory pipeline system (Table 3.32).

Table 3.32: Natural gas composition and emission factors, 2007^(a)

Pipeline	Longford, Melb. (Victoria)	Moomba, Sydney, Adelaide (NSW, SA)	Roma, Bris. (Qld)	Denison, Gladstone (Qld)	Dampier, Perth (WA)	Dongarra, Perth (WA)	Amadeus, Darwin (NT)	Australia (wtd 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			

Source: a) In previous years, emission factors for both combustion and fugitive natural gas emissions have been calculated from pipeline gas composition data, published by the Australian Gas Association. However, as from 2001 the Association no longer collect this data from its members. It has been assumed that all natural gas emission factors are unchanged from 2000.

Oil and Gas Production Venting and Flaring (1.B2c)

Venting refers to the controlled release of unburnt gases to the atmosphere. Venting at oil and gas processing facilities is mainly associated with the release of CO₂, 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 CO₂ is incomplete, the vented CO₂ contains small quantities of CH₄. The quantities of CO₂ and CH₄ vented will depend on the concentration of CO₂ in the raw gas, which varies significantly between gas fields, and on the mode of operation and efficiency of the CO₂ stripping plant. At all gas processing facilities, the volumes of the vent gas and CO₂ and CH₄ concentrations are monitored in routine plant operation. Venting of CH₄, meaning that CH₄ is released to the atmosphere without combustion in a flare, also occurs at a number of locations.

Flaring refers to the controlled release to 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. Gas sent to flare is normally mostly CH₄ with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas. As with venting, flaring is monitored as part of routine plant operation. Most state governments require oil and gas producing companies to provide regular reports of volumes of gas flared.

Venting – Gas

Emissions are based on direct measurement company data (APPEA). As indicated previously, the Australian Petroleum Production and Exploration Association (APPEA) publishes data on industry emissions in the form of a public annual inventory report to the DCC Greenhouse Challenge Program. The data is collected through survey of industry companies. The approach adopted here, of direct measurement, is equivalent to a *Tier 3* estimation, or highest-order approach.

Flaring – Oil and Gas Combined

Emissions reported combines flaring from both oil and gas sources (APPEA). Emission factors can be found in Table 3.32, and are sourced from the E and P Forum (1994).

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. The oil and gas production and distribution emissions levels are relatively stable over time, while emissions from venting and flaring tend to be more variable, reflecting the impact of large projects.

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.

3.9.5 Recalculations Since The 2006 Inventory

There have been no recalculations since the 2006 Inventory.

3.9.6 Planned Improvements

All relevant data are kept under constant review.

Appendix 3.A: Additional Information on Activity Data

Table 3.A1: Non-CO₂ Emission Factors – 1.A1 Energy Industries

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
1.A1.b Petroleum Refining (ANZSIC Group 251)						
Petroleum Products nec	0.8	0.6	54.0	383.8	0.8	NA
Natural Gas	1.1	0.1	56.6	722.9	1.1	NA
Fuel Oil	0.8	0.6	44.8	330.9	0.8	1,282.1
ADO	3.8	0.6	254.6	1234.8	67.4	57.0
LPG	4.0	0.6	349.0	1322.0	45.0	2.3
1.A1c Coke Oven Operation (ANZSIC Class 2711, part)						
Black Coal	1.0	0.8	201.0	287.0	1.0	370
Coal By-Products	1.0	0.8	36.7	287.0	1.0	370
Fuel Oil	1.0	0.6	75.0	502.0	0.9	1282.1
Briquette Manufacture (ANZSIC Class 1103, part)						
Brown Coal	1.3	0.8	105.0	287.0	1.0	150
ADO	3.6	0.6	221.4	1166.2	70.0	57.0
Coal Mining (ANZSIC Subdivision 11, remainder)						
LPG	0.1	0.6	13.0	154.0	5.0	2.3
ADO	3.6	0.6	221.4	1166.2	70.0	57.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
Petrol	8.6	.6	476.0	1306.0	163.0	15.0
Natural Gas	1.1	0.1	14.0	86.2	1.1	2.3
Oil and Gas Extraction (ANZSIC Subdivision 12)						
LPG	4.0	0.6	349.0	1,322.0	45.0	2.3
ADO	3.8	0.6	254.6	1,234.8	67.4	57.0
Petroleum products nec	4.0	0.6	346.8	1,320.0	45.5	57.0
Natural gas	7.3	0.1	42.7	176.3	2.3	2.3
Ethane	1.1	0.1	41.8	492.6	1.1	2.3
Fuel Oil	0.8	0.6	44.8	330.9	0.8	1282.1
Other Transport (Natural Gas Transmission) (ANZSIC Subdivision 65)						
LPG	0.6	0.6	13.0	53.0	1.0	2.3
ADO	0.6	0.6	13.0	53.0	0.9	57.0
IDF	0.6	0.6	13.0	53.0	0.9	57.0
Natural gas	7.8	0.1	45.5	187.9	2.4	2.3
Gas Production and Distribution (ANZSIC Subdivision 362)						
Natural gas	8.0	0.1	46.0	190.0	2.4	2.3
Town Gas	8.0	0.1	46.0	190.0	2.4	2.3

Source: Derived from Table 3.A4

Table 3.A2: Non-CO₂ Emission Factors – 1.A2 Manufacturing and Construction

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
Iron and steel (ANZSIC Group 271)						
Black coal	1.1	0.8	82.2	450.5	1.0	370.0
Coal byproducts	1.1	0.1	36.7	274.0	1.0	370.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	22.0	0.5	5,465.0	437.0	409.0	2.3
ADO	2.5	0.5	175.5	553.6	43.3	57.0
Fuel oil	0.4	0.5	34.7	256.6	0.9	1,282.1
Natural gas	0.9	0.1	68.2	914.6	1.1	2.3
Town gas	0.9	0.1	68.2	914.6	1.1	2.3
Blast furnace gas	1.1	0.8	82.2	450.5	1.0	370.0
1.A2.b Non-Ferrous Metals (ANZSIC Group 272)						
Black coal	1.2	0.8	103.6	316.9	1.0	370.0
Coke	1.2	0.8	103.6	316.9	1.0	370.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	8.5	0.6	1,798.9	340.4	133.2	2.3
Power kerosene	2.0	0.6	38.5	294.0	0.8	57.0
ADO	5.2	0.6	341.0	906.7	93.0	57.0
IDF	2.0	0.6	38.5	294.0	0.8	57.0
Fuel oil	2.0	0.6	38.5	294.0	0.8	1,282.1
Petroleum products nec	2.0	0.6	38.5	294.0	0.8	57.0
Natural gas	1.1	0.1	43.6	519.2	1.1	2.3
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	370.0
Petroleum and Coal Product Manufacturing (ANZSIC Group 252)						
Brown coal	1.0	1.4	77.1	488.5	1.0	150.0
Coal byproducts	1.0	0.8	77.1	488.5	1.0	370.0
Brown coal briquettes	1.0	0.8	77.1	488.5	1.0	150.0
LPG	1.5	0.6	294.5	281.9	20.2	2.3
Lighting kerosene	0.5	0.6	34.5	274.1	0.7	57.0
ADO	4.4	0.6	301.1	823.0	81.2	57.0
IDF	0.5	0.6	34.5	274.1	0.7	57.0
Fuel oil	0.5	0.6	34.5	274.1	0.7	1,282.1
Natural gas	1.1	0.1	21.3	199.0	1.1	2.3
Basic Chemical Manufacturing (ANZSIC Group 253)						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Coke	1.3	0.8	105.0	287.0	1.0	370.0
Coal byproducts	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
LPG	5.8	0.6	1,303.1	487.0	93.9	2.3
ADO	1.0	0.6	77.0	505.0	1.6	57.0
IDF	1.0	0.6	75.0	501.7	0.9	57.0
Fuel oil	1.0	0.6	75.0	501.7	0.9	1,282.1
Petroleum products nec	1.0	0.6	75.0	501.7	0.9	57.0
Natural gas	1.1	0.1	41.8	492.6	1.1	2.3

continued

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
Town gas	1.1	0.1	41.8	492.6	1.1	2.3
LESS SEQUESTERED						
from ethane	1.1	0.1	41.8	492.6	1.1	2.3
from petroleum products	1.0	0.6	75.0	501.7	0.9	57.0
Factors Other Chemicals, Rubber and Plastic Products (ANZSIC Groups 254–256)						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
LPG	6.8	0.6	1,581.0	465.8	115.2	2.3
ADO	1.1	0.6	84.6	500.2	5.6	57.0
IDF	0.9	0.6	70.6	477.0	0.9	57.0
Fuel oil	0.9	0.6	70.6	477.0	0.9	1,282.1
Natural gas	1.2	0.1	22.4	190.6	1.1	2.3
1.A2.D Pulp, Paper And Print (ANZSIC Subdivisions 23 And 24)						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal	1.3	0.8	105.0	287.0	1.0	150.0
Brown coal briquettes	1.3	1.4	105.0	287.0	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	1.1	0.6	212.7	165.8	15.5	2.3
Heating oil	0.3	0.6	13.5	155.6	0.6	57.0
ADO	5.7	0.6	390.0	1,006.0	108.0	57.0
Fuel oil	0.3	0.6	13.5	155.6	0.6	1,282.1
Petroleum products nec	0.3	0.6	13.5	155.6	0.6	57.0
Natural gas	1.2	0.1	13.8	58.4	1.1	2.3
1.A2.E Food Processing, Beverages, Tobacco (ANZSIC subdivision 21)						
Black coal	1.3	0.8	105.9	207.1	1.0	370.0
Brown coal	1.3	0.8	105.9	207.1	1.0	150.0
Coal byproducts	1.2	0.1	13.6	42.9	1.1	370.0
Brown coal briquettes	1.3	0.8	105.9	207.1	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
Bagasse	9.3	4.1	1,625.0	84.0	16.3	NA
LPG	0.6	0.6	13.2	154.2	0.6	2.3
ADO	4.9	0.6	329.1	868.2	90.6	57.0
IDF	5.5	0.6	375.5	973.2	103.9	57.0
Fuel oil	0.6	0.6	13.2	154.2	0.6	1,282.1
Petroleum products nec	0.6	0.6	13.2	154.2	0.6	57.0
Natural gas	1.1	0.1	11.0	49.5	1.7	2.3
Town gas	1.2	0.1	13.5	58.0	1.1	2.3
Coke oven gas	1.2	0.1	13.6	42.9	1.1	370.0
Textile, Clothing, Footwear and Leather (ANZSIC Subdivision 22)						
Black Coal	1.3	0.8	105.0	287.0	1.0	370
Brown Coal Briquettes	1.3	0.8	105.0	287.0	1.0	150
LPG	7.5	0.6	1810.1	248.4	135.2	2.3
ADO	0.4	0.6	13.6	155.7	0.6	57.0
Fuel Oil	0.4	0.6	13.6	155.7	0.6	1282.1
Natural Gas	1.2	0.1	13.7	58.0	1.1	2.3

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
Other Metal Products (ANZSIC Groups 274–276)						
Black coal	1.3	0.8	105.0	157.0	1.0	370.0
LPG	22.0	0.6	5,465.0	437.0	409.0	2.3
ADO	1.4	0.6	103.6	547.8	10.6	57.0
IDF	1.0	0.6	75.0	502.0	0.9	57.0
Natural gas	1.1	0.1	8.5	41.0	2.2	2.3
Town gas	1.0	0.1	70.9	949.5	1.1	2.3
Machinery and Equipment (ANZSIC Subdivision 28)						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
LPG	21.1	0.6	5,242.0	435.6	392.2	2.3
Heating oil	0.7	0.6	57.3	402.6	0.8	57.0
ADO	2.8	0.6	194.3	651.0	44.9	57.0
IDF	0.7	0.6	57.3	402.6	0.8	57.0
Fuel oil	0.7	0.6	57.3	402.6	0.8	1,282.1
Natural gas	1.1	0.1	44.9	542.2	1.1	2.3
Town gas	1.1	0.1	44.9	542.2	1.1	2.3
Other Manufacturing (ANZSIC Subdivision 29)						
Black coal	1.3	0.8	105.0	157.0	1.0	370.0
LPG	0.2	0.6	20.3	100.6	0.5	2.3
ADO	0.2	0.6	20.3	100.6	0.5	57.0
IDF	0.2	0.6	20.3	100.6	0.5	57.0
Natural gas	1.1	0.1	20.3	189.3	1.1	2.3
1.A2.F(II) Construction (ANZSIC Division E)						
LPG	1.0	0.6	15.0	160.0	0.3	2.3
Lighting kerosene	1.0	0.6	15.0	160.0	0.3	57.0
ADO	5.7	0.6	389.7	1,005.4	107.9	57.0
Fuel oil	1.0	0.6	15.0	160.0	0.3	1,282.1
Natural gas	1.0	0.1	10.0	58.0	0.3	2.3
Petrol	5.7	0.6	389.7	1005.4	107.9	15.0
Glass and Glass Products (ANZSIC Group 261)						
LPG	1.0	0.6	75.0	502.0	0.9	2.3
ADO	1.0	0.6	75.0	502.0	0.9	57.0
IDF	1.0	0.6	75.0	502.0	0.9	57.0
Fuel oil	1.0	0.6	75.0	502.0	0.9	1,282.1
Natural gas	1.0	0.1	75.0	1,010.0	1.1	2.3

continued

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
Ceramics (ANZSIC Group 262)						
Black coal	1.0	0.8	75.0	502.0	1.0	370.0
Brown coal	1.0	0.8	75.0	502.0	1.0	150.0
Brown coal briquettes	1.0	0.8	75.0	502.0	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	8.2	0.6	1,932.7	474.1	141.6	2.3
ADO	5.7	0.6	390.0	1,006.0	108.0	57.0
IDF	1.0	0.6	73.5	493.7	0.9	57.0
Fuel oil	1.0	0.6	73.5	493.7	0.9	1,282.1
Petroleum products nec	1.0	0.6	73.5	493.7	0.9	57.0
Natural gas	1.0	0.1	74.5	1,002.1	1.1	2.3
Town gas	1.0	0.1	74.5	1,002.1	1.1	2.3
Cement, Lime, Plaster and Concrete (ANZSIC Group 263)						
Black coal	1.0	0.8	75.7	500.0	1.0	370.0
Brown coal briquettes	1.0	1.4	75.7	500.0	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	21.7	0.6	5,398.1	435.6	404.0	2.3
Lighting kerosene	0.9	0.6	43.5	322.8	0.9	57.0
Heating oil	0.9	0.6	43.5	322.8	0.9	57.0
ADO	5.3	0.6	359.9	946.6	98.7	57.0
IDF	0.9	0.6	43.5	322.8	0.9	57.0
Fuel oil	0.9	0.6	43.5	322.8	0.9	1,282.1
Petroleum products nec	0.9	0.6	43.5	322.8	0.9	57.0
Solvents	0.9	0.6	43.5	322.8	0.9	57.0
Natural gas	1.0	0.1	61.8	815.5	1.1	2.3
Coal byproducts	1.3	0.8	105.0	287.0	1.0	370.0
Coke	1.0	0.8	75.6	500.0	1.0	370.0
Tyres	0.9	0.6	43.5	322.8	0.9	57.0
Non-Metallic Mineral Products nec (ANZSIC Code: 264)						
Black coal	1.1	0.8	80.0	466.5	1.0	370.0
Coke	1.1	0.8	80.0	466.5	1.0	370.0
LPG	19.7	0.6	4,884.1	441.3	365.1	2.3
ADO	5.7	0.6	390.0	1,006.0	108.0	57.0
Fuel oil	0.4	0.6	70.6	477.1	0.9	1,282.1
Petroleum products nec	0.4	0.6	70.6	477.1	0.9	57.0
Natural gas	0.9	0.1	67.8	900.1	1.1	2.3
1.A2.F(iv) Mining (non-Energy Minerals (ANZSIC subdivisions 13,14 and 15))						
Black coal	1.0	0.8	78.0	493.0	1.0	370.0
Coke	1.0	0.8	78.0	493.0	1.0	370.0
Coal byproducts	3.9	0.1	28.0	122.6	1.6	370.0
LPG	1.1	0.6	44.8	330.9	0.8	2.3
Aviation turbine fuel	1.1	0.6	44.8	330.9	0.8	8.2
Heating oil	1.1	0.6	44.8	330.9	0.8	57.0
ADO	3.7	0.6	226.2	1,190.4	71.1	57.0
Natural gas	1.1	0.1	14.0	86.2	1.1	2.3
Fuel oil	0.8	0.6	44.8	330.9	0.8	1,282.1

Source: Derived from Table 3.A4.

Table 3.A3: Non- CO₂ Emission Factors – Other Sectors

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
37 Water, Sewerage and Drainage						
Lighting kerosene	0.1	0.6	13.0	154.0	0.5	57.0
ADO	5.7	0.6	390.0	1,006.0	108.0	57.0
Natural gas	1.2	0.1	14.0	58.0	1.1	2.3
62 Railway Transport						
Natural gas	1.6	0.1	16.0	39.0	3.1	2.3
65–67 Other Transport, Services and Storage (part)						
LPG	0.6	0.6	13.0	53.0	1.0	2.3
ADO	0.6	0.6	13.0	53.0	0.9	57.0
IDF	0.6	0.6	13.0	53.0	0.9	57.0
Natural gas	7.8	0.1	45.5	187.9	2.4	2.3
Div. F, G Wholesale and Retail Trade						
Wood, woodwaste	3.4	4.1	330.0	75.0	5.6	NA
LPG	0.6	0.6	13.1	53.2	0.9	2.3
ADO	0.6	0.6	13.1	53.2	0.9	57.0
IDF	0.6	0.6	13.1	53.2	0.9	57.0
Fuel oil	0.6	0.6	13.1	53.2	0.9	1,282.1
Natural gas	1.1	0.2	15.6	42.3	2.8	2.3
Town gas	1.1	0.2	15.6	42.3	2.8	2.3
Div. H, P, Q Accommodation, Cultural and Personal						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Wood, woodwaste	3.4	4.1	330.0	19.0	5.6	NA
LPG	0.6	0.6	13.0	53.0	0.9	2.3
Aviation gasoline	0.6	0.6	13.0	53.0	0.9	8.2
Aviation turbine fuel	0.6	0.6	13.0	53.0	0.9	8.2
Heating oil	0.6	0.6	13.0	53.0	0.9	57.0
ADO	0.6	0.6	13.0	53.0	0.9	57.0
Fuel oil	0.6	0.6	13.0	53.0	0.9	1,282.1
Natural gas	1.1	0.1	9.7	44.8	2.0	2.3
Div. J Communication						
Heating oil	0.6	0.6	13.0	53.0	0.9	57.0
ADO	0.6	0.6	13.0	53.0	0.9	57.0
IDF	0.6	0.6	13.0	53.0	0.9	57.0
Fuel oil	0.6	0.6	13.0	53.0	0.9	1,282.1
Natural gas	1.1	0.1	8.5	41.0	2.2	2.3
Div. K, L Finance, Insurance, Property and Business						
Natural gas	1.1	0.1	8.5	41.0	2.2	2.3

continued

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
Div. M Government Administration and Defence						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	0.4	0.6	13.0	84.4	0.8	2.3
Heating oil	0.4	0.6	13.0	84.4	0.8	57.0
ADO	0.4	0.6	13.0	84.4	0.8	57.0
IDF	0.4	0.6	13.0	84.4	0.8	57.0
Fuel oil	0.4	0.6	13.0	84.4	0.8	1,282.1
Natural gas	1.1	0.1	10.3	46.6	1.8	2.3
Town gas	1.1	0.1	10.3	46.6	1.8	2.3
Div. N, O Education, health and community services						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0
Brown coal briquettes	1.3	0.8	105.0	287.0	1.0	150.0
Wood, woodwaste	4.2	4.1	680.0	75.0	6.8	NA
LPG	0.4	0.6	13.0	53.0	0.7	2.3
Lighting kerosene	0.4	0.6	13.0	53.0	0.7	57.0
Heating oil	0.4	0.6	13.0	53.0	0.7	57.0
ADO	0.4	0.6	13.0	53.0	0.7	57.0
IDF	0.4	0.6	13.0	53.0	0.7	57.0
Fuel oil	0.4	0.6	13.0	53.0	0.7	1,282.1
Natural gas	1.1	0.1	10.4	44.8	1.8	2.3
Town gas	1.1	0.1	10.4	44.8	1.8	2.3
Residential						
Black coal	105.0	0.8	5,753.0	190.0	209.0	370.0
Brown coal briquettes	105.0	0.8	5,753.0	190.0	209.0	150.0
Wood, woodwaste ^(a)						
LPG	4.7	0.6	13.0	48.0	1.9	2.3
Lighting kerosene	4.7	0.6	13.0	48.0	1.9	57.0
Heating oil	4.7	0.6	13.0	48.0	1.9	57.0
ADO	4.7	0.6	13.0	48.0	1.9	57.0
Natural gas	1.6	0.1	16.0	39.0	3.1	2.3
Town gas	1.6	0.1	16.0	39.0	3.1	2.3
1.A4.c Agriculture, Forestry & Fisheries: (ANZSIC Division A)						
LPG	1.3	0.6	14.0	154.0	0.5	2.3
Aviation gasoline	8.6	0.6	476.0	1,306.0	163.0	8.2
Power kerosene	1.3	0.6	14.0	154.0	0.5	57.0
Heating oil	1.3	0.6	14.0	154.0	0.5	57.0
ADO	8.6	0.6	476.0	1,306.0	163.0	57.0
Natural gas	1.1	0.1	8.5	41.0	2.2	2.3

Source: Derived from Table 3.A4. Note: a) See Table 3.A4 for Residential biomass emission factors.

Table 3.A4: Derivation of non-CO₂ emission factors for stationary energy

Sector	Fuel	Equipment	Emission Factors(Mass/Mass or Volume or Energy)								Conversion Factors		Emission Factors (Mass/Gross Energy Use)				
			CH ₄	N ₂ O ^a	NO _x	CO	NM VOC	Units	Value	Units	CH ₄	N ₂ O ^a	NO _x	CO	NM-VOC		
Electricity Generation/Utility																	
1	Natural Gas	Boiler[b]	4.8		8,800	640	23.24	kg/10 ⁶ m 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 ³ L	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 ³ L	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 ⁶ m 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 ³ L	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 ³ L	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		
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		

continued

Sector	Fuel	Equipment	Emission Factors(Mass/Mass or Volume or Energy)							Conversion Factors		Emission Factors (Mass/Gross Energy Use)				
			CH ₄	N ₂ O ^a	NO _x	CO	NMVOC	Units	Value	Units	CH ₄	N ₂ O ^a	NO _x	CO	NM-VOC	
Commercial																
23	Natural Gas	Boiler[s]	43.5		1,600	330	84.48		kg/10 ⁶ m 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 ³ L	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 ³ L	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 ⁶ m 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 ³ L	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 ³ L	45.6	MJ/L	4.7	0.6	48	13	1.9
General																
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 (1995a) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from natural gas fired utility/large industrial boilers (>29 MW).
- [c] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ 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 (1995a) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration (tangentially fired boiler).
- [f] USEPA (1995a) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration.
- [g] Assume CH₄ and NMVOC emission factors identical to black coal combustion. CO and NO_x emission factors based on average of SECV data (1994). N₂O emission rate based on mid-range value as reported by IEA Coal Research (1993).
- [h] USEPA (1995a) Pg 3.1-3 and 3.1-5. Uncontrolled emissions of CO and NO_x for large stationary natural gas turbines. NMVOC and CH₄ emissions estimated from ratio of NMHC and CH₄, respectively; to Total Organic Compounds for selective catalytic reduction controlled turbines.
- [i] USEPA (1995a) Pg 3.4-3. Assume dual fuel emission factors.
- [j] USEPA (1995a) Pg 3.4-3. Assume diesel emission factors.
- [k] USEPA (1995a) Pg 3.4-3.
- [l] USEPA (1995a) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from natural gas fired 'small industrial' boilers (3-29 MW).

- [m] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from residual oil fired industrial boilers.
- [n] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from distillate oil fired industrial boilers.
- [o] USEPA (1995a) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for spreader stoker firing configuration.
- [p] USEPA (1995a) 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 CH₄/TOC as for [z].
- [q] IPCC (1997a) data for NOx and CO converted to gross calorific equivalent by dividing by 1.05. CH₄ and NMVOC emission rates estimated by scaling relative to wood boiler data (see [p]).
- [s] USEPA (1995a) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from natural gas fired 'commercial' boilers (0.1-2.9 MW).
- [t] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from residual oil (No. 5 and 6) fired commercial boilers (0.1-2.9 MW).
- [u] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from distillate oil fired commercial boilers (0.1-2.9 MW).
- [v] USEPA (1995a) Pg 1.1-6 and 1.1-23. Uncontrolled emissions for overfeed stoker firing configuration.
- [w] USEPA (1995a) 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 CH₄/TOC as for [z].
- [x] USEPA (1995a) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from natural gas fired residential furnaces (< 0.1 MW).
- [y] USEPA (1995a) Pg 1.1-7 and 1.1-23. Uncontrolled emissions for hand fired units.
- [z] USEPA (1995a) Pg 1.9-3. Assume CH₄ constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion).
- [aa] USEPA (1995a) Pg 1.10-3. Assume CH₄ constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion).
- [ab] USEPA (1995a) Assume propane combustion (commercial boiler) and CH₄ to constitute 34% of total organic emissions (as recommended by USEPA for residential gas fired furnace).
- [ac] USEPA (1995a) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, NMVOC and CH₄ from distillate oil fired residential furnace (< 0.1 MW).
- [ad] Assume emission factors for commercial boilers (0.1 - 2.9 MW).

Table 3.A5: Passenger and light commercial vehicles: CH₄ 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			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	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source
Petrol																				
post 2005	0.003		0.171	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)	0.003		0.171	COPERT IV (converted to a per start EF)	0.004		0.171	COPERT IV (converted to a per start EF)	0.004					COPERT IV (Highway)
2004-2005	0.017	COPERT IV	0.249		0.011		0.017		0.249		0.011		0.249		0.011					
1998 - 2003	0.007	USEPA (as cited in IPCC 2006)	0.076		0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.010						0.112		0.009					
1985 – 1997 (3-way cat)	0.039		0.151		0.030		0.040						0.192		0.030					
1985 – 1997 (2-way cat)	0.112	FORS 1996	0.345	USEPA (as cited in IPCC 2006)	0.063		0.110						0.429	USEPA (as cited in IPCC 2006)	0.085					Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1976 – 1985	0.125	Carnovale 1991	0.434		0.065	Carnovale 1991	0.140						0.487		0.087					
Pre 76	0.133		0.461		0.112		0.150						0.521		0.100					
LPG																				
post 2005	0.080		0.240	COPERT IV (converted to a per start EF)	0.025	COPERT IV (Highway)	0.080		0.240	Petrol LCV EF x Pass car LPG to petrol ratio	0.025		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	COPERT IV	0.240		0.025		0.080		0.240		0.025		0.240		0.025					
1998 - 2003	0.024		0.096		0.011		0.024						0.096		0.011					
1985 – 1997 (3-way cat)	0.024		0.096		0.011		0.024						0.096		0.011					
1985 – 1997 (2-way cat)	0.033	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.131	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.014	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.033						0.131	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.014					Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
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		0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)	0.003		0.021	COPERT IV (converted to a per start EF)	0.000		0.021	COPERT IV (converted to a per start EF)	0.000					COPERT IV (Highway)
2004-2005	0.007	COPERT IV	0.018		0.002		0.007		0.018		0.002		0.018		0.002					
1998 - 2003	0.001		0.003		0.000		0.001						0.003		0.000					
1985 – 1997 (3-way cat)	0.001		0.003		0.000		0.001						0.003		0.000					
1985 – 1997 (2-way cat)	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.004	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.001						0.004	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.001					Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
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									
post 2005		0.037		0.049		0.037		0.049	
2004-2005	USEPA (as cited in IPCC 2006) - mid-point of reported range	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	NA		Hot Ef x Petrol Non-urban to Hot Urban ratio		Passenger car EF x LCV to car ratio		Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
1985 – 1997 (2-way cat)	Post 97 EF x earlier petrol age class relativity	0.592		0.158		0.211		0.159	
1976 – 1985		0.661		0.331		0.581		0.449	
Pre 76		0.703		0.344		0.740		0.460	
				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)

Table 3.A6: Medium and heavy duty trucks and buses: CH₄ 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		0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.123		0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.067		0.029	Passenger car LPG COPERT IV non-urban to urban ratio
1996 - 2002	0.220	USEPA 1989	0.096		0.220	USEPA 1989	0.096		0.120	USEPA 1989	0.053	
Pre 1996	0.220		0.096		0.220		0.096		0.120		0.053	
ADO												
Post 2003	0.048	COPERT IV (x EF reduction %)	0.022	Hot urban EF x COPERT IV non-urban to urban ratio	0.098	COPERT IV (x EF reduction %)	0.045	Hot urban EF x COPERT IV non-urban to urban ratio	0.017	COPERT IV (x EF reduction %)	0.008	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.157	USEPA 1989	0.072		0.157	USEPA 1989	0.072		0.030	USEPA 1989	0.014	
Pre 1996	0.157		0.072		0.157		0.072		0.030		0.014	

Table 3.A7: Passenger and light commercial vehicles: N₂O 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		Non-urban		Hot		Cold		Non-urban	
	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	0.003	COPERT IV	0.036	COPERT IV (converted to a per start EF)	0.002	COPERT IV (Highway)	0.005	COPERT IV	0.108	COPERT IV (converted to a per start EF)	0.005	COPERT IV (Highway)
2004-2005	0.011		0.072		0.003		0.022		0.186		0.022	
1998 - 2003	0.029		0.199		0.005		0.080		0.440		0.080	
1985 – 1997 (3-way cat)	0.029		0.178		0.005		0.048	Passenger car EF x USEPA	0.297		0.048	Hot urban EF x
1985 – 1997 (2-way cat)	0.011	Weeks et al 1993	0.106	USEPA (as cited in IPCC 2006)	0.002	Copert IV (IPCC 2006) non-urban to urban ratio	0.015	IPCC 2006) LCV to car EF ratio	0.138	USEPA (as cited in IPCC 2006)	0.015	Copert IV (IPCC 2006) non-urban to urban ratio
1976 – 1985	0.004		0.041		0.002		0.005		0.047		0.005	
Pre 76	0.003		0.036		0.002		0.003		0.041		0.002	
LPG												
post 2005	0.005		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	COPERT IV	0.069		0.002		0.026		0.178		0.018	
1998 - 2003	0.016		0.048		0.006		0.016		0.048		0.006	
1985 – 1997 (3-way cat)	0.006		0.017		0.001		0.006		0.017		0.001	
1985 – 1997 (2-way cat)	0.003	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.008	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.008	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
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												

continued

fuel type	Passenger Car						LCV					
	Urban			Non-urban			Urban			Non-urban		
	Hot		Cold		Non-urban		Hot		Cold		Non-urban	
	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	0.009	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		0.010		0.001		0.003		0.010		0.001	
1985 – 1997 (3-way cat)	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.002	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)	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
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												
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				0.029		0.049				0.049	
1985 – 1997 (2-way cat)	0.012	Post 97 EF x earlier petrol age class relativity		NA	0.011	Post 97 hot Ef x Petrol Non-urban to Hot Urban ratio	0.015	Passenger car EF x LCV to car ratio		NA	0.015	ethanol car hot EF x LCV non-urban to petrol hot urban ratio
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

Source (as indicated in table): Weeks et al. (1993)
IPCC (2006)

Table 3.A8: Medium and heavy duty trucks and buses: N₂O 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	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol																		
Post 2002	0.006		0.006		0.006		0.006		0.006		0.006		0.006		0.006		0.006	
1996 - 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	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV
Pre 1996	0.006		0.006		0.006		0.006		0.006		0.006		0.006		0.006		0.006	
LPG																		
Post 2002	0.020		0.020		0.020		0.020		0.020		0.020		0.011		0.011		0.011	
1996 - 2002	0.020	USEPA 1989	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	USEPA 1989	0.020	USEPA 1989	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	USEPA 1989	0.011	USEPA 1989	0.011	Hot urban EF x COPERT IV non-urban to urban ratio	0.011	Hot urban EF x COPERT IV non-urban to urban ratio
Pre 1996	0.020		0.020		0.020		0.020		0.020		0.020		0.011		0.011		0.011	
ADO																		
Post 2002	0.030		0.030		0.030		0.030		0.030		0.030		0.030		0.030		0.030	
1996 - 2002	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	Hot urban EF x COPERT IV non-urban to urban ratio
Pre 1996	0.025	USEPA 1989	0.025		0.025		0.025	USEPA 1989	0.025		0.025	USEPA 1989	0.025	USEPA 1989	0.025		0.025	

Table 3.A9: Passenger and light commercial vehicles: emission factors for indirect gases

Fuel type	Passenger Car				LCV				Medium Duty Truck				Heavy Duty Truck				Bus			
	NO _x	CO	NMVOc	NO _x	NO _x	CO	NMVOc	NO _x	NO _x	CO	NMVOc	NO _x	NO _x	CO	NMVOc	NO _x	CO	NO _x	CO	NMVOc
Petrol																				
Post 97	0.225	0.869	0.077	0.459	1.516	0.236														
1985 – 1997 (3-way cat)	0.450	3.850	0.294	0.917	6.712	0.894														
1985 – 1997 (2-way cat)	0.930	5.460	0.260	1.895	9.519	0.791			2.52	10.87	1.04	2.52	10.87	1.04	1.04	3.91	48.61	3.47		
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														
1985 – 1997 (3-way cat)	0.942	10.305	0.755	0.942	10.305	0.755														
1985 – 1997 (2-way cat)	1.947	14.614	0.669	1.947	14.614	0.669			4.83	24.00	4.21	4.83	10.87	4.21	4.21	2.76	24.00	2.41		
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														
1985 – 1997 (3-way cat)	0.500	0.515	0.237	0.500	0.515	0.237														
1985 – 1997 (2-way cat)	1.034	0.731	0.210	1.034	0.731	0.210			5.20	6.44	1.15	5.20	24.00	1.15	1.15	4.90	2.88	1.56		
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														

Table 3.A10: vehicle non-carbon dioxide emission factor deterioration rates (g/km/km)

	Vehicle Age Class				
	Pre '76	'76-'85	'85-'97 ^a	'85-'97 ^b	Post '97
CH₄	6.35E-07	4.76E-07	8.43E-07	1.49E-06	8.43E-07
N₂O	0	0	0	0	0
CO	1.45E-04	1.27E-04	7.82E-05	1.57E-04	7.82E-05
NO_x	0.00E+00	6.48E-06	8.91E-06	7.81E-06	8.91E-06
NM VOC	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06

Notes: a 3-way catalyst; b 2-way catalyst

Source: EPA NSW 1995

Table 3.A11: Road transport: non-carbon dioxide emission factors

Source Category		Emission Factor (g/km)				
Sector	Fuel Type	CH ₄ ^a	N ₂ O ^b	NO _x ^c	CO ^c	NM VOC ^c
Road Transport						
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	0.110	0.110	0.020
Light Commercial Vehicles	NG ^e	0.261	0.001	0.110	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.A12: Shares used to allocate ABARE fuel consumption to unlisted categories

ANZSIC category fuel consumption reported by ABARE	General use	Military	Small marine craft	Off-road vehicles	Utility engines
Road transport automotive gasoline	96.81%	0.06%	2.39%	0.1%	0.63%
Road transport ADO	99.5%	0.5%			
Water transport ADO	60%	40%			
Water transport fuel oil	99.95%	0.05%			
Air transport aviation gasoline	96.5%	3.5%			
Air transport aviation turbine fuel	92%	8%			

Source: Derived from Farrington 1988 and ABS 2006

Table 3.A13: Shares of total road fuel consumption by vehicle and fuel type 2007

Vehicle Type	Fuel Type			
	Automotive Gasoline	ADO	LPG	NG ^a
Passenger cars	0.849	0.102	0.712	0.053
Light commercial vehicles	0.142	0.180	0.252	0.053
Medium duty trucks	0.002	0.266	0.010	0.010
Heavy duty trucks	-	0.400	0.001	-
Buses	0.002	0.053	0.024	0.884
Motor cycles	0.006	-	-	-

Source: ABS 2008a. a) Apelbaum Consulting Group 2006

Table 3.A14: Australian petrol-fuelled vehicle stock age distribution and fuel consumption rates 2007

Passenger cars: year of manufacture	Passenger cars			Light commercial Vehicles			Medium Duty Trucks			Heavy Duty Trucks			Buses		
	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)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers
2007 ^b	356889	0.110	33261	0.129	272	0.213	106	0.300	572	0.150					
2006	701488	0.111	66761	0.131	713	0.197	119	0.300	1195	0.160					
2005	740693	0.111	99840	0.131	661	0.197	77	0.300	867	0.160					
2004	704932	0.111	95091	0.131	655	0.197	108	0.300	513	0.160					
2003	694094	0.111	88605	0.131	483	0.197	64	0.300	1012	0.160					
2002	622548	0.111	71402	0.131	586	0.197	53	0.300	836	0.160					
2001	602495	0.112	65395	0.135	491	0.189	38	0.312	642	0.151					
2000	611582	0.113	61189	0.134	390	0.198	17	0.324	1094	0.140					
1999	577521	0.113	65852	0.134	359	0.198	22	0.324	821	0.140					
1998	613309	0.113	61327	0.134	474	0.198	48	0.324	894	0.140					
1997	535309	0.113	50990	0.134	443	0.198	36	0.324	774	0.140					
1996	447135	0.113	50222	0.134	375	0.198	30	0.324	667	0.140					
1995	441613	0.113	47677	0.134	357	0.198	38	0.324	660	0.140					
1994	403718	0.113	48265	0.134	358	0.198	55	0.324	572	0.140					
1993	345030	0.113	37562	0.134	318	0.198	34	0.324	497	0.140					
1992	308813	0.113	38496	0.134	456	0.198	25	0.324	473	0.140					
1991	274854	0.114	32811	0.132	394	0.211	9	0.352	437	0.155					
1990	295592	0.114	38411	0.133	548	0.225	29	0.379	482	0.184					
1980 – 1989 ^a	987616	0.114	204067	0.133	8655	0.225	253	0.379	2343	0.184					
1979 and earlier	265054	0.114	84666	0.133	24057	0.225	403	0.379	382	0.184					

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: ABS 2009, ABS 2008a.

Table 3.A15: Australian diesel-fuelled vehicle stock age distribution and fuel consumption rates 2007

Passenger cars: year of manufacture	Passenger cars			Light commercial Vehicles			Medium Duty Trucks			Heavy Duty Trucks			Buses	
	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)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2007 ^b	33400	0.112	43251	0.123	12663	0.283	3853	0.556	1694	0.289				
2006	54252	0.118	79686	0.123	23142	0.289	5553	0.563	3462	0.270				
2005	39216	0.118	63197	0.123	23685	0.289	5958	0.563	3452	0.270				
2004	34020	0.118	56976	0.123	22289	0.289	5637	0.563	2562	0.270				
2003	29212	0.118	47050	0.123	16482	0.289	4763	0.563	2420	0.270				
2002	24746	0.118	42880	0.123	19037	0.289	3650	0.563	2409	0.270				
2001	21127	0.128	30499	0.124	13534	0.290	2742	0.551	2339	0.262				
2000	19889	0.123	36179	0.125	13177	0.293	2804	0.532	3250	0.267				
1999	16812	0.123	33858	0.125	13769	0.293	3008	0.532	2757	0.267				
1998	16171	0.123	31402	0.125	12938	0.293	3389	0.532	2870	0.267				
1997	13673	0.123	27337	0.125	10496	0.293	2553	0.532	2463	0.267				
1996	12102	0.123	24758	0.125	9453	0.293	2217	0.532	2526	0.267				
1995	12413	0.123	22900	0.125	10571	0.293	2561	0.532	2870	0.267				
1994	13544	0.123	23506	0.125	11784	0.293	2759	0.532	2842	0.267				
1993	12800	0.123	20760	0.125	9398	0.293	1710	0.532	2378	0.267				
1992	15439	0.123	19225	0.125	9367	0.293	988	0.532	2404	0.267				
1991	13454	0.119	14714	0.126	8142	0.298	740	0.527	1936	0.308				
1990	13090	0.134	18172	0.122	12501	0.298	1597	0.526	2008	0.355				
1980 – 1989 ^a	60265	0.134	79931	0.122	96801	0.298	11012	0.526	11141	0.355				
1979 and earlier	1749	0.134	3940	0.122	22677	0.298	959	0.526	1112	0.355				

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: ABS 2009, ABS 2008a

Table 3.A16: Australian LPG-fuelled vehicle stock age distribution and fuel consumption rates 2007

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
	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)
2007 ^b	4869	0.168	2634	0.147	25	0.372	12	0.644	139	0.530
2006	12159	0.162	6498	0.151	52	0.441	14	0.600	270	0.471
2005	11146	0.162	4854	0.151	40	0.441	14	0.600	163	0.471
2004	11519	0.162	4152	0.151	36	0.441	7	0.600	137	0.471
2003	14534	0.162	4604	0.151	34	0.441	2	0.600	108	0.471
2002	14208	0.162	5218	0.151	37	0.441	3	0.600	124	0.471
2001	15210	0.160	6052	0.157	30	0.340	2	0.528	280	0.392
2000	15305	0.162	6620	0.155	41	0.276	3	0.500	174	0.362
1999	19337	0.162	6072	0.155	19	0.276	2	0.500	169	0.362
1998	17102	0.162	5606	0.155	23	0.276	5	0.500	52	0.362
1997	15522	0.162	5256	0.155	36	0.276	2	0.500	50	0.362
1996	15762	0.162	5513	0.155	20	0.276	2	0.500	45	0.362
1995	15706	0.162	5525	0.155	25	0.276	2	0.500	134	0.362
1994	15579	0.162	5770	0.155	24	0.276	0	0.500	147	0.362
1993	13693	0.162	4408	0.155	25	0.276	0	0.500	87	0.362
1992	10498	0.162	3555	0.155	46	0.276	0	0.500	56	0.362
1991	7472	0.166	3117	0.167	52	0.305	1	0.466	66	0.305
1990	8920	0.161	3797	0.163	55	0.270	0	0.432	86	0.260
1980 – 1989 ^a	34992	0.161	19487	0.163	1380	0.270	8	0.432	286	0.260
1979 and earlier	9613	0.161	11320	0.163	2065	0.270	5	0.432	41	0.260

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: ABS 2009, ABS 2008a.

Table 3.A17: 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	0.058	NA	NA

Source: ABS 2008a. Note: a) Refer to Table 3.A14 - 3.A16

Table 3.A18: 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 of 11.0 psi

4. Industrial Processes

4.1 Overview

Total net emissions estimated from industrial processes were 30.3 Mt CO₂-e in 2007, or 5.6% of net national emissions (excluding LULUCF) (Table 4.1).

Table 4.1: Industrial processes sector CO₂-e emissions 2007

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)				
	CO ₂	CH ₄	N ₂ O	HFC/PFC/SF ₆	Total
2 INDUSTRIAL PROCESSES	17,726	72	17	6141	30,343
A Mineral products	5,867	NA	NA	NA	5,867
B Chemical industry	1,317	9	IE	NA	1,326
C Metal production	10,542	63	17	502	11,124
D Other production	IE	NA	NA	NA	IE
E Production of halocarbons and sulphur hexafluoride	NO	NO	NO	NO	NO
F Consumption of halocarbons and sulphur hexafluoride	NA	NA	NA	5,639	5,639
G Other ^(a)	C	C	C	NA	6,388

Source: a) Includes confidential emissions from soda ash production and use (CO₂), magnesia production (CO₂), nitric acid production (N₂O) ammonia production (CO₂), acetylene use (CO₂), and use of N₂O in aerosols and anaesthesia (N₂O).

Metal production contributed 36.7% (11.1 Mt CO₂-e) of the sector's emissions, *mineral products* contributed 19.3% (5.9 Mt CO₂-e), *chemical industries* contributed 4.4% (1.3 Mt CO₂-e), and the *consumption of HFCs and SF₆* contributed 18.6% (5.6 Mt CO₂-e).

Activity data for soda ash production and use, magnesia production, nitric acid production ammonia production, acetylene use, and N₂O use in aerosols and anaesthesia are commercial-in-confidence and, due to the direct relationship between activity and emissions, emissions estimates by gas species are also confidential. These emissions are aggregated and reported as CO₂-e emissions. Total emissions from this subsector are 6.4 Mt CO₂-e.

The main gas emitted by industrial processes is carbon dioxide, contributing 58.4% (17.7 Mt) of the sector's emissions in 2007. CO₂-e emissions from the subsectors where data are confidential (2.G Other) contributed 21.1% (6.4 Mt). PFCs contributed 1.7% (0.5 Mt), HFCs contributed 16.9% (5.1 Mt), SF₆ contributed 1.7% (0.5 Mt), nitrous oxide contributed 0.1% (0.02 Mt), and methane 0.2% (0.1 Mt).

Trends

Net emissions from *industrial processes* increased by 25.7% (6.2 Mt CO₂-e) from 1990 to 2007, and, by 3.3% (1.0 Mt CO₂-e) between 2006 and 2007 (Figure 4.1). The increases in sectoral emissions observed over the longer term are principally due to growth in emissions associated with the consumption of halocarbons and the sub-sectors making up confidential emissions reported as CO₂-e. Each source category's contribution to total emissions and to sectoral trends within the Industrial Processes sector between 1990 and 2007 is shown in Figure 4.1.

Clinker Production

Emissions of CO₂ per tonne of clinker fluctuate according to the quantities of cement kiln dust (CKD) calcined. The quantities of CKD which are recycled to kiln are continually adjusted in order to produce clinker with the most desirable chemical properties. The quantities of CKD recycled also vary significantly from plant to plant as raw materials and fuel inputs vary in composition.

Iron and Steel Production

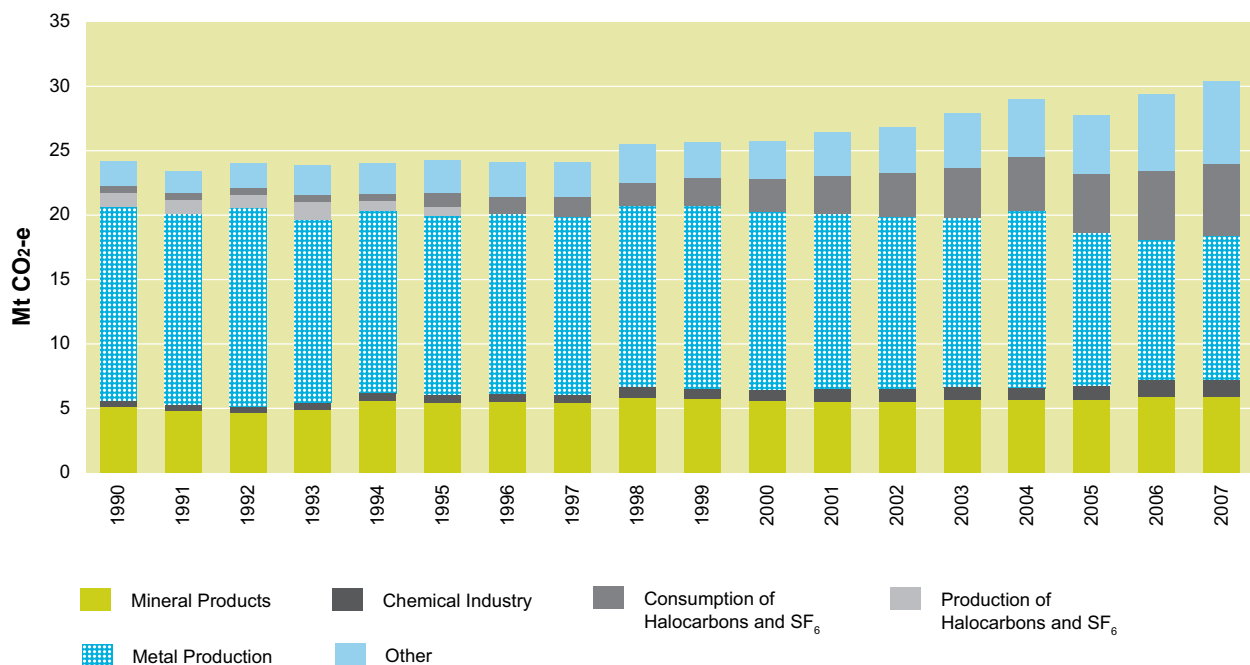
Emissions per tonne of Iron and Steel produced vary according to changing quantities of reductants used. The down-turn in emissions during 2005 occurred due to the blast-furnace re-lining activities at the Whyalla steel works. There has been a general declining trend in the Iron and Steel CO₂-e implied emission factor due to the increased use of pulverised coal injection in lieu of coke. All coal used in iron and steel production whether for energy purposes or reductant is accounted for under 1.A2 Manufacturing Industries and Construction.

Emissions per tonne of raw steel dropped in 1998 – this occurred due to a slight drop in the consumption of coke – but a significant increase in raw steel production. There is agreement in the raw steel production reported by the companies and that reported in the ABARE commodity statistics.

Aluminium Production

The downward trend in CO₂-e emissions per tonne of aluminium produced has occurred as a result of improvements in process control and the resultant reduction in PFC emissions. Any fluctuations in implied emission factors 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 implied emission factor between 2005 and 2007 is 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).

Figure 4.1: Emissions from industrial processes by subsector 1990–2007



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 (ie limestone, dolomite and magnesite); carbon when used as a chemical reductant (eg iron and steel or aluminium production); chemical industry processes (eg 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 process 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 emission factors (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.

Table 4.2: Summary of methods and emission factors: Industrial Processes

Greenhouse Gas Source and Sink Categories		CO ₂		CH ₄		N ₂ O		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													
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		T2	D	NA	NA	NA	NA						
6. Road Paving with Asphalt		NE	NA	NA	NA	NA	NA						
7. Other <i>(please specify)</i>													
Magnesia production		T2	CS	NA	NA	NA	NA						
B. Chemical Industry													
1. Ammonia Production		T1, T2	CS,D	T2	D	T2	CS	NA	NA	NA	NA	NA	NA
2. Nitric Acid Production		T1b	D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5. Other <i>(please specify)</i>		NA	NA	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
Polymers and other chemicals		NE	NA	T2	D	NA	NA	NA	NA	NA	NA	NA	NA
Synthetic Rutile		T2	CS	NA	NA	NA	NA			NA	NA	NA	NA
C. Metal Production													
1. Iron and Steel Production		T1b	CS	T2	CS	T2	CS	T1c	CS	T2	CS		
3. Aluminium Production		T1b	CS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4. SF ₆ Used in Aluminium and Magnesium Foundries		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	CS	CS
5. Other <i>(please specify)</i>													
Other Metals		IE	IE	NA	NA	NA	NA			NA	NA	NA	NA
D. Other Production		NA	NA										

E. Production of Halocarbons and SF₆									
1. By-product Emissions									
Production of HCFC-22									
Other									
F. Consumption of Halocarbons and SF₆									
1. Refrigeration and Air Conditioning Equipment									
2. Foam Blowing									
3. Fire Extinguishers									
4. Aerosols/ MDIs									
5. Solvents									
6. Semiconductor Manufacture									
7. Electrical Equipment									
8. Other (<i>please specify</i>)									
G. Other ^(a)									

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.
Source: a) Confidential emissions reported as CO₂-e. Methodology and emission factor information listed under CO₂.

Data Sources

The inventory for the *industrial processes* sector relies on an annual survey of industries conducted by consultants on behalf of the Department of Climate Change. 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

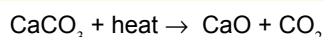
Industrial Processes Sector	Activity data
2.A1. Cement clinker	Cement Industry Federation
2.A2. Lime	Pacific Lime, Blue Circle Southern Cement, Adbri (Adelaide Brighton Cement and Cockburn Cement), Loongana Lime, Unimin, Hyrock and Queensland Alumina
2.A3. Limestone and dolomite	BlueScope Steel, OneSteel, ACI, Amcor, Temmco, MIM, Smorgon, Zinifex
2.A4. Soda ash	Penrice Soda Products
2.A6. Bitumen	ABARE Commodity Statistics
2.A7. Magnesita Production	Qmag, Causmag
2.B1. Ammonia	Incitec, Wesfarmers CSBP, BHP Billiton, Queensland Nitrate
2.B2. Nitric acid	Incitec, Wesfarmers CSBP, Queensland Nitrate
2.B5. Other chemicals	Dynea W.A, Borden Chemicals, Orica, BP, Shell, Huntsman Chemicals, Dow Chemicals, Qenos, ExxonMobil, Continental Carbon, Cabot Australia, Australian Vinyl, BOC Gases, Airliquide, Caltex
2.B5 Synthetic Rutile and Titanium Dioxide	WA Department of Minerals and Energy, Ti-west, Iluka Resources, Milenium Chemicals
2.C1. Iron and steel	BlueScope Steel, OneSteel and Smorgon Steel
2.C3. Aluminium	Australian Aluminium Council
2.C4. SF ₆ used in metal production	CSIRO, Brisbane
2.C5. Other (sulphur dioxide)	ABARE Commodity Statistics for various metals
2.D2. Food and drink (bread)	ABS apparent consumption data
2.F Consumption of Halocarbons and SF ₆	Bulk import and pre-charged equipment data reported to the Department of the Environment, Water, Heritage and the Arts under the regulations applying under the <i>Ozone Protection and Synthetic Greenhouse Gas Management Act 2003</i>

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. Carbon dioxide is produced during the manufacture of portland clinker, which is an intermediate product in the production of cement. Calcium carbonate (CaCO₃) 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 carbon dioxide in a process known as calcination.



Carbon dioxide 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 and Cement Australia. Activity data are collected for the Cement Industry Federation of Australia by an annual survey conducted by Price Waterhouse Coopers.

The production of blended cements, incorporating waste materials from other industries (eg 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 CO₂ emissions per unit of cement produced.

Methodology

Based on industry data, it is assumed that non-carbonate calcium sources and carbonates (other than calcium carbonates) are insignificant sources of material for cement production in Australia. The relative lime content of portland cement clinker in Australia is typically 0.65-0.67 by weight (Ryan and Samarin 1992). A lime content value of 0.66 has been adopted based on Cement Industry Federation data. Carbon dioxide emissions from clinker manufacture are estimated by applying an emission factor EF_{cl} , in kilograms of CO₂ released per tonne of clinker produced, to the annual clinker production A_{cl} . The emission factor is the product of the fraction of lime used in the clinker and a constant reflecting the mass of CO₂ released per unit of lime produced. 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).

The CO₂ emission factor has been derived using the World Business Council for Sustainable Development (WBCSD 2005) methodology. Assuming CaO and MgO proportions of 0.66 and 0.015 respectively leads to an emission factor of 534 kg CO₂ per tonne of clinker. F_{ckd} is the degree of calcination of cement kiln dust (range 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 emission factor for TOC is taken from WBCSD 2005 (equivalent to 10kg CO₂ per tonne of clinker).

$$E_{cl} = [EF_{cl} \cdot A_{cl} + EF_{cl} \cdot F_{ckd} \cdot A_{ckd} + EF_{toc} \cdot (A_{cl} + A_{ckd})] \cdot 10^{-6}$$

Table 4.4: Australian cement clinker production and emissions 1990: 2000–2007

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	42	3,644
2006	7,076	72	3,888
2007	7,112	48	3,895

Source: Beyond Neutral 2008

4.3.2 Lime Production (2.A2)

Source Category Description

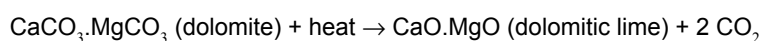
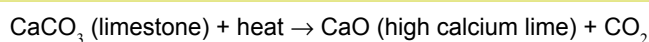
Lime is an important chemical having major uses in metallurgy (steel, copper, gold, aluminium and silver), other industrial applications (water softening, pH control, sewage sludge stabilisation), and construction (soil stabilisation, asphalt additive and masonry lime). Carbon dioxide is emitted during the pyroprocessing of raw materials rich in calcium carbonate (limestone and dolomite) for the production of lime (ie calcining).

CO₂ emissions associated with the production of commercial and in-house lime are accounted for under this category. In-house lime production is undertaken by the steel and alumina industries. Emissions from in-house production of lime in the iron and steel industry cannot be differentiated from direct limestone use and are reported under 2.A3, whilst emissions from in-house lime production in alumina are confidential. Dolomitic lime is not commercially manufactured in Australia, although some dolomitic lime is produced and used in-house in the ferrous metal industry. These emissions are also reported under 2.A3 (Limestone and Dolomite Use).

The producers of lime in Australia include Pacific Lime, Blue Circle Southern Cement, Adbri (Adelaide Brighton Cement and Cockburn Cement), Loongana Lime, Unimin, Hyrock and Queensland Alumina.

Methodology

A Tier 2 method is utilised for the Australian inventory. Both high calcium lime (CaO) and dolomitic lime (CaO.MgO) are manufactured by heating calcium rich raw materials (limestone or dolomite) in a kiln:



The mass of CO₂ produced per unit of lime manufactured may be estimated from a consideration of the molecular weights (56 for CaO, 44 for CO₂) and the lime content of products. The lime content F_q varies depending on the purpose of lime consumption. For commercial lime used in Australian steel production, F_q is 0.86 while for the in-house lime used in Australian alumina production, F_q is 0.93.

Total CO₂ emissions E_q associated with quicklime production A_q are estimated as the sum of the commercial and in-house production according to:

$$E_q = \sum A_q \cdot F_q \cdot EF_q$$

Table 4.5: Lime production emissions 1990: 2000–2007

Year	Lime production (kt)	Emissions (Gg CO ₂)
1990	1,035	705
2000	1,277	869
2001	1,533	1,040
2002	1,569	1,065
2003	1,593	1,082
2004	1,624	1,101
2005	1,617	1,093
2006	1,467	990
2007	1,492	1,007

Source: Beyond Neutral 2008

4.3.3 Limestone And Dolomite Use (2.A3)

Source Category Description

Apart from use in clinker and lime production, limestone (CaCO_3) and dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$) are basic raw materials that have commercial applications in a number of industries including metallurgy (for example, iron and steel), glass manufacture, agriculture, construction and environmental pollution control.

All CO_2 emissions associated with limestone and dolomite use, 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 glass production industry. Emissions from the use of limestone in cement and lime production are accounted for under 2A1 and 2A2 respectively (with an exception being lime produced in-house and used in the iron and steel industry). In-house production of lime in iron and steel production is accounted together with direct limestone and dolomite use under this source category (2.A3).

Companies using limestone or dolomite in their production processes and which provide data for the Inventory include Bluescope Steel, Onesteel, Xstrata, Pilkington ACI, Amcor Packaging Temco and Tyco Foundries.

Methodology

A Tier 2 method is utilised for the Australian inventory. The mass of CO_2 emitted per unit of limestone EF_{ls} or dolomite use EF_{d} 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). The fractional purity of limestone, F_{ls} , is 0.90 for Australia. The fractional purity of dolomite F_{d} is estimated to be 0.95 for Australia. Total CO_2 emissions E are estimated from total limestone A_{ls} and dolomite use A_{d} and the relevant fractional purities and emission factors:

$$E = A_{\text{ls}} \cdot F_{\text{ls}} \cdot \text{EF}_{\text{ls}} + A_{\text{d}} \cdot F_{\text{d}} \cdot \text{EF}_{\text{d}}$$

Table 4.6: Limestone and dolomite consumption and emissions 1990: 2000–2007

Year	Limestone Use (kt)	Limestone Use Emissions (Gg)	Dolomite Use (kt)	Dolomite Emissions (Gg CO_2)
1990	1,587	628	721	327
2000	1,863	737	660	299
2001	1,563	619	600	272
2002	1,635	647	640	290
2003	1,665	659	698	316
2004	1,616	639	657	298
2005	1,566	620	625	283
2006	1,701	673	656	298
2007	1,673	662	667	302

Source: EnerGreen Consulting 2008

4.3.4 Soda Ash Production And Use (2.A4)

Source Category Description

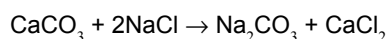
Soda ash (sodium carbonate, Na_2CO_3) is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper manufacture and water treatment. Coke used in soda ash manufacture is commercially purchased and the CO_2 emissions associated with its use are accounted for in the Energy sector.

Soda ash is produced by one company, Penrice Soda Products, located in South Australia, using the Solvay process. Emissions are generated from the consumption of soda ash. Activity data and emissions for recent years are confidential. For reporting purposes, emissions estimates from soda ash are aggregated with confidential emissions from ammonia, magnesia and nitric acid production and reported under 2.G Other: Confidential emissions reported as CO_2 -equivalent.

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. 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:



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 assumed to be stoichiometrically neutral in relation to CO_2 gas (that is, generation equals uptake). Emissions from the use of coke are included elsewhere under the energy sector.

Soda Ash Consumption

A Tier 2 method is utilised for the Australian inventory. Carbon dioxide 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 and the stoichiometry of the chemical process (where 44 is the molecular weight of CO_2 and 105.99 is the molecular weight of Na_2CO_3).

$$E_{\text{sau}} = 0.415 \text{ kg/tonne Na}_2\text{CO}_3$$

Table 4.7: Soda ash use and emissions

Year	Soda ash use (kt)	Emissions (Gg CO_2)
1990	450	186
2007	C	C

Source: EnerGreen Consulting 2008

4.3.5 Asphalt Roofing (2.A5)

There is negligible use of asphalt for roofing purposes in Australia.

4.3.6 Road Paving With Asphalt (2.A6)

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 per cent (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 per cent (Treadrea 1995). Bitumen data are sourced from *Australian Commodity Statistics* (ABARE 2008b).

4.3.7 Other (2.A7) Magnesia And Glass Production

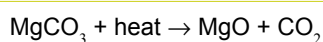
Source Category Description

Magnesia and CO₂ are produced from the calcination of magnesite (magnesium carbonate ore). Two companies produce magnesia in Australia; Causmag and Qmag. Both of these companies provided production data for this Inventory. Magnesia production and emissions are confidential and are reported under 2.G Other: confidential remissions reported as CO₂-equivalent.

Glass production requires the consumption of limestone and soda ash, which generate emissions of carbon dioxide. These emissions are included elsewhere and reported under section 2.A3 and 2.G Other: confidential remissions reported as CO₂-equivalent, respectively.

Methodology

A Tier 2 method for the estimation of emissions from magnesia production is utilised for the Australian inventory. Emissions are estimated from magnesia production, the fractional purity of magnesia produced, and the stoichiometry of the chemical process. Magnesia is produced from the calcination of magnesite (magnesium carbonate ore):



Based on the molecular weights of MgO and CO₂, the production of 1 tonne of pure MgO generates 1.092 tonnes of CO₂. Commercial magnesia is not 100% pure and the emission factor needs to be adjusted to reflect the fractional purity, F_p .

Emissions E_m are estimated as a function of the quantity of MgO produced A_{MgO}

as follows:

$$E_m = F_p \cdot 1.092 \cdot A_{\text{MgO}}$$

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 is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

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. Data are obtained direct from companies and are subject to verification against known published sources. The level of cooperation of Australian companies is very high.

In order to ensure completeness, reconciliation between sources of carbonate supply and use in the Australian economy are undertaken (see Table 4.8).

Table 4.8: Reconciliation of limestone supply and use in the Australian economy 2007

	Raw material(kt)	CaCO ₃ (kt)	Emissions (Gg CO ₂)	Carbon (kt)
<i>Limestone use</i>				
2.A1 Cement – clinker	9,843	8,859	3,895	1,062
2.A2 Quicklime production – in-house lime	0	0	0	0
2.A2 Quicklime production – commercial lime	2,663	2,290	1,007	275
2.A3 Limestone use	1,673	1,531	662	181
5.G Agricultural Liming	3,429	3,406	1,498	408
Change in stocks, statistical discrepancy, and residual available for non-pyro processes	1,982	-	-	-
Total Use ^(a)	19,618			1,926
<i>Limestone supply</i>				
Production	19,223			
Net imports	395			
Total supply ^(b)	19,618			

Source: a) DCC b) ABARE 2008a c) Clinker emissions excluding those from the calcination of magnesium carbonates

The Mineral Products sector was reviewed independently by an international expert (Tsaranu 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.

Australia's cement production emissions estimates are based on clinker production, in line with IPCC guidelines. 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.

4.3.10 Recalculations Since The 2006 Inventory

There have been no recalculations since the 2006 Inventory.

4.3.11 Planned Improvements

- All relevant data are kept under constant review.

4.4 Source Category 2.B Chemical Industry

4.4.1 Ammonia Production (2.B1)

Source Category Description

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 multi stage process involved in ammonia production (from natural gas feedstock) results in the industrial process emissions of CO₂, NMVOC, and CO in addition to ammonia and sulphur compounds.

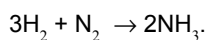
Carbon dioxide emissions from ammonia reflect the use of natural gas for both energy and reductant uses. In Australia's inventory, as there is no data available to differentiate between the two processes, all CO₂ emissions from this source are reported under this sector and an appropriate deduction has been made in natural gas consumption in the Stationary Energy sector to remove the possibility of double-counting.

A portion of CO₂ emissions arising from the production of ammonia are principally recovered for use in the production of urea. This recovery is deducted from the total CO₂ emissions from ammonia production reported in *industrial processes*. Emissions from the use of urea as fertiliser are covered in the *agriculture* sector.

Ammonia is produced by four producers in Australia; Wesfarmers, Incitec, BHP-Billiton and Queensland Nitrates. All companies provided production data for this Inventory; however, ammonia production data and emissions 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,



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 CO₂, NMVOC and CO. While the CO₂ 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 CO₂.

The general method for deriving emissions relates plant specific emission factors EF_i to plant specific production data A_i:

$$E_a = \sum A_i \cdot EF_i$$

Plant specific emission factors used to estimate emissions from ammonia production in Australia are confidential.

4.4.2 Nitric Acid Production (2.B2)

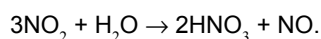
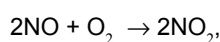
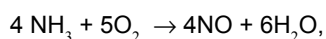
Source Category Description

The manufacture of nitric acid (HNO_3) generates nitrous oxide (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, Incitec and QLD Nitrate. All companies provided data for the 2007 Inventory. Nitric acid production data and emissions are confidential and are reported under *2.G Other: confidential emissions reported as CO_2 equivalent*.

Methodology

A Tier 2 method is utilised for the Australian inventory. Nitric acid production involves three distinct chemical reactions. These are summarised as follows:



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.

The emission factor for N_2O from nitric acid production EF_n is based on measurements of the off-gas emitted at nitric acid production plants in the Australia. This emission factor is confidential.

The emission of N_2O , E_n , from the manufacture of nitric acid production A_n is calculated according to:

$$\text{E}_n = \text{A}_n \cdot \text{EF}_n$$

4.4.3 Adipic Acid Production (2.B3)

There is no adipic acid production occurring in Australia.

4.4.4 Carbide Production (2.B4)

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, and have been included in *2.G Other: confidential emissions reported as CO_2 equivalent*. Imported calcium carbide is also used in small quantities as a flux in electric arc furnace steel production. At present complete data to estimate emissions from this source are not available.

4.4.5 Other (2.B5) Synthetic Rutile

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.

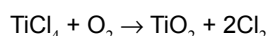
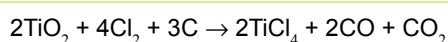
Synthetic rutile is produced in Australia by Iluka Resources and the Ti-West Joint Venture.

The use of coal and petroleum coke as reductants in the synthetic rutile and TiO₂ 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.

Methodology

A Tier 2 method is utilised for the Australian inventory. The processes that are used in the production of TiO₂ in Australia that lead to process greenhouse gas emissions are synthetic rutile production using the Becher process, and rutile TiO₂ 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 per cent purity. Rutile TiO₂ is produced through the carbothermal chlorination of rutile ore or synthetic rutile to produce titanium tetrachloride (TiCl₄) and oxidation of the TiCl₄ vapours to TiO₂ according to the following reactions (Kirk-Othmer, 1999; p.2017):



Based on stoichiometry and assuming complete conversion of the input C to CO₂ through further conversion of CO in excess air, the CO₂ emission factor cannot be less than 0.826 tonnes of CO₂ per tonne of TiO₂ (based on 1.5 moles of CO₂ per mole of TiO₂).

Emissions from rutile and TiO₂ respectively may be calculated by:

$$\text{CO}_2 \text{ Emissions} = \text{EF}_i \cdot \text{Production}_i$$

Data on synthetic rutile production were obtained from various Statistics Digests published by the WA Department of Minerals and Energy. TiO₂ production is provided by Ti-West and Millennium Chemicals. Cefic (the European Chemical Industry Council) provided an emission factor for TiO₂ production which is applied to Millennium's TiO₂ production, while the emission factor used for Ti-West is derived from petroleum coke use supplied by the company. The emission factor for synthetic rutile is derived from confidential data supplied by Iluka Resources.

Table 4.9: Australian synthetic rutile production and emissions 1990: 2000-2007

Year	Synthetic Rutile production (kt)	Titanium Dioxide production (kt)	Synthetic Rutile Emissions (Gg CO ₂)	Titanium Dioxide Emissions (Gg CO ₂)
1990	284	0	407	0
2000	553	92	791	111
2001	643	88	921	107
2002	586	96	839	117
2003	597	95	855	115
2004	592	107	848	130
2005	649	105	929	127
2006	738	204	1,057	247
2007	746	206	1,068	250

Source: Beyond Neutral 2008

4.4.6 Other (2.B5) Polymers And Other Chemicals

Source Category Description

The manufacture of organic chemicals results in process emissions of NMVOC. Other gases such as CO₂, CH₄, N₂O, NO_x and CO may also be generated depending on the manufacturing process.

Complete time series of emissions of CH₄ and NMVOCs are included in the inventory for 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, Cabot Australia, Australian Vinyl, BOC Gases, Airliquide, and Caltex.

Methodology

A Tier 2 method is utilised for the Australian inventory. The emissions (E_{ij}) are estimated as a function of output (A_{ij}); an emission factor (EF_{ij}), emissions from process units, F_{ij}, and the number of processing units (N_{ij}) where a process unit is taken as a plant manufacturing a product. The plant is referred to in this way because in most cases, organic chemical manufacturing plants are large closed-loop operations.

Table 4.10: 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 ₂ H 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
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 2008; a) Based on stoichiometry; b) IPCC 1997

Emissions from miscellaneous organic chemical manufacture are dependent on the level of activity and extent of emission control and estimated according to equation:

$$E_{ij} = A_j \cdot EF_{ij} + N_j \cdot F_{ij}$$

Fugitive emissions are not linearly dependent on the activity level but rather depend on the process

complexity (in terms of such equipment counts as valves, seals and compressors) and leak maintenance programs conducted by industry. For these reasons, the term F in the equation is independent of activity but varies with industry category.

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. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

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. Data are obtained direct from companies and are subject to verification against known published sources. The level of co-operation of Australian companies is very high.

The Chemical Products sector was reviewed independently by an international expert (Tsaranu 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 2006 Inventory

There have been no recalculations since the 2006 Inventory.

4.4.10 Planned Improvements

Activity data and emission factors are kept under review.

4.5 Source Category 2.C Metal Production

4.5.1 Iron And Steel Production (2.C1)

Source Category Description

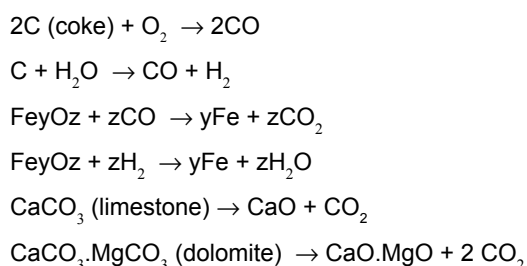
Iron and Steel production is a key source in the Australian inventory. Emission sources relate to the in-house production of metallurgical coke and lime, the use of limestone and dolomite as flux in iron, steel and ferro-alloy production and fugitive gas leaks associated with the distribution of coke oven gas and other products within industrial premises. In-house lime production as well as limestone and dolomite use is accounted for under 2.A3.

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. Emissions from the use of coke as a reductant are reported in this sector. Emissions from the production of coke are reported under sector 1.A1 while the emissions generated by the combustion of coke oven gas to produce energy are reported under the industry category of sector 1.A2.

There are two major producers of iron and steel in Australia; Onesteel and Blue Scope. Integrated iron and steel production occurs in New South Wales and South Australia. A new plant in Western Australia has commenced operation. This plant is operated by Hismelt. The plant uses non-coking coal to produce pig iron. The coal reductant used in the Hismelt process and pulverised coal used in other iron and steel production processes are accounted for in section 1.A1. A hot briquetted iron (HBI) plant that used natural gas as a reductant in Western Australia closed in 2005. All companies provided data for the inventory process.

Methodology

A Tier 2 method is utilised for 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,



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, using emission factors reported in the following tables.

Table 4.11: Carbon dioxide emission factors for iron and steel

Fuel Type	P Oxidation Factor (%)	F Emission Factor (Gg/PJ) ^(c)
Coke	98 ^(a)	108.8
Natural Gas	99.5 ^(b)	51.4

Source: a) IPCC (1997) default value; b) IPCC (1997) default value; c) the CO₂ emission factor for coke is derived from a carbon balance calculation conducted for the coke oven process. The natural gas emission factor is provided by the Australian Gas Association.

Table 4.12: Non-carbon dioxide emission factors for iron and steel

Fuel Type	Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	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. On advice from the industry (Energreen Consulting pers. comm., 2007), the average carbon content of raw steel is estimated to be 0.17%.

Fugitive Emissions

In addition to the estimation of emissions from the use of coke and gas as reductants, a process emission factor is established for methane from integrated iron and steel production (0.44 kg CH₄/tonne of crude steel produced) to reflect mainly sources of fugitive emissions. The estimated methane emission factor 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 methane associated with leakage from coke ovens and the bleeding of unflared gas from blast furnaces are estimated to be of

minor significance.

Crude steel production is sourced directly from companies.

Table 4.13: Australian steel production, coke consumption and emissions 1990: 2000-2007

Year	Steel production (kt)	Coke consumption (kt)	Hot Briquetted Iron production (kt)	Natural Gas consumption (PJ)	Total emissions from iron and steel production (Gg CO ₂ -e)
1990	6,223	87	NO	NO	9,099
2000	6,345	92	558	6	9,883
2001	6,027	77	1,223	22	9,144
2002	5,933	74	1,142	23	8,911
2003	6,282	67	1,670	34	8,655
2004	6,312	72	1,592	32	9,191
2005	5,977	69	NO	NO	7,255
2006	6,560	68	NO	NO	7,293
2007	6,600	69	NO	NO	7,425

Source: EnerGreen Consulting 2008, DCC

4.5.2 Ferroalloys Production (2.C2)

There is one company producing ferroalloys in Australia, consuming coal, coke and limestone in the process. Emissions from this source are included elsewhere under 1.A2, fuel combustion by the 'Manufacturing Industries and Construction' Sector, and 2.A3 'Limestone and Dolomite Use'.

4.5.3 Aluminium Production (2.C3)

Source Category Description

Aluminium is a key source in the Australian inventory. It 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.

PFC emissions result from anode effects (process upsets). The emission factor is an average across smelters. Individual smelters use plant emission factors based on empirical models from like plants and consistent with the requirements of the IPCC Good Practice Guidance.

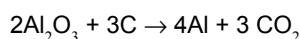
Alumina is calcined at about 1200 °C to eliminate chemically and physically bound water from the alumina, and to impart crystalline properties which are advantageous for aluminium production.

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 CO₂ emissions, which are accounted for under Lime (see Section 2.A2).

There are three main companies operating aluminium smelters in Australia; Alcoa, Tomago Aluminium and Comalco. The Australian Aluminium Council provided emission factor data for the 2007 Inventory and production data were obtained from ABARE 2008b.

Methodology

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:



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.

Carbon emitted during electrolysis is reported as if all the carbon is oxidised to CO_2 (at a rate of 1.514 tonnes of CO_2 per tonne of Aluminium produced (EF_{Alac})) plus an additional factor EF_{Alap} reflecting smelter level data on emissions generated in the production of the carbon anodes themselves (see Table 4.13).

Carbon dioxide emissions are derived using the equation:

$$E_{\text{al}} = A_{\text{Al}} \cdot \text{EF}_{\text{Alap}} + A_{\text{Al}} \cdot \text{EF}_{\text{Alac}}$$

The perfluorinated 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. The factors which determine the rate of formation of CF_4 and C_2F_6 during anode effects are not well understood. However, the quantities emitted are accurately measurable.

The Australian Aluminium Council report updated emission factors each year (see Table 4.14). Facility-specific emission factors are estimated in accordance with accepted international measurement protocols (International Aluminium Institute (2006), *The Aluminium Sector Greenhouse Gas Protocol, Addendum to the WRI/WBCSD GHG Protocol*, US EPA, International Aluminium Institute, *Protocol for Measurement of Tetrafluoromethane (CF_4) and Hexafluoroethane (C_2F_6) Emissions from Primary Aluminium Production*).

Table 4.14: Emission factors: kg per tonne of aluminium production 1990: 2000-2007

Year	CO_2	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

Source: Beyond Neutral 2008

The carbon anode consumed in aluminium smelting is approximately three per cent 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. Aluminium production for Australia is reported by ABARE 2008b.

Table 4.15: Aluminium: production and emissions

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	1,964	3,698

Source: a) ABARE (2008b); b) Beyond Neutral 2008

4.5.4 SF₆ Used In Aluminium And Magnesium Foundries (2.C4)

The inventory includes experimental quantities of SF₆ 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 SF₆ use for this experimental foundry was supplied by CSIRO.

4.5.5 Other Metals Production (2.C5)

Source Category Description

In Australia the other metals source category includes copper, lead, nickel, silver and zinc. There are approximately 10 companies involved in the production of other metals in Australia. Production data are sourced from ABARE Commodity Statistics.

Australia's metal ores are predominantly sulphide ores, leading to the generation of SO₂ as a byproduct of metal production. SO₂ emissions from metal production are reported under this category. 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 while another smaller lead-zinc refinery, at Cockle Creek, uses the Imperial Smelting Furnace technology. Carbon dioxide emissions from the use of fossil fuels in these refineries are reported under the Energy sector while carbon dioxide emissions from the consumption of limestone are reported under 2.A3. Other industries that consume limestone include copper smelting, foundries, ferromanagane production, and silicomanganese production.

Methodology

Ore composition and stoichiometric relationships have been used to derive 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 (ZnCO₃). 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 SO₂ will be released per tonne of primary refined zinc. Emission factors for other metals, based on stoichiometry relationships, are given in the Table 4.16.

Table 4.16: 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

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. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

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. Data are obtained direct from companies and are subject to verification against known published sources. The level of co-operation of Australian companies is very high.

The Metal Products sector was reviewed independently by an international expert (Tsaranu 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-CO₂ methodology and general refinements made to the metal products chapter in response to recommendations made in this review.

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.

4.5.8 Recalculations Since The 2006 Inventory

The CO₂ emission factor for the use of coke as a reductant in iron and steel production has been revised for 2005 and 2006 as a result of a revision to the carbon-balance calculations for this source. In addition, PFC emission factors have been revised for 2005 and 2006 as a result of a revision of plant-level data. The net result of these recalculations is an increase of 94.1 Gg CO₂-e in the 2006 estimate.

4.5.9 Planned Improvements

Activity data and emission factors are kept under review.

4.6 Source Category 2.D Other Production

4.6.1 Source Category Description

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 CO₂ emissions, consistent with the IPCC guidelines, Australia does not estimate CO₂ 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 (2008b).

4.6.2 Methodology

Food and drink emissions are based on tier 2 methods and IPCC default emission factors. Generally the methods involve multiplying the product activity level data (the amount of material produced or consumed) by an associated emission factor per unit of production or consumption. The emission factors 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);
- 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 emission factors 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 2006 Inventory

There have been no recalculations since the 2006 Inventory.

4.6.6 Planned Improvements

Activity data and emission factors are kept under review.

4.7 Source Category 2.E Production of Halocarbons and SF₆

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 emission factor 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 SF₆

4.8.1 Source Category Description

This sub-sector comprises emissions of synthetic gases from their use in refrigeration and air conditioning, foam blowing, fire extinguishers, aerosols, solvents and other uses.

4.8.2 Methodology

The methodology used for compiling emissions estimates from this range of sources relies on activity data (potential emissions) reported to the Department of the Environment, Water, Heritage and the Arts under the *Ozone Protection and Synthetic Greenhouse Gas Management Act, 2003*. Quantities of bulk import gas and pre-charged equipment imports are recorded and used in the emissions estimation model developed by ICF consulting. The model relates emissions to the consumption of HFC gases in various equipment end-use categories. Where additional data are available, the capital stock of appliances, characteristics of the capital stock such as age and average lifetimes, and the stored bank of HFC gases in household and commercial equipment have been used to estimate emissions.

Activity Data

The bulk gas import data collected under the Act are disaggregated into HFC 134a, 'Other HFCs' and 'Exotic HFCs'. The 'Other' and 'Exotic' gas categories are reported as an aggregate CO₂-e due to the confidential nature of the speciated data. Bulk import data for 2007 financial year are shown in Table 4.17.

Table 4.17: Quantities of HFCs imported in bulk in 2007

Total Imports, Mt CO ₂ -e	2007
HFC-134a	1.91
Other HFC	3.09
Exotic HFC	0.14
SUM HFC	5.14

Source: Australian Government Department of the Environment, Water, Heritage and the Arts

These bulk gases reported are also disaggregated into end-use categories. Estimates of the quantities of bulk gas within each end-use are based on knowledge of the percentage of each gas type going to each particular sector of the industry or on equipment stocks. Quantities of gas imported in bulk and contained in pre-charged equipment by end-use category are shown in Table 4.18.

Table 4.18: End-use allocation of bulk and pre-charged HFCs (2007)

End Use Breakdown	Bulk Imports 2007 (Mt CO ₂ -e)	Pre-charged imports 2007 (Mt CO ₂ -e)
Refrigeration	3.027	0.166
Transport refrigeration	0.566	0.01
Commercial refrigeration	1.965	0.04
Domestic refrigeration and freezers	0.697	0.116
Stationary air-conditioning	0.351	0.93
Chillers	0.217	0.03
Refrigerated portable	0.002	0.01
Split systems	0.128	0.81
Packaged systems	0.094	0.07
Mobile air-conditioning	1.411	0.38
Cars	1.494	0.34
Trucks	0.55	0.04
Foam	0.122	-
Aerosols/solvents	0.098	-
Fire equipment	0.132	-
TOTAL	5.141	1.477

Source: Australian Government Department of the Environment, Water, Heritage and the Arts

Backcasting

Data on HFC imports are available from July 2004 onwards. It is therefore necessary to backcast consumption data to enable a full time-series of emissions estimates. For each of the end-uses identified in Table 4.18, information on the transition into HFC use has been used to determine a time-series of HFC consumption.

Refrigeration and Air conditioning (2.F1)

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 equipment operation and the amount emitted during service. 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, freezers and airconditioning

A capital stock model has been used to determine a time-series for the bank of gas contained in domestic refrigeration and freezers and domestic airconditioning systems. The estimates are based on data on domestic fridge freezer and airconditioner populations in Australia (ABS 2005), data on domestic production presented in Burnbank 2002 and pre-charged equipment import data.

Average charges per unit for domestic refrigerators and air-conditioners have been derived based on the pre-charged equipment data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* and are presented in Table 4.19. It is assumed that all new equipment and imports from 1994 onwards contain HFC refrigerants. Service life emissions are derived using the IPCC default leakage rates presented in table 4.19.

Table 4.19: Domestic refrigeration, air-conditioning and mobile air-conditioning model parameters

Equipment type	Charge ^a (kg)	Lifetime ^b (years)	Leakage rates ^b (% of initial charge/year)		% of initial charge remaining at disposal	Disposal emission rate (%) of remaining charge ^d
			Initial	Operation		
Domestic refrigeration	0.157	15	0.6	0.3	95	70
Split System airconditioners	1.90	15	0.6	5.5	60 ^c	81
Packaged system airconditioners	0.99	15	0.6	5.5	60 ^c	81
Refrigerated-portable systems	0.60	15	0.6	5.5	60 ^c	81
Mobile airconditioners	0.69	12	0.5	15	25 ^c	37

Sources: a) DCC estimates; b) IPCC 2006; c) based on the assumption that each unit is serviced once during its operation life and receives replenishment of all loss up to the date of servicing; d) Burnbank 2002

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 would be retired after 25 years. It is assumed that 70% of each unit's residual charge is emitted upon disposal. Changes in the capital stocks of refrigerators, freezers and airconditioners and the associated bank and emissions of synthetic gases are presented in Tables 4.20 and 4.21.

Table 4.20: Refrigerator/freezer stocks and the associated bank and emissions of HFC-134a

Year	Total Refrigerator Population ^a	sales ^{b,c}	Disposals ^e	Bank (Mt CO ₂ -e) ^d	Emissions (Mt CO ₂ -e) ^d
1994	8,382,254	566,464		0.1	0.001
1995	8,578,471	576,086		0.2	0.001
1996	8,774,688	585,897		0.4	0.002
1997	8,970,905	595,708		0.5	0.002
1998	9,167,123	605,519		0.6	0.002
1999	9,363,340	615,330	28,323	0.7	0.006
2000	9,538,827	604,410	57,128	0.8	0.010
2001	9,714,313	614,221	86,422	0.9	0.015
2002	9,889,800	624,032	116,208	1.0	0.019
2003	10,162,167	730,723	146,484	1.2	0.024
2004	10,434,533	740,534	177,250	1.3	0.028
2005	10,706,900	749,308	207,471	1.4	0.033
2006	10,979,267	758,082	207,961	1.5	0.033
2007	11,171,633	795,011	269,383	1.6	0.041

Sources: a) ABS 2008a; b) Burnbank 2002; c) Department of the Environment, Water, Heritage and the Arts; d) DCC Estimates; e) Disposal of units containing HFC 134a.

Table 4.21: Stationary airconditioner stocks and the associated bank and emissions of HFCs as CO₂ equivalent

Year	Total Air Con Population ^a	Sales ^b	Disposals ^c	Bank (Mt CO ₂ -e) ^b	Emissions (Mt CO ₂ -e) ^b
1995	8,518,708	39,794		0.1	0.007
1996	8,626,067	78,575		0.3	0.019
1997	8,733,426	116,342		0.6	0.036
1998	8,840,784	153,096		1.0	0.060
1999	8,948,143	188,837		1.5	0.088
2000	9,012,289	235,043	1,990	2.8	0.168
2001	9,076,434	274,217	5,918	4.4	0.259
2002	9,140,580	313,391	11,736	6.1	0.364
2003	9,418,232	462,659	19,390	8.2	0.485
2004	9,695,885	517,900	28,832	10.4	0.620
2005	9,973,537	572,210	40,584	12.7	0.779
2006	10,251,189	626,978	54,295	15.1	0.961
2007	10,604,597	752,548	69,965	18.6	1.20

Sources: a) ABS 2008a; b) DCC estimates; c) Disposal of units containing HFCs

The estimated bank of gas in domestic refrigeration, freezers and airconditioners is cross-checked against data on the bulk import of synthetic gases to ensure that appropriate allocations are made to each of the remaining end uses.

Mobile Air-conditioning (Passenger Cars)

Mobile air-conditioning represents the most significant source of synthetic greenhouse gas emissions within the refrigeration and air-conditioning sector in Australia.

As with domestic refrigeration, published ABS 2006 data on the stock of motor vehicles have been used to construct a capital stock model. In Table 4.22 the 2007 motor-vehicle stock by year of manufacture (starting from 1995) and the assumed percentages of each vintage with air-conditioning are reported. It is assumed that all new units manufactured from 1995 onwards contain HFC-134a.

Table 4.22: Vehicle stocks and assumed air-conditioner penetration 1995-2007

Year of Manufacture	New vehicle population (2007) ^a	Percentage of vehicles with air-conditioning ^b
1995	532,484	95%
1996	535,278	95%
1997	563,212	95%
1998	656,980	100%
1999	675,956	100%
2000	606,081	100%
2001	688,826	100%
2002	668,622	100%
2003	705,009	100%
2004	752,062	100%
2005	786,266	100%
2006	773,014	100%
2007	805,948	100%

Source: a) ABS 2008a; b) Burnbank 2002

A HFC-134a bank time-series has been compiled using the ABS data, assumptions about proportions of each vintage with air-conditioning and an average charge per unit of 0.68 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 bank of gas have been taken from Burnbank 2002.

The estimated growth in the bank of HFC-134a associated with domestic production, pre-charged imports and retrofits of pre 1995 vehicles are reported in Table 4.23.

Table 4.23: Estimated bank of HFC 134a contained in passenger vehicles 1995–2007 and associated emissions

Year	Bank (Mt CO ₂ -e)	Emissions (Mt CO ₂ -e)
1995	3.62	0.56
1996	4.20	0.65
1997	4.92	0.76
1998	5.74	0.89
1999	6.55	1.02
2000	7.25	1.13
2001	7.98	1.25
2002	8.65	1.36
2003	9.31	1.47
2004	9.99	1.58
2005	10.62	1.68
2006	11.24	1.78
2007	11.90	1.89

Source: Department of Climate Change

The estimated bank of gas in mobile air-conditioning is cross-checked against data on the bulk import of HFC-134a to ensure that residual gas is allocated to each of the remaining end uses appropriately.

Equipment disposals are based on the IPCC default average life-span of 12 years with 7% of each vintage retiring in the 6th year after manufacture. Under these assumptions, the last units of each vintage would be retired after 19 years. The remaining bulk HFC 134a in mobile air-conditioning is allocated to trucks. It is assumed that between 1995 and 2000, 40% of the remaining charge contained in disposed units is recovered for destruction. From 2000 onwards, the 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.

An in-service emissions rate of 15% of initial charge loss per year has been applied to derive life-time emissions estimates. This falls within the IPCC default range of 10% to 20%. When considered in conjunction with disposal emissions, the lifetime loss rate is approximately 18% per year.

Foam Blowing (2.F2)

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100 per cent emissive in the year of manufacture, as described below. 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.

Fire Extinguishers (2.F3)

Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time. Following the IPCC Good Practice Guidance, fire extinguishing equipment leaks are assumed to flow at a constant rate for an average equipment lifetime of 15 years. In streaming systems, emissions are assumed to be 2 per cent of all chemical in use in each year, while in flooding systems, 1.5 percent of the installed base of chemical is assumed to leak annually (IPCC 2000).

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 Department has liaised with the Australian Fire Protection Association (FPA) which 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'.

Aerosols/Metered Dose Inhalers and Solvents (2.F4 and 2.F5)

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 per cent of the charge size (e.g., 100 percent of consumption). Data regarding the consumption of HFC-134a and Other HFCs for aerosol product and solvent use are provided by industry survey. Aerosol emissions are calculated using these data. Solvent emissions are based on the remaining imports distributed to the solvent and aerosol category of bulk imports.

As there are no data available on the use of HFCs in metered dose inhalers, the emissions from this source are reported as 'Not Estimated'.

Semiconductor Manufacture (2.F6)

There is no semiconductor manufacture activity occurring in Australia.

Electrical Equipment (2.F7)

The Electricity Supply Association of Australia publishes maps of the Australian electricity network that indicate that there are around 109 transmission substations of 220kV (kilovolts) or higher and approximately 258 substations of 132kV or less. It is assumed that each of the 220kV and higher installations contains on average 40 tonnes of SF₆. This implies a total contained amount of 4,360 tonnes. An average annual leakage rate of 0.5% (Burnbank 2002) is then used to derive a final emissions estimate.

As the size and extent of the electricity supply network remain stable year on year, these assumptions are held constant for the entire time-series.

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 emission factors or methodologies occur, a full time series recalculation is undertaken.

4.8.4 Source Specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Data are obtained by the Department of the Environment, Water, Heritage and the Arts 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 emissions model has been reviewed 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.

The Consumption of Halocarbons and SF₆ sector was reviewed independently by an international expert (Tsaranu 2007). The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. In response to recommendations made in this review, potential emission from the use of SF₆ in electrical equipment have been reported for the first time.

4.8.5 Recalculations Since The 2006 Inventory

There have been no recalculations since the 2006 Inventory.

4.8.6 Planned Improvements

All relevant data are kept under constant review.

4.9 Source Category 2.G Confidential Emissions Reported as CO₂-e

4.9.1 Source Category Description

This sub-sector comprises confidential emissions of CO₂ from soda ash production and use, magnesia production, ammonia production, and acetylene use; and, N₂O emissions from nitric acid production and the use of N₂O in aerosols and anaesthesia.

The recent UNFCCC expert reviews of Australia's inventory recommended that emissions from the confidential subsectors of the *industrial processes* sector be reported at a more disaggregated level. As the voluntary data provision by soda ash, magnesia, ammonia, nitric acid, acetylene and N₂O producers has been contingent upon the aggregation of these data to protect the confidentiality of the activity data no change has been made to the allocation of emissions at this time.

However, under the National Greenhouse and Energy Reporting (NGER) system, which commenced in July 2008, the Department will obtain facility level activity data which will enable the re-examination of the reporting of disaggregated emissions from sub-sectors comprising 2.G Other. The first data under the new reporting arrangements will become available in October 2009.

4.9.2 Methodology

The methodologies used for the calculation of emissions in the subsectors that comprise 2.G are described in sections 4.3.4, 4.3.7, 4.4.1, 4.4.2 and 5.3.4.

4.9.3 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 ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

4.9.4 Source Specific QA/QC

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

4.9.5 Recalculations Since The 2006 Inventory

The 2006 estimates were recalculated following the provision of updated production data by industry. These changes resulted in an increase of 766.94 Gg CO₂-e in the 2006 estimates.

4.9.6 Planned Improvements

Australia plans to examine the disaggregation of emissions reported under 2.G Other in light of data obtained under the NGER system which will become available from October 2009.

5. Solvent And Other Product Use

5.1 Overview

Activities in the *solvent and other products use* source category results in emissions of N₂O and NMVOCs. Total net emissions estimated from *solvents and other products* were 153.3 Gg NMVOC in 2007 (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 2007

Greenhouse Gas Source and Sink Categories	N ₂ O Emissions (Gg)	NMVOC emissions Gg)
3 SOLVENT AND OTHER PRODUCT USE		153
A Paint application	NA	65
B Degreasing and dry cleaning	NA	38
C Chemical products manufacture and processing	NA	0.8
D Other	IE	50

Note: Confidential N₂O emissions are reported in the industrial processes sector – 2.G Other

Paint application was the main source of NMVOCs contributing 42.2% (64.7 Gg NMVOC) of the sector's emissions. The next largest source was *other* (32.6%), followed by *degreasing and dry cleaning* (24.6). *Chemical products manufacture and processing* contributed only 0.5%.

Emissions from *solvent and other products use* declined by 0.8 Gg (0.5%) between 1990 and 2007. This decline is primarily driven by a reduction in paint application.

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 emission factors are given in Table 5.2.

Table 5.2: Properties of surface coatings and thinners^a

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: a) 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 conveyerised cleaning. Emission factors 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

Source: a) US EPA (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.

Emission factors 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 N₂O in aerosol products and for medical use.

N₂O emissions from Aerosol Products and Anaesthesia

Emissions of N₂O 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.G Other source category of the Industrial Processes Sector as confidential emissions reported as CO₂-e.

NM VOC Emissions from General Solvent use and Consumer Cleaning

Per-capita emission factors 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 NM VOC emissions from Other Domestic/Commercial products and Consumer Cleaning Products.

Emission factors 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

Source: a) Aerosol Association of Australia (pers. comm., 1994); b) USEPA (1997)

NM VOC 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 emission factor and the result is expressed in gigagrams (Gg). Emission factors 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 2006 Inventory

There have been no recalculations since the 2006 Inventory.

5.3.8 Planned Improvements

All activity data, methodologies and emission factors are kept under review.

6. Agriculture

6.1 Overview

Agriculture produced an estimated 88.1 Mt CO₂-e emissions or 16.3% of net national emissions (excluding LULUCF) in 2007 (Table 6.1).

Enteric fermentation was the main source of *agriculture* emissions contributing 65.3% (57.6 Mt CO₂-e) of the sector's emissions. The next largest source was *agricultural soils* (17.0%), followed by *prescribed burning of savannas* (13.1%) and *manure management* (3.9%). *Rice cultivation* and *field burning of agricultural residues* contributed less than 1% of the sector's emissions.

The *agriculture* sector is the dominant national source of both methane and nitrous oxide - accounting for 58.9% and 85.9% respectively of the net national emissions (excluding LULUCF) for these two gases.

Table 6.1: Agriculture sector CO₂-e emissions, 2007

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)			
	CO ₂	CH ₄	N ₂ O	Total
4 AGRICULTURE	NA	67950	20156	88106
A Enteric fermentation	NA	57561	NA	57561
B Manure management	NA	1859	1594	3453
C Rice cultivation	NA	196	NA	196
D Agricultural soils	NA	NA	15002	15002
E Prescribed burning of savannas	NA	8122	3463	11585
F Field burning of agricultural residues	NA	211	98	309

Trends

Emissions from *agriculture* increased by 1.5% (1.3 Mt) between 1990 and 2007 but had declined by 3.0% (2.7 Mt) between 2006 and 2007 (Figure 6.1).

The emissions from *enteric fermentation* declined by 9.9% (6.3 Mt) between 1990 and 2007 (Figure 6.2). The decline in emissions in the early 1990's was principally driven by a fall in sheep numbers, however by the late 1990's the emissions had begun to increase as the numbers of beef cattle began to rise, reflecting changing relative returns to each industry. Since 2002 many animal populations have been declining in response to the prolonged drought conditions which have occurred over extensive areas of southern and eastern Australia. Between 2006 and 2007, emissions from *enteric fermentation* declined by 2.9% (1.7 Mt).

Figure 6.1: CO₂-e emissions from agriculture 1990–2007

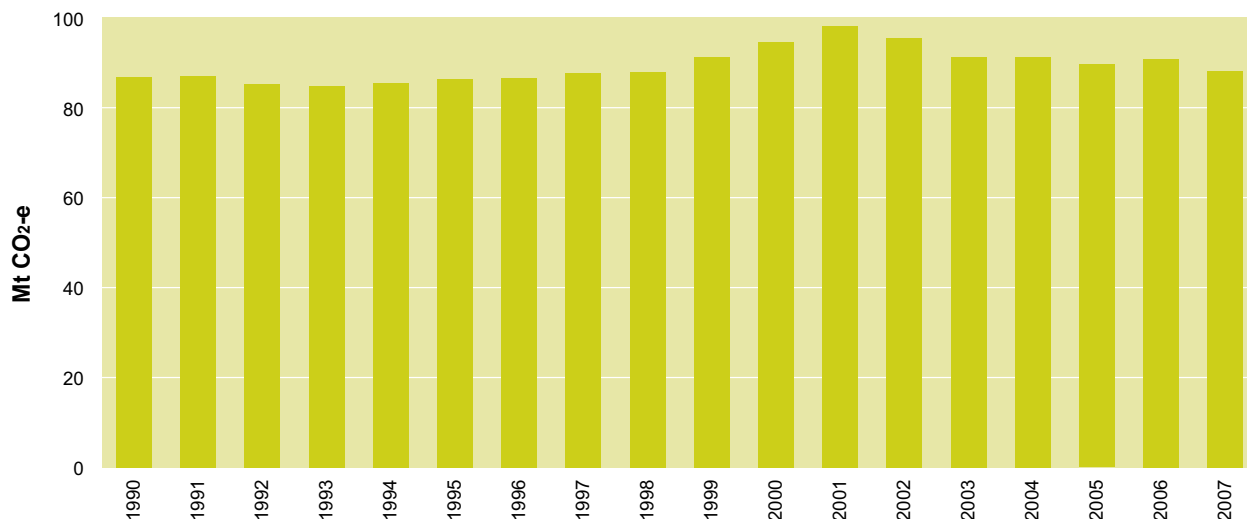
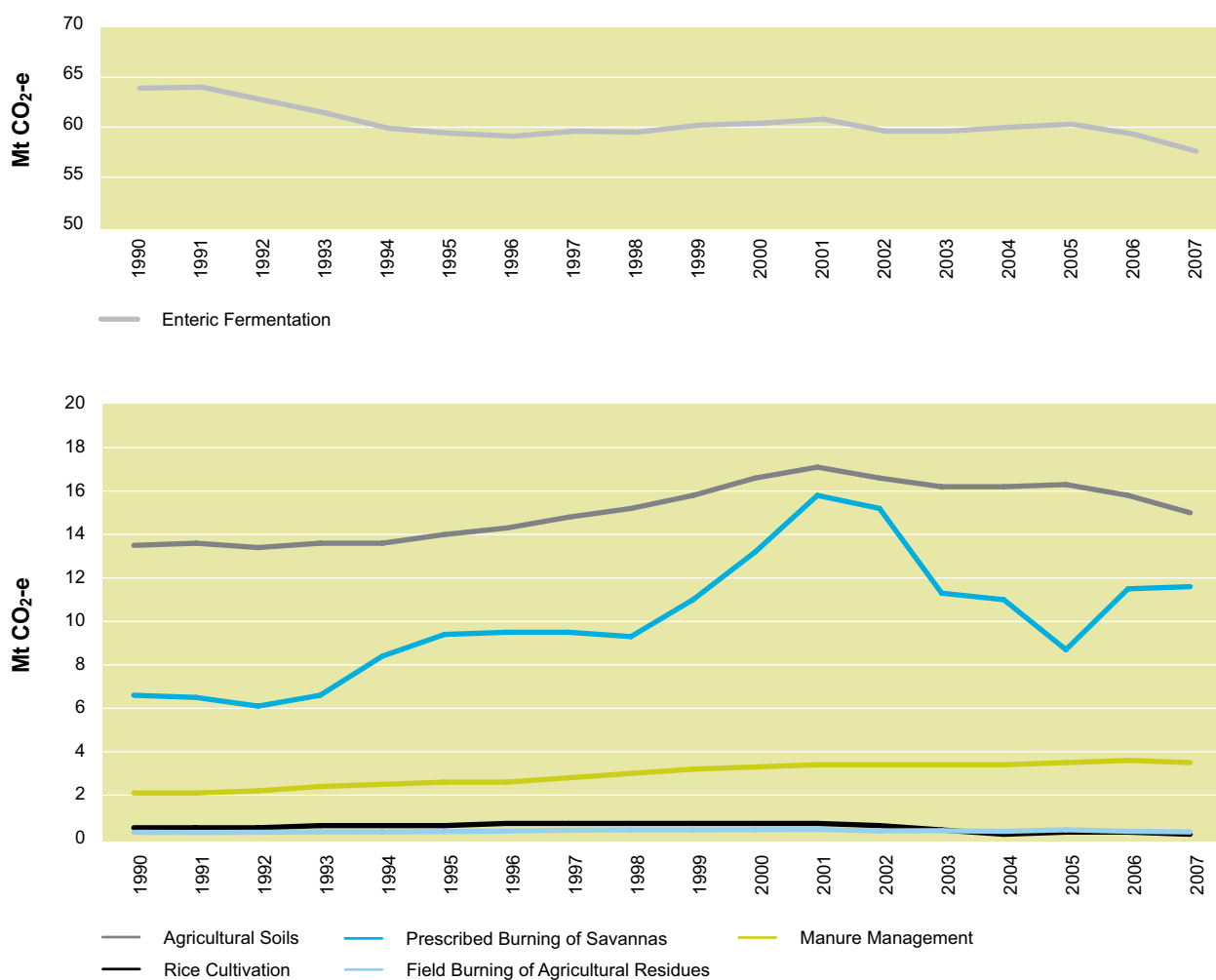


Figure 6.2 CO₂-e emissions from agriculture, by sub-sector 1990–2007



Manure management emissions have actually increased by 67.3% (1.4 Mt) between 1990 and 2007 due to the strong growth in the intensive feedlot cattle industry over this period. *Manure management* emissions declined by 3.9% (0.1 Mt) between 2006 and 2007 reflecting the decline in populations of dairy and feedlot cattle and pigs.

As all rice cultivation in Australia is flood irrigated this industry has been severely affected by the ongoing drought. Emissions from *rice cultivation* in 2007 were 60.0% (0.3 Mt) lower than in 1990 and 25.9% (0.1 Mt) lower than in 2006.

Agricultural soils emissions have increased by 11.2% (1.5 Mt) between 1990 and 2007, but have declined by 5.2% (0.8 Mt) between 2006 and 2007. Since 1990 there has been a significant increase in the use of synthetic fertilisers, and increased retention of crop residues as the sugar cane industry has shifted towards green cane harvesting. The growth in the intensive livestock industries has also led to an increase in the amount of wastes applied to soils. As crop production, animal populations and fertiliser use has reduced during the ongoing drought, emissions have declined since 2006.

Emissions from *prescribed burning of savannas* peaked in 2001 and have declined significantly since then. 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).

The emission from *field burning of agricultural residues* have increased by 5.8% (0.02 Mt) between 1990 and 2007 and decreased by 9.0% (0.03 Mt) between 2006 and 2007.

6.2 Overview of Source Category Description and Methodology – Agriculture

CH₄ and N₂O 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 CH₄, N₂O, 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 emission factors (Table 6.2).

The agriculture inventory is compiled on a State basis to reduce errors associated with averaging input data across areas with large physical and management differences. The State emission totals are then aggregated to give national totals.

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).

6.2.1 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 come from Dairy Australia.

The areas of savanna burnt are largely based on a time series of AVHRR satellite images processed by WA Department of Land Information. The assessments of the area burnt in some areas (particularly for earlier years up to the mid-1990s) are based on field surveys of State and Territory departments with responsibility for managing fires.

Other primary data used in the algorithms (liveweights, liveweight gains, pasture digestibility, savanna fuel loads, combustion emission factors etc) are based on reviews of published data and expert assessments.

Comparison of with international data

The ABS report agricultural data to the Food and Agriculture Organisation (FAO) of the United Nations annually. 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:

- 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;
- 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 6.2a: Summary of methods and emission factors – Agriculture

Greenhouse Gas Source and Sink Categories		CH ₄		N ₂ O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
A Enteric Fermentation					
1	Cattle				
	a. Dairy Cattle	CS, T2	CS		
	b. Free-range Beef Cattle	CS, T2	CS		
	c. Feedlot Cattle	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	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

Greenhouse Gas Source and Sink Categories		CH ₄		N ₂ O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
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			T1	IPCC
	d. Crop Residues			T1	IPCC
	e. Cultivation of Histosols			T1	IPCC
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

Table 6.2b: Reporting of additional gases for agricultural burning

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

6.3 Source Category 4.A Enteric Fermentation

6.3.1 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, CO₂ and CH₄. 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.

6.3.2 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.

6.3.2.1 Cattle (4.A1)

Pasture Fed

It was considered that the approach developed by Blaxter and Clapperton (1965) would be the most appropriate method for estimating methane emissions from pasture fed 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) and Kurihara et al (2006) 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 energy⁸ 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 CH₄ (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 (NRC 1996). 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.

⁸ It should be noted that Blaxter and Clapperton (1965) use a figure for the digestibility of feed energy which is slightly smaller than the dry matter digestibility values used for pasture in Australia. However, there is no consolidated data that will allow conversion to be made between the two digestibility classes

Dairy Cattle

The large volumes of milk produced by dairy cattle under modern management regimes, nearly 5000 litres per annum (see Appendix 6.A8), requires that they 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).

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):

$$I_{ijk} = (1.185 + 0.00454W_{ijk} - 0.0000026W_{ijk}^2 + 0.315LWG_{ijk})^2 \times MR_l + M_{l_{ijk}} \quad (4A.1a_1)$$

Where: W_{ijk} = weight in kg (Appendix 6.A1)

LWG_{ijk} = liveweight gain in kg/day (Appendix 6.A2)

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 (ie. intake of non-lactating animal with liveweight gain is set to zero).

$$L_{ijk} = I_{ijk} / (1.185 + 0.00454W_{ijk} - 0.0000026W_{ijk}^2 + (0.315 \times 0))^2 \quad (4A.1a_4)$$

The percentage of the gross energy intake (GEI_{ijk}) that is yielded as methane (Y_{ijk}) is given by Blaxter and Clapperton (1965) as:

$$Y_{ijk} = 1.3 + 0.112DMD_{ijk} + L_{ijk}(2.37 - 0.050DMD_{ijk}) \quad (4A.1a_5)$$

Where: DMD_{ijk} = digestibility of feed (expressed as a %) (Appendix 6.A3)
 L_{ijk} = intake relative to that needed for maintenance

The total daily production of methane (M_{ijk} kg CH_4 /head/day) is thus:

$$M_{ijk} = Y_{ijk} / 100 \times GEI_{ijk} / F \quad (4A.1a_6)$$

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:

$$E = \sum_{i=1}^7 \sum_{j=1}^3 (365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \sum_{i=2}^7 \sum_{j=4}^5 (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (4A.1a_7)$$

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:

$$I_{ijkl} = (1.185 + 0.00454W_{ijkl} - 0.0000026 W_{ijkl}^2 + 0.315 LWG_{ijkl})^2 \times MA_{ijkl=5} \quad (4A.1b_1)$$

Where: W_{ijkl} = liveweight in kg (Appendix 6.B1)
 LWG_{ijkl} = live weight gain in kg/head/day (Appendix 6.B2)

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 (Appendix 6.B5)

$FA_{ijkl=5}$ = feed adjustment (Appendix 6.B5)

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 (ie. intake of non-lactating animal with liveweight gain is set to zero).

$$L_{ijkl} = I_{ijkl} / (1.185 + 0.00454 W_{ijkl} - 0.0000026 W_{ijkl}^2 + (0.315 \times 0)) \quad (4A.1b_4)$$

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.B3)

L_{ijkl} = feed intake relative to that needed for maintenance

The total daily production of methane (M_{ijkl} , kg CH₄/head/day) for animals on temperate pastures is thus:

$$M_{(i=1-5)(j=1,2,3a,3b,4,5)kl} = Y_{ijkl} / 100 \times GEI_{ijkl} / F \quad (4A.1b_6a)$$

For animals on tropical pastures total daily production of methane (M_{ijkl} , kg CH₄/head/day) is given by Kurihara et al. (1999) and Kurihara et al (2006) as:

$$M_{(i=3,6,7)(j=3c,6,7)kl} = (34.9 \times I_{ijkl} - 30.8) / 1000 \quad (4A.1b_6b)$$

Where: $M_{(i=1-5)(j=1,2,3a,3b,4,5)kl}$ = 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 CH₄ 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 2.1.3.

The approach is represented in the following equation:

$$N_{ijkl} = N_{ijk(l=1, l=2, l=3... l=6, [(l=7) - \text{total feedlot numbers}])} \quad (4A.1b_7)$$

Where: N_{ijkl} = numbers of non-feedlot beef cattle in each State, region, season and class.

$N_{ijk(l=1, l=2, l=3... l=6)}$ = number of cattle in State i , region j , season k and class l .

$(l=7)$ – 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 (G_g) for all classes of beef cattle across all seasons can then be calculated as:

$$E = \sum_i \sum_j \sum_k \sum_l (91.25 \times N_{ijkl} \times M_{ijkl}) \times 10^{-6} \quad (4A.1b_8)$$

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:

$$Y_{ij} = 3.406 + 0.510SR_{ij} + 1.736H_{ij} + 2.648C_{ij} \quad (4A.1c_1)$$

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.C2), the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C3) and the soluble residue, hemicellulose and cellulose fractions of each of these components (Appendix 6.C4).

The total daily production of methane (M_{ij} kg CH_4 /head/day) is thus:

$$M_{ij} = Y_{ij} / F \quad (4A.1c_2)$$

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:

$$E = \sum_i \sum_j (365 \times N_{ij} \times M_{ij}) \times 10^{-6} \quad (4A.1c_3)$$

Where: N_{ij} = numbers of feedlot cattle as an annual equivalent in each class in each State

M_{ij} = methane production (kg/head/day)

6.3.2.2 Sheep (4.A3)

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 (Margan et al. 1985, 1987, 1988 and Graham 1964a,b, 1967, 1969) with sheep fed diets typical of the range found in Australia. 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 ($CH_4 = 0.0187 \times DMI - 0.0003$) to that reported in Howden et al. (1994) ($CH_4 = 0.0188 \times DMI + 0.00158$).

Table 6.6: Symbols used in algorithms for sheep

State (i)	Season (j)	Sheep Classes (k)
		<i>Sheep > 1 year</i>
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		<i>Sheep < 1 year</i>
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:

$$PI_{ijk} = (104.7 q_{m,ijk} + 0.307 W_{ijk} - 15.0) W_{ijk}^{0.75} / 1000 \quad (4A.3_1)$$

Where: W_{ijk} = liveweight (kg) (Appendix 6.D1)

$q_{m,ijk}$ = 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:

$$RI_{ijk} = 1 - \exp(-2(DMA_{ijk})^2) \quad (4A.3_2)$$

Where: DMA_{ijk} = dry matter availability tonnes/hectare (Appendix 6.D3)

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:

$$I_{ijk} = PI_{ijk} \times RI_{ijk} \times MA_{ijk=4} \quad (4A.3_3)$$

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:

$$MA_{ijk=4} = (LE_{ijk=4} \times FA_{ijk=4}) + ((1 - LE_{ijk=4}) \times 1) \quad (4A.3_4)$$

Where: $LE_{ijk=4}$ = proportion of breeding ewes lactating, calculated as the average lambing rates x proportion of lambs receiving milk in each season (Appendix 6.D6)
 $FA_{ijk=4}$ = 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):

$$M_{ijk} = I_{ijk} \times 0.0188 + 0.00158 \quad (4A.3_5)$$

The annual methane production (in Gg) of Australian sheep is calculated as:

$$E = \sum_i \sum_j \sum_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (4A.3_6)$$

Where: N_{ijk} = numbers of sheep in each class for each season and state
 M_{ijk} = methane production (kg/head/day)

6.3.2.3 Pigs (4.A8)

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 CH₄/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.E1)

F = 55.22 MJ/kg CH₄ (Brouwer 1965)

18.6 = MJ GE/kg feed DM

The annual production of methane (Gg) for all classes of pigs is calculated as:

$$E = \sum_i \sum_j (N_{ij} \times M_{ij} \times 365) \times 10^{-6} \quad (4A.8_2)$$

Where: N_{ij} = the number of pigs in each class for each State

M_{ij} = methane production (kg/head/day)

6.3.2.4 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, Aselmann and Seiler (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)

Emission factors for deer, alpacas, emus and ostriches are not provided by IPCC (1997, 2000), so

alternative sources were used. The emission factor 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 emission factors 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 emission factor 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:

$$E = \sum_i \sum_j (N_{ij} \times M_{ij} \times 10^{-6}) \quad (4A.10_1)$$

Where: N_{ij} = numbers of 'other livestock' types in each State
 M_{ij} = methane emission factor (kg/head/year) (Appendix 6.F1)

6.3.7 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.

6.3.8 Source Specific QA/QC

6.3.8.1 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 DCC. 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.

6.3.8.2 Implied Emission Factors

As country specific tier 2 methods are used to estimate emissions from cattle, sheep and pigs, the implied emission factors (IEFs) have been compared with the IPCC defaults (Table 6.9).

The dairy cattle IEF is significantly higher than the 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 4000-5500 kg/head/year. Australia's IEF is more consistent with the default values for the regions with milk production at these levels (100-118 kg/head/year). The non-dairy cattle IEFs differ from the defaults as the methane conversion rates differ to the IPCC defaults (see section 6.3.8.4).

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 (see section 6.3.8.4).

Table 6.9: Implied emission factors – enteric fermentation (kg/head/year)

Livestock Type	Australia	IPCC Default (Oceania)
Dairy Cattle	113	68
Non-dairy cattle		
Range-kept	72	53
Feedlot	77	53
Sheep	6.8	8
Swine	1.45	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:

- 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. The most significant is that there is a step change in the input (average intakes, feed components and liveweight gain) in 1996 (see Appendix 6.c). There is an increase in the amount of concentrates fed post 1996 which leads to lower IEFs. 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 1990 while from the mid 1990's there are only minor shift between markets ($\pm 10\%$).

6.3.8.3 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 overprediction 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 quantity 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.

6.3.8.4 Methane Conversion Rates

As Australia uses country specific methods for estimating methane emissions, methane conversion rates (Y_m) 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 Guidelines 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 Guidelines acknowledge that animals on tropical feeds may have higher methane conversion rates, however the Australian method predicts considerably higher methane yields (10.9%) on tropical feeds than the IPCC defaults (7%). The IPCC (2000, 2006) acknowledges that Y_m values outside the default ranges may occur on tropical pastures and that further research is needed in this area.

Feedlot Cattle

The IPCC Guidelines indicate that animals fed diets containing 90 percent concentrates should use Y_m 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 (1999,2006) 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 Y_m 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 6.3.2.2, independent verification has been undertaken on the emission estimates for sheep.

6.3.8.5 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.

6.3.9 Recalculations Since The 2006 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 standard QC checks identified errors in the 2005 and 2006 'other livestock' activity data which led to a recalculation of the 2004 to 2006 estimates. The net effect of these changes was an increase of 21.7 Gg CO₂-e in the 2006 estimates.

6.3.10 Source Specific Planned Improvements

All data and methodologies are kept under review.

6.4 Source Category 4.B Manure Management

6.4.1 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.

6.4.2 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):

$$\text{DMM}_{ijk} = I_{ijk} \times (1 - \text{DMD}_{ijk})$$

Gonzalez-Avalos and Ruiz-Suarez (2001) do not document emission factors in kg CH₄/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) — 1.4×10^{-5} kg CH₄/kg DM manure

Warm — 5.4×10^{-5} kg CH₄/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 6.11). 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 6.12. The ‘other’ category includes pig manure treated in a digester and poultry manure with and without bedding.

Table 6.11: Symbols and emissions factors used in algorithms for nitrous oxide emissions

Manure Management Systems (MMS)	Emission Factor ^a (kg N ₂ O-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 6.12: 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.Bb)

6.4.2.1 Cattle (4.B1)

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:

$$VS_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times (1 - A) \quad (4B.1a_1)$$

Where: I_{ijk} = dry matter intake calculated in Section 6.3.2.1
 DMD_{ijk} = dry matter digestibility expressed as a fraction (Appendix 6.A3)
 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:

$$M_{ijk} = VS_{ijk} \times B_o \times MCF \times \rho \quad (4B.1a_2)$$

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.A4) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.A5)
 ρ = density of methane ($0.662 kg/m^3$)

The annual methane production (Gg) from the manure of dairy cattle is calculated as:

$$Total = \sum_{i=1,3-7} \sum_j (365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \sum_{i=2} \sum_j \sum_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (4B.1a_3)$$

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)

As dairy calves are usually removed from their mothers very early and are either sold for slaughter or receive a supplement, protein from milk intake was not included in the equation.

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.A3)
 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 retained 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 6.32.1

Z_{ijk} = relative size (liveweight / standard reference weight (Appendix 6.A7))

LWG_{ijk} = liveweight gain (kg/day) (Appendix 6.A2)

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.A1)

The total annual faecal (AF_{jk} Gg) and urinary (AU_{jk} Gg) nitrogen excreted is calculated as:

$$AF_{ijk} = \sum_{i=1,3,7} \sum_j (365 \times N_{ij} \times F_{ij}) \times 10^{-6} + \sum_{i=2} \sum_j \sum_k (91.25 \times N_{ijk} \times F_{ijk}) \times 10^{-6} \quad (4B.1a_8a)$$

$$AU_{ijk} = \sum_{i=1,3,7} \sum_j (365 \times N_{ij} \times U_{ij}) \times 10^{-6} + \sum_{i=2} \sum_j \sum_k (91.25 \times N_{ijk} \times U_{ijk}) \times 10^{-6} \quad (4B.1a_8b)$$

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:

$$Faecal_{MMS} = (AF_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1a_9a)$$

$$Urine_{MMS} = (AU_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1a_9b)$$

$$Total_{MMS} = \sum_i \sum_j \sum_k (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1a_9c)$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems (Appendix 6.A4).

$EF_{(MMS)}$ = 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:

$$\text{Total} = \sum_i \sum_j \sum_k \sum_l (N_{ijkl} \times M_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_2)$$

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.B4)
 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.B5)

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.B3)
 ME_{ijkl} = metabolizable energy - calculated by Minson and McDonald (1987) as:
 ME (MJ/kg DM) = $0.1604 DMD_{ijkl} - 1.037$; (DMD expressed as %).
 I_{ijkl} = feed intake (kg DM/head/day)
 MC_{ijkl} = milk intake (kg/head/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.B5)
 $1/6.25$ = 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 in 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.B5)
 L_{ijkl} = relative intake as calculated in Section 6.3.2.1
 Z_{ijkl} = relative size (liveweight / standard reference weight (Appendix 6.B6))
 LWG_{ijkl} = liveweight gain (kg/day) (Appendix 6.B2)

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.B1)

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:

$$\text{Faecal}_{MMS} = (AF_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8a)$$

$$\text{Urine}_{MMS} = (AU_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8b)$$

$$\text{Total}_{MMS} = \sum_i \sum_j \sum_k \sum_l (\text{Faecal}_{MMS} + \text{Urine}_{MMS}) \quad (4B.1b_8c)$$

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 2% 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:

$$VS_{ij} = I_{ij} \times (1 - DMD_{ij}) \times (1 - A) \quad (4B.1c_1)$$

Where: I_{ij} = dry matter intake (Appendix 6.C2)

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:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad (4B.1c_2)$$

Where: B_o = emissions potential - 0.17m³ CH₄/kg VS (IPCC 1997)

MCF = methane conversion factor - Drylot MCF values for 'warm' regions for Queensland and the Northern Territory (5%) and MCF values for 'temperate' regions for all other States (1.5%).

ρ = density of methane (0.662 kg/m³)

The annual methane production (Gg) from the manure of beef cattle in feedlots is calculated as:

$$E = \sum_{ij} (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad (4B.1c_3)$$

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:

$$CPI_{ij} = NI_{ij} \times 6.25 \quad (4B.1c_4)$$

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.C2) of the animals as the proportion of the diet that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C3) and the nitrogen fraction of each of these components (Appendix 6.C4).

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:

$$F_{ij} = \{0.3(CPI_{ij} \times (1 - [(DMD_{ij} + 10)/100])) + 0.105(ME_{ij} \times I_{ij} \times 0.008) + 0.0152 \times I_{ij}\} / 6.25 \quad (4B.1c_5)$$

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.C1)

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:

$$NR_{ij} = \{[0.212 - 0.008(L_{ij} - 2) - \{(0.140 - 0.008(L_{ij} - 2)) / (1 + \exp(-6(Z_{ij} - 0.4)))\}] \times (LWG_{ij} \times 0.92)\} / 6.25 \quad (4B.1c_6)$$

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/standard reference weight - Appendix 6.C5 - steers >1)

LWG_{ij} = liveweight gain (Appendix 6.C5)

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:

$$U_{ij} = (CPI_{ij} / 6.25) - NR_{ij} - F_{ij} - [(1.1 \times 10^{-4} \times W_{ij}^{0.75}) / 6.25] \quad (4B.1c_7)$$

Where: W_{ij} = liveweight (Appendix 6.C1)

The total annual faecal (AF_{ij} Gg) and urinary (AU_{ij} Gg) nitrogen excreted is calculated as:

$$AF_{ij} = (N_{ij} \times F_{ij} \times 365) \times 10^{-6} \quad (4B.1c_8a)$$

$$AU_{ij} = (N_{ij} \times U_{ij} \times 365) \times 10^{-6} \quad (4B.1c_8b)$$

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:

$$Faecal_{MMS} = (AF_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad (4B.1c_9a)$$

$$Urine_{MMS} = (AU_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad (4B.1c_9b)$$

$$E_{MMS} = \sum_i \sum_j (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1c_9c)$$

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 6.11)

$Cg = 44/28$ factor to convert elemental mass of N_2O to molecular mass

6.4.2.2 Sheep (4.B3)

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:

$$Total = \sum_i \sum_j \sum_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_2)$$

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.D4)

MC_{ijk} = milk intake (kg/head/day) – calculated as proportion of lambs receiving milk in each season x milk intake (Appendix 6.D6). 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.D2)

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.D6). 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:

$$NR_{ijk} = \{(0.045 \times MP_{ijk}) + (WP_{ijk} \times 0.84) + \{[(212 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) - (140 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) / \{1 + \exp(-6(Z_{ijk} - 0.4))\}) \times EBG_{ijk} / 1000\} / 6.25 \quad (4B.3_5)$$

Where: MP_{ijk} = milk production in kg/day - calculated as: proportion of ewes lactating (LE_{ijk}) x milk production (Appendix 6.D6). 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 $LWG_{ijk} \times 0.92$

SRW_{ijk} = standard reference weight (SCA 1990) in Appendix 6.D7

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:

$$\text{Faecal}_{\text{MMS}} = (\text{AF}_{ijk} \times \text{MMS} \times \text{EF}_{(\text{MMS})} \times \text{C}_g) \quad (4\text{B.3_8a})$$

$$\text{Urine}_{\text{MMS}} = (\text{AU}_{ijk} \times \text{MMS} \times \text{EF}_{(\text{MMS})} \times \text{C}_g) \quad (4\text{B.3_9b})$$

$$\text{E}_{\text{MMS}} = \sum_i \sum_j \sum_k (\text{Faecal}_{\text{MMS}} + \text{Urine}_{\text{MMS}}) \quad (4\text{B.3_10c})$$

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 (N₂O-N kg/ N excreted) for the different manure management systems (Table 6.11)

C_g = 44/28 factor to convert elemental mass of N₂O to molecular mass

6.4.2.3 Pigs (4.B8)

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 I).

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 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:

$$\text{M}_{ij} = \text{VS}_{ij} \times \text{B}_o \times \text{MCF} \times \rho \quad (4\text{B.8_1})$$

Where: VS_{ij} = volatile solids production (kg/head/day) = (Appendix 6.E2)

B_o = emissions potential - 0.45m³ CH₄/kg VS (IPCC 1997)

MCF = integrated methane conversion factor - based on the proportion of different manure management regimes (Appendix 6.E3) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.E4).

ρ = density of methane (0.662 kg/m₃)

The annual methane production (Gg) from the wastes of Australian pigs is calculated as:

$$\text{E} = \sum_i \sum_j (365 \times \text{N}_{ij} \times \text{M}_{ij} \times 10^{-6}) \quad (4\text{B.8_2})$$

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:

$$AE_{ij} = N_{ij} \times E_{ij} \times 10^{-6} \quad (4B.8_3)$$

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.E5)

The total emissions of nitrous oxide from the different manure management systems (E_{MMS} Gg) can then be calculated as follows:

$$E_{MMS} = \sum_i \sum_j (AE_{ij} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.8_4)$$

Where: MMS = the fraction of AE that is managed in the different manure management systems (Appendix 6.E3).
 $EF_{(MMS)}$ = 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

6.4.2.4 Other Livestock (Including 4.B2, 4, 5, 6, 7, 9, and 10)

Methane

Poultry

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:

$$VS_{ij} = I_{ij} \times (1 - DMD_{ij}) \times (1 - A) \quad (4B.10_1)$$

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:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad (4B.10_2)$$

Where: B_o = emission potential - $0.32m^3 CH_4/kg$ VS (IPCC 1997)
 MCF = methane conversion factor - as defined by IPCC (1997) use MCF values for 'warm' regions for Queensland and the Northern Territory (2%) and MCF values for 'temperate' regions 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:

$$E = \sum_i \sum_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad (4B.10_3)$$

Where: N_{ij} = numbers of all types of poultry
 M_{ij} = methane production (kg/head/day)

Other Livestock

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) were some multiple of those calculated for either sheep or beef cattle.

- 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:

$$M_{ijk} = DMM_{ij} \times MEF \quad (4B.3_1)$$

Where: DMM_{ij} = dry matter in manure Appendix 6.F3

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:

$$Total = \sum_i \sum_j (N_{ij} \times M_{ij}) \times 10^{-6} \quad (4B.3_2)$$

Where: N_{ij} = numbers of animals in each State

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 (NRC 1994), 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 (eg. turkeys and ducks) are assumed to be the same as for meat chickens.

Little is known about the nitrogen intake and nitrogen excretion rates of the remaining livestock types in this group. In the absence of adequate information, it was assumed that the rates of nitrogen excretion (E_{ij} kg/head/year) were some multiple of those calculated for either sheep or beef cattle.

- 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)
- 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:

$$AE_{ij} = (N_{ij} \times E_{ij}) \times 10^{-6} \quad (4B.10_4)$$

Where: N_{ij} = numbers in each State

E_{ij} = nitrogen excreted (kg/head/year) (Appendix 6.F2)

The total emissions of nitrous oxide from the different manure management systems (E_{MMS} Gg) can then be calculated as follows:

$$E_{\text{MMS}} = \sum_i \sum_j (AE_{ij} \times \text{MMS} \times EF_{(\text{MMS})} \times C_g) \quad (4\text{B.10_5})$$

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.
 $EF_{(\text{MMS})}$ = emission factor ($\text{N}_2\text{O-N}$ 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

6.4.3 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.

6.4.4 Source Specific QA/QC

6.4.4.1 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 DCC. 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.

6.4.4.2 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 implied emission factors (IEFs) have been compared with the IPCC defaults (Table 6.13).

Table 6.13: 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	2.86	6.7	Different waste allocation
Sheep	0.002	0.28-0.37	CS EF
Swine	23	20	Inclusion of waste feed
Poultry	0.02	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: 1) 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.; 2) for temperate regions Australia uses a slightly lower MCF for pasture/range than the IPCC default (1% vs 1.5%); and 3) average volatile solid production is lower than the IPCC default (see section 6.4.4.3).

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 emission factor is used (see section 6.4.2).

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.

6.4.4.3 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 6.14). The volatile solids 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 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 6.14: 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.

6.4.4.4 Nitrogen excretion

The country specific estimates of nitrogen excretion were compared against the IPCC defaults (Table 6.15) 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 using 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 6.15: Nitrogen Excretion Rates (kg/head/year)

	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

6.4.4.5 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.

6.4.5 Recalculations Since The 2006 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, standard QC checks identified errors in the 2005 and 2006 'other livestock' activity data which led to a recalculation of the 2004 to 2006 estimates. The net effect of these changes was an increase of 29.1 Gg CO₂-e in the 2006 estimate.

6.4.6 Source Specific Planned Improvements

All data and methodologies are kept under review.

6.5 Source Category 4.C Rice Cultivation

6.5.1 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. Australian rice culture does not have the large inputs of organic matter as rice stubble is usually burnt and mineral fertilisers are used rather than manures.

6.5.2 Methodology

For the purpose of estimating the emission rate of CH₄ from rice grown in Australia, the extensive data compilation of field measurements of CH₄ 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, personal communication).

The range of 0.5 to 5.5 kg CH₄/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 CH₄ emissions from rice in Australia. A seasonally weighted average of this data of 1.5 kg CH₄/ha/day or 225 kg CH₄/ha for the 150 day growing season has been selected as the appropriate average emission rate for Australia.

Table 6.16: 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 CH₄/ha).

6.5.3 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.

6.5.4 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 DCC. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.5.5 Recalculations Since The 2006 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, standard QC checks identified a typographic error in the 2006 activity data. The net effect of these changes as an increase of 0.3 Gg CO₂-e in the 2006 estimates.

6.5.6 Planned Improvements

All data and methodologies are kept under review.

6.6 Source Category 4.D Agricultural Soils

6.6.1 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:

1. the application of inorganic fertilisers
2. the application of animal wastes to pastures
3. biological nitrogen fixation
4. the application of crop residues
5. mineralisation due to cultivation of organic soils
6. atmospheric nitrogen deposition
7. leaching of inorganic nitrogen and subsequent denitrification in rivers and estuaries.

The IPCC (2000) also indicates that application of sewage sludge to agricultural soils can be included if sufficient information is available. Application of untreated sewage sludge is not permitted in Australia. Although application of biosolids (sludge which has undergone treatment) does occur the amounts are believed to be small as application is restricted due to health concerns. Further analysis of this source is being undertaken.

6.6.2 Methodology

6.6.2.1 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) 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/ha N 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 emission factor of 1.25% across different classes of crop and pasture systems. Variation in emission factor with region and cropping system is to be expected. For example, much of Australia's cereal production is in low-rainfall regions (<600 mm annual rainfall) with porous soils where 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 N₂O emission rates. Finally, it is now becoming more apparent that emission factors often increase with the nitrogen application rate

and high emission factors occur when application rates and timing produce soil nitrate concentration substantially in excess of plant demand.

A recent series of coordinated studies undertaken by the Cooperative Research Centre for Greenhouse Accounting (Galbally et al. 2005) has specifically addressed these issues and has established a set of emission factors suitable for Australian agricultural systems. These are summarised in Table 6.17. It is recommended by the IPCC that when reliable local emission factors are available, these should be used in the preparation of national inventories.

Table 6.17: N₂O emission factors from four agricultural systems in Australia

Site	Crop	Treatment ^a	EF(%)
Griffith, NSW	Irrigated maize	Stubble burning 300N	2.8
		Stubble retention 300N	1.6
Kyabram, VIC	Irrigated dairy pasture	Urine 1000N	0.4-0.5
		Urea 150N	0.4-0.5
Rutherglen, VIC	Rainfed wheat	Conventional cultivation 83N/ Direct drilling 83N	0.05-0.1
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⁻¹ are listed with the treatments.

Source: Galbally et al. (2005).

Irrigated crops, particularly summer crops (eg. 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 emission factor 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 (Galbally et al. 1994; 2005). Since the nitrogen content of urine is principally urea there is typically little difference between losses of N₂O from synthetic or animal-source urea (Table 6.17). 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 emission factors have been reported from well drained silty loam soils in New Zealand (de Klein et al. 2004) where the agricultural practices are similar to Australia.

Average nitrogen application rates for cotton are 200 kg N/ha, therefore an emission factor of 0.5 is considered to be a conservative estimate, based on the ranged presented in Table 6.17, and is used to estimate emissions.

Weier (1999) reported some 15N tracer measurements of N₂O emissions from sugar cane production. He estimated that between 0.06% and 0.28% of synthetic nitrogen applied at a rate of 160 kg/ha was emitted as N₂O, or an average of 0.15%. However this loss was additional to a substantial background emission of 14N₂O. Taking the worst case in which the total background N₂O emission to be the result of residual fertiliser N from previous crops, the overall emission rate was 0.7% of applied N. Some further Australian studies are in progress, and therefore, in the interim, the IPCC default EF of 1.25% to estimate emissions from sugar cane is retained.

The majority of Australian grain production is from rain-fed cultivation in relatively low rainfall areas where denitrification potential is low. The current studies of rain-fed wheat in dryland regions of Australia at Rutherglen in Victoria (Table 6.17), and preliminary analyses from dryland wheat experiments in Western Australia indicate extremely low emission factors of 0.1. 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 this low EF is applicable. To date there are no published EFs in the more temperate regions, where, based on European and North American experience, higher EFs are expected to occur. In the absence of comprehensive measurements the IPCC default EF (1.25%) is probably a reasonable estimate for these higher rainfall areas. Weighting these emissions factors by the area of rain-fed cropping in dryland areas yields the national average emission factor of 0.3%.

The emission factors used in the inventory are summarised in Table 6.19

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 from the production areas and the average fertiliser application rates for each of these crops, and then distributing the balance of fertiliser use to rain-fed crops and non-dryland pastures in proportion to their respective areas. The fertiliser application rates assigned to irrigated crops, irrigated pastures, cotton, sugar cane and horticultural crops and vegetables are respectively 80 kg N/ha, 40 kg N/ha, 200 kg N/ha, 200 kg N/ha and 125 kg N/ha.

Table 6.18: 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/vegetables
8 = ACT		

Table 6.19: Nitrous oxide emissions factors for synthetic fertiliser

Production System	Emission Factor (Gg N ₂ O-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/vegetables	0.021

Note: 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)

The mass of fertiliser applied to soils is calculated as

$$M_{ijk} = TM_{ij} \times FN_{ijk} \quad (4D1_1)$$

Where: M_{ijk} = Mass of fertiliser applied to production system k (Gg N)

TM_{ij} = 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:

$$E_{ijk} = \sum_i \sum_j \sum_k (M_{ijk} \times EF_{ijk} \times C_g) \quad (4D1_2)$$

Where: E_{ijk} = annual emissions from fertiliser (Gg N_2O)

M_{ijk} = mass of fertiliser in production system k applied (Gg N)

EF_{ijk} = emission factor (Gg N_2O -N/Gg N applied) (Table 6.19)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.6.2.2 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 emission factor 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 6.20) 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 emission factor 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 6.4.

Table 6.20: 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	
<i>Cattle slurry</i>	0.25	0.04 - 0.57
<i>Pig slurry</i>	0.45	0.17 - 0.95
<i>Poultry litter</i>	0.50	0.50 - 0.50

Source: Bouwman et al. 2002

Table 6.21: 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:

$$MN\ Soil = \sum_{MMS=1-7} ((AE_{ij} \times MMS_{=1-7}) - (E_{MMS=1-7} / C_g) - MNatmos_{iMMS=1-7}) \quad (4D1_3)$$

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

$E_{MMS=1-7}$ = total emissions of nitrous oxide from the different manure management systems as estimated in section 6.4

MN_{atmos_mms} = mass of animal wastes N volatilised as calculated in section 6.6.2.7 Atmospheric deposition

Annual nitrous oxide production is calculated as:

$$E_{ijk} = \sum_i \sum_j \sum_k (MN\ Soil_{ijk} \times EF_j \times C_g) \quad (4D1_4)$$

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

6.6.2.3 Nitrogen Fixing Crops

The default IPCC *Tier 1* methodology is used to estimate emissions from N fixing crops and pastures.

Table 6.22: 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:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \quad (4D1_5)$$

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:

$$E_j = \sum_i \sum_k (M_{ijk} \times EF_j \times C_g) \quad (4D1_6)$$

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

6.6.2.4 Crop Residues

The default IPCC *Tier 1* methodology is used to estimate emissions from crop residues returned to the soil.

Table 6.23: 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:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \times (1 - F_{ik} - FFOD_{ik}) \quad (4D1_7)$$

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)
 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:

$$E_j = \sum_i \sum_k (M_{ijk} \times EF_j \times C_g) \quad (4D1_8)$$

Where: E_j = annual emissions from N fixing crops (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

6.6.2.5 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. The issue is currently under review.

Table 6.24: 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:

$$E_j = \sum_i (A_{ij} \times EF_{ij} \times C_g \times 10^{-6}) \quad (4D1_9)$$

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

6.6.2.6 Animal Production

Nitrous oxide is emitted from soil through the metabolism of urine and faeces deposited directly on pastures. The current IPCC default emission factor 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 6.23 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), as discussed above.

Table 6.25: 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, emission factors of 0.005 and 0.004 Gg N₂O-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 6.4.

Table 6.26: Symbols used in algorithms for animal wastes

State (i)	Activity (j)	Subset (k)	Manure Management Systems (MMS)
1 = NSW	1 = urine excreted on pastures	1 = dairy cattle	1 = Anaerobic lagoon
2 = TAS	2 = faeces excreted on pastures	2 = beef cattle	2 = Liquid systems
3 = WA		3 = sheep	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 N₂O, NH₃ and NO_x during storage in the different manure management systems.

Thus the faecal and urinary nitrogen excreted on pasture range and paddock (4D2) is calculated as:

FN Soil = $\sum_{MMS=8} (AF_{ij} \times MMS_{=8})$	(4D2_1)
UN Soil = $\sum_{MMS=8} (AU_{ij} \times MMS_{=8})$	(4D2_2)

Where: AF and AU = mass of faecal and urinary nitrogen excreted as calculated in section 6.4. For the 'other livestock' class category AF is calculated as AE x PMF and AU is calculated as AE x PMU.

MMS = the fraction of nitrogen that is managed in the different manure management systems.

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:

$E_{ijk} = \sum_i \sum_j \sum_k ((FN\ Soil_{ijk} \times EF_j \times C_g) + (UN\ Soil_{ijk} \times EF_j \times C_g))$	(4D2_3)
--	---------

Where: E_{ijk} = annual emission from animal waste (Gg N₂O)

EF_j = emission factor (Gg N₂O-N/Gg N deposited)

C_g = 44/28 factor to convert elemental mass of N₂O to molecular mass

6.6.2.7 Atmospheric Deposition

The default IPCC *Tier 1* methodology is used to estimate emissions from the atmospheric deposition.

Table 6.27: 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		
6 = QLD		
7 = NT		
8 = ACT		

The mass of N fertiliser volatilised is calculated as:

$$M_{ijk=1} = TM_{ijk=1} \times \text{FracGASF}_j \quad (4D3_1)$$

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 NOx -N.

The mass of animal waste volatilised is calculated as:

$$M_{ijk=2} = \sum_{\text{MMS}} (\text{AE} \times \text{MMS} \times \text{FracGASM}_{\text{MMS}}) \quad (4D3_2)$$

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.
 $\text{FracGASM}_{\text{MMS}}$ = the fraction of N volatilised in each manure management systems (Table 6.28).

Table 6.28: 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

The mass of savanna burning and field burning of agricultural residue NO_x -N emissions that volatilise is calculated as:

$$M_{ijk=3,4} = (E_{ik=3,4} / (46/14)) \quad (4D3_3)$$

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 6.7 and 6.8
 $46/14$ = factor to convert elemental mass of NO_x to molecular mass

Annual nitrous oxide production from atmospheric deposition is calculated as:

$$E = \sum_i \sum_k (M_{ijk} \times EF_{ijk} \times C_g) \quad (4D3_4)$$

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 $\text{N}_2\text{O-N/Gg N}$) IPCC default emission factor
 C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.6.2.8 Leaching And Runoff

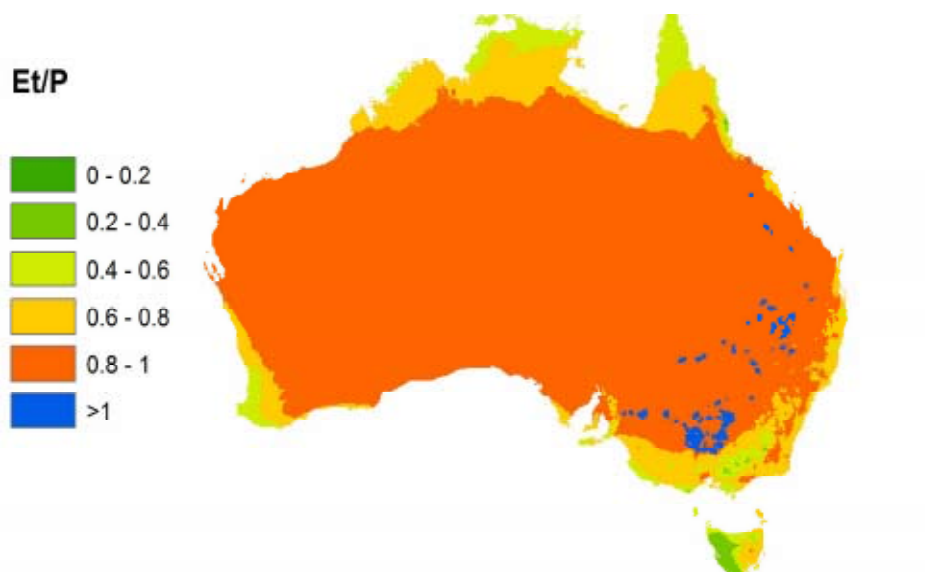
Australia is the driest continent, with substantially less runoff than all other continents. In Australia, much of the cropping takes place in semi-arid regions, or regions of marginal rainfall. The revised 1996 IPCC methodology makes no allowance for reduced rates of leaching in regions of low rainfall 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 accounts 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 $\text{Et/P} < 0.8$ or $\text{Et/P} > 1$ (Figure 6.3). 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)



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 N₂O-N/kg N (Reay et al. 2004, Sawamoto et al. 2005). Therefore, the emission factor has been changed from the IPCC default of 0.025 to 0.0125 kg N₂O-N/kg N leached/runoff as recommended in the 2006 IPCC Guidelines (IPCC 2006).

Table 6.29: 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		
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:

$$M_{ijk=1} = M_{ik} \times \text{FracWET}_{ik} \times \text{FracLEACH}_j \quad (4D3_5)$$

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.J1)

$\text{FracLEACH}_j = 0.3$ (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:

$$M_{ijk=2} = (MNsoil_{ik} + UNsoil_{ik} + FNsoil_{ik}) \times \text{FracWET}_{ik} \times \text{FracLEACH}_j \quad (4D3_6)$$

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 6.6.2.2 Animal Wastes Applied to Soils
 $UNsoil_{ik}$ = mass of urinary N applied to soils (Gg N) as calculated in the section 6.6.2.6 Animal Production
 $FNsoil_{ik}$ = mass of faecal N applied to soils (Gg N) as calculated in the section 6.6.2.6 Animal Production
 FracWET_{ik} = fraction of N available for leaching and runoff (Appendix 6.J2)
 $\text{FracLEACH}_j = 0.3$ (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:

$$E = \sum_i \sum_k (M_{ijk} \times EF_{ijk} \times C_g) \quad (4D3_7)$$

Where: E = annual emissions from leaching and runoff (Gg N_2O)
 M_{ijk} = mass of N lost through leaching and runoff (Gg N)
 $EF_{ijk} = 0.0125$ (Gg N_2O -N/Gg N)
 $C_g = 44/28$ factor to convert elemental mass of N_2O to molecular mass

6.6.3 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.

6.6.4 Source Specific QA/QC

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 DCC.

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.

6.6.5 Recalculations Since The 2006 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. Preliminary 2006 production estimates for some of the minor crop types were replaced with the final ABS estimates. In addition the fraction of N fertiliser applied to different production systems for 2006 has been updated using the land area data from the 2006 ABS census. Atmospheric deposition was also recalculated due to changes in the savanna burning activity data for 1997 and 2006. The net effect of these changes was an increase of 621.6 Gg CO_2 -e in the 2006 estimate.

6.6.6 Planned Improvements

All data and methodologies are kept under review.

6.7 Source Category 4.E Prescribed Burning of Savannas

6.7.1 Source category description

Savanna burning is a key source of CH₄ and N₂O and is an important source of CO, NO_x and NMVOCs. As per the IPCC Guidelines (IPCC, 1997) the CO₂ emissions from savanna burning are not included in the inventory since it is assumed that an equivalent amount of CO₂ is removed by regrowing vegetation in the following year.

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 38000 BP (Singh et al. 1981).

It should not be assumed that stopping anthropogenic fires would lead to a reduction in greenhouse gas emissions, because they would be replaced by natural wildfires. In many cases it is impossible to determine whether a fire has been deliberately lit or is the result of a natural ignition process such as a lightning strike. As recommended by the IPCC (1997) all fires in Australian savannas and temperate grasslands are included in the inventory.

6.7.2 Methodology

Stratification of Savanna Types

The inventory methodology stratifies the savanna regions of the Northern Territory (NT) and Western Australia (WA) into two broad vegetation classes of woodlands and grasslands. These are defined in terms of the agroecological zones (AEZs) of the Interim Biogeographic Regionalisation for Australia (IBRA)⁹ version 4.1.

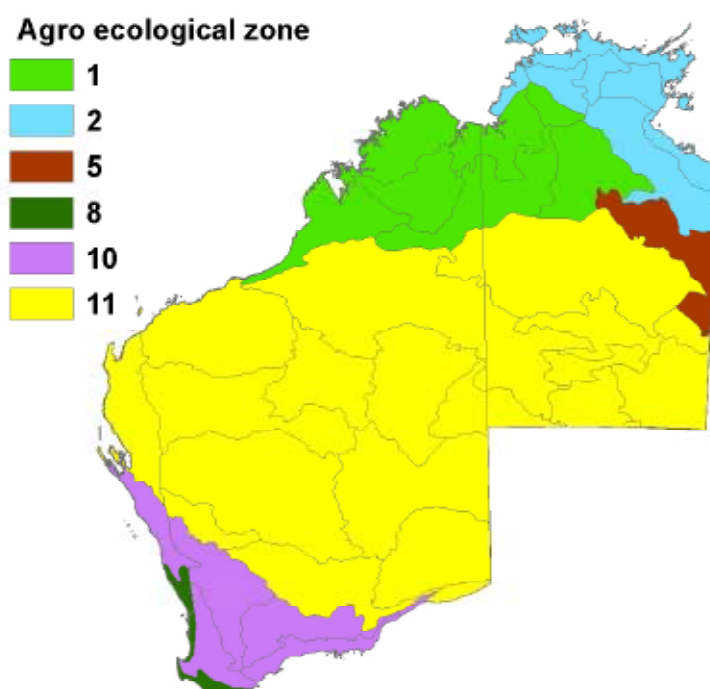
The 11 AEZs are an aggregation of the IBRA regions based mainly on rainfall, soils and climatic conditions, and are used to help identify key land and vegetation management issues at a regional level. The inventory methodology uses groupings of the AEZs as a proxy for classifying regions as grassland or woodland.

The northern part of the NT and WA 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 and AEZ 2, which are predominantly woodland with smaller areas of open forest and grassland (these are under similar management to the surrounding woodland and are not distinguished in this analysis). The inventory methodology uses these two zones as its definition of savanna woodlands. The savanna grasslands of the arid interior of central Australia (‘the Centre’) comprise AEZ 5 and AEZ 11 of the NT and WA, and these zones are used as the inventory definition of grassland. The higher rainfall south-western corner of WA is not classified as savanna, and makes up the remainder of the state (AEZ 8 and AEZ 10). These zones are shown in Figure 6.4.

Savannas in Queensland have not been stratified at this time. All savanna fires are currently reported under the savanna grassland category.

⁹ IBRA is a framework used for sustainable resource management and conservation planning. The 80 IBRA regions 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

Figure 6.4: Agroecological zones of NT and WA from IBRA 4.1



Area Burnt

Prior to 1998 the areas of savanna burning for the NT and WA were obtained from a mix of regional fire authority data based on local records or the expert judgment of district officers and high resolution AVHRR satellite imagery. Since 1998 the Western Australian Department of Land Administration (DOLA) has mapped fires for Queensland, Northern Territory, Western Australia and South Australia using the AVHRR imagery

Together the NT and WA jurisdictions make up approximately 80% of the total area of savannas burnt nationally. To improve the time-series for these States, Meyer (2004) supplementing the fire areas measured by regional fire authorities with statistically predicted areas based on rainfall. Regressions on rainfall over the preceding two years were used to predict fire areas for the Northern Territory for 1989 and 1993–1996, and for Western Australia for 1989 and 1993.

With a spatial resolution of 100 hectares, AVHRR imagery provides a major improvement to the reliability of fire data in northern Australia. Firescars are mapped at a resolution of 400 hectares, i.e. 4 pixels. In the southern states (New South Wales, Tasmania and Victoria), however, the areas of individual grass fires are frequently less than 100 hectares and, therefore, statistics recorded by the State fire authorities continue to form the basis of estimates.

Table 6.30: Source of data on area of savanna and temperate grassland burnt

State	ACT, NSW, TAS, VIC	QLD	SA	NT	WA
1989	State agencies	State agencies	State agencies	Meyer 2004	Meyer 2004
1990	State agencies	State agencies	State agencies	AVHRR	AVHRR
1991	State agencies	State agencies	State agencies	AVHRR	AVHRR
1992	State agencies	State agencies	State agencies	AVHRR	AVHRR
1993	State agencies	State agencies	State agencies	Meyer 2004	Meyer 2004
1994–1996	State agencies	State agencies	State agencies	Meyer 2004	AVHRR
1997	State agencies	State agencies	State agencies	AVHRR	AVHRR
1998 +	State agencies	AVHRR	AVHRR	AVHRR	AVHRR

Fuel Loads and Burning Efficiencies

Fuel loads and burning efficiencies are assumed to be constant from year to year and throughout the year, that is, for early, mid and late fire seasons.

When fuel loads are relatively constant throughout the year, emissions can be estimated from annual total areas of savanna and grassland burnt. However in tropical savannas, there are large changes in the amount of grass fuels as the grasses develop, mature and dry through the growing season and the following dry season. Hence the best method for calculating annual emissions from tropical savannas, is to sum the emissions from each fire, taking into account the actual fuel load at the time of the fire. Currently, there is insufficient data to permit this approach.

Temperate grasslands such as the button grass communities in Tasmania and the grasslands in semi-arid Australia do not have such large seasonal variation in standing biomass and fine fuels, and hence emission estimates calculated using the total area of grassland burnt annually are appropriate.

Estimates of fuel loads for the savanna woodlands and grasslands in the NT and WA are drawn from the field measurements in a number of recent studies on grasslands and rangelands (Carter *et al.*, 2000, Dyer *et al.*, 2001, and Carter and Henry, 2003) and from a recently completed study on woodlands in Arnhem Land in the NT (Russell-Smith *et al.*, 2004). Fuel loads in the savanna regions and temperate grassland regions in the remaining States and Territories (ACT, NSW, Queensland, South Australia, Tasmania and Victoria) are based on values in the scientific literature or the experience of State government experts (see Table 29).

The inventory uses separate burning efficiency estimates for savanna grasslands and for woodlands derived from Russell-Smith *et al.* (2004) and Price *et al.* (2003). The inventory estimates are shown in Table 30. Meyer (2004) describes the specific derivations of these estimates from the results of Russell-Smith *et al.* (2004) and Price *et al.* (2003). The inventory estimate of burning efficiency for the temperate grasslands of 0.72 was provided by Tolhurst (1994) based on work on grassland in Victoria and the NT.

Table 6.31: Savanna and temperate grassland fuel loads

State	ACT ^(a)	NSW ^(b)	NT ^(c)	QLD ^(d)	SA ^(a)	TAS ^(e)	VIC ^(b)	WA ^(c)
FL _{ij} (Mg/ha)								
Temperate Grassland	11.1	6.9	NO	NO	3.0	9.0	11.7	NO
Savanna Grassland	NO	NO	3.0	3.0	NO	NO	NO	3.0
Savanna Woodland	NO	NO	12.7	NE	NO	NO	NO	12.7

Source: a) Tolhurst (1994); b) Chatto (1997); c) Meyer (2004); d) Carter *et al.* (2000), Dyer *et al.* (2001), Carter and Henry (2003); e) Marsden-Smedley and Catchpole (1995a, b)

Table 6.32: Savanna and temperate grassland burning efficiencies

	Burning Efficiency Z_{ij}
Temperate Grassland ^(a)	0.72
Savanna Grassland ^(b)	0.76
Savanna Woodland ^(b)	0.40

Source: a) Tolhurst (1994); b) Meyer (2004)

Composition of Biomass and Emission Factors

Composition of Biomass

Inventory estimates of the composition of the biomass, i.e. the carbon mass fraction and the nitrogen to carbon ratio, are based on measurements from fires in Australia (Hurst et al. 1994a,b, Henry and Carter 2003, and Russell-Smith et al. 2004).

Meyer (2004) assessed work on Queensland pastures (Henry and Carter 2003) and data for grass fuels in the Northern Territory (Hurst et al., 1994a, and Russell-Smith et al., 2004) and recommended a N:C ratio of 0.012 for temperate and savanna grasslands. Based on studies of woody fuels (Hurst et al. 1994a,b, and Russell-Smith et al. 2004) Meyer (2004) recommended a N:C ratio of 0.011 for savanna woodlands.

Table 6.33: C mass fraction and N – C ratios for savanna and temperate grassland

Carbon mass fraction in dry residue ^(a) CC_{ij}	Nitrogen to carbon ratio ^(b) NC_{ij}	
	Savanna and Temperate Grasslands	Savanna Woodlands
0.46	0.012	0.011

Source: a) Hurst et al. (1994 a, b); b) Meyer (2004)

Emission Factors

The emission factors used in the Australian methodology are derived from direct measurement of fire plumes from experimental savanna fires in the Northern Territory (Hurst et al., 1994a,b). The Australian factors are encompassed by those reported for other continents in the international literature (Andreae et al., 1996) although the factor for NO_x is outside the current range specified in the IPCC guidelines (IPCC, 1997).

Table 6.34: Savanna and temperate grassland burning – emission factors

Gas species	Emission factor ^(a) EF_{ij} (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	0.21	46/14
4. CO	0.078	28/12
5. NMVOC	0.0091	14/12

Source: a) Hurst et al. (1994 a, b)

Table 6.35: Symbols used in algorithms for savanna and temperate grassland burning

State (i)	Activity (j)
1 = NSW	1 = savanna woodland (NT, WA)
2 = TAS	2 = savanna grassland (NT, QLD, WA)
3 = WA	3 = temperate grassland (ACT, NSW, TAS, SA, VIC)
4 = SA	
5 = VIC	
6 = QLD	
7 = NT	
8 = ACT	

For each State, calculate the total mass burnt as:

$$M_{ij} = A_{ij} \times FL_{ij} \times Z_{ij} \times 10^{-3} \quad (4E_1)$$

Where: M_{ij} = mass of fuel burnt in fires (Gg)

A_{ij} = annual area burnt (ha)

FL_{ij} = fuel load (dry weight) (Mg/ha)

Z_{ij} = burning efficiency of fires

then for CH₄, CO and NMVOCs calculate annual emissions:

$$E_{ij} = M_{ij} \times CC_{ij} \times EF_{ij} \times C_g \quad (4E_2)$$

Where: E_{ij} = annual emission from fires

M_{ij} = mass of fuel burnt in fires (Gg)

CC_{ij} = carbon mass fraction in fuel burnt in fires

EF_{ij} = emission factor (Table 6.34)

C_g = factor to convert from elemental mass of gas to molecular mass

and annual emissions for NO_x and N₂O:

$$E_{ij} = M_{ij} \times CC_{ij} \times NC_{ij} \times EF_{ij} \times C_g \quad (4E_3)$$

Where: E_{ij} = annual emission from fires

M_{ij} = mass of fuel burnt in fires (Gg)

CC_{ij} = carbon mass fraction in fires

NC_{ij} = nitrogen to carbon ratio in fuel burnt in fires

EF_{ij} = emission factor (Table 6.34)

C_g = factor to convert from elemental mass of gas to molecular mass

6.7.3 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 –50 to +115%. 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. Significant effort has been made to ensure time-series consistency in the activity data for this source category given the changes in data sources over time (Meyer 2004).

6.7.4 Source Specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Section 1.6. Activity data and input parameters for this source category were updated in 2005 following a comprehensive review of current literature and experimental data (Meyer 2004).

6.7.5 Recalculations Since The 2006 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 a typographic error was identified in the activity data for Tasmania (1997) and preliminary estimates for Victoria (2006) were updated. These changes resulted in an increase of 4.3 Gg CO₂-e in the 2006 estimate.

6.7.6 Planned Improvements

All data and methodologies are kept under review.

6.8 Source Category 4.F Field Burning of Agricultural Residues

6.8.1 Source Category Description

The burning of residual crop material also releases CH₄, N₂O, 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 CO₂ emissions from burning of agricultural residues are not included in the inventory total since it is assumed that an equivalent amount of CO₂ 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 through 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 emission factors appropriate to high temperature stubble fires are assumed to be the same as observed in savanna burning (Table 6.36).

Table 6.36: 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 ₂ O	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 6.37: 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

$$M_{ijk} = P_{ijk} \times R_{jk} \times S_{jk} \times DM_{jk} \times Z_j \times F_{ijk} \quad (4F_1)$$

Where: M_{ijk} = mass of residue burnt from crop (Gg)
P_{ijk} = annual production of crop (Gg)
R_{jk} = residue to crop ratio (kg crop residue/kg crop) (Appendix 6.I)
S_{jk} = fraction of crop residue remaining at burning (Appendix 6.I)
DM_{jk} = 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_{ijk} = 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 CO, CH₄ or NMVOC by multiplying by the carbon content of the fuel, and an emission factor. That is:

$$E_{ijk} = M_{ijk} \times CC_{jk} \times EF_j \times C_g \quad (4F_2)$$

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 6.36)
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:

$$E_{ijk} = M_{ijk} \times CC_{jk} \times NC_{jk} \times EF_j \times C_g \quad (4F_3)$$

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 6.36)
 C_g = factor to convert from elemental mass of gas to molecular mass

6.8.3 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.

6.8.4 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 DCC. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.8.5 Recalculations Since The 2006 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. Preliminary 2006 production estimates for some of the minor crop types were replaced with the final ABS estimates. This led to a minor recalculation of the 2005 to 2006 estimates. The change to 2006 estimate was 9.2 Gg CO_2 -e.

6.8.6 Planned Improvements

All data and methodologies are kept under review.

Appendix 6.A: Dairy Cattle

Table 6.A1: 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.A2: 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.A3: 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
	Summer	65	65	65	65	65
	Autumn	65	65	65	65	65
	Winter	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.A4: 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.A5: 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.A6: 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.A7: 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

Source: Based on SCA 1990

Table 6.A8: Dairy cattle – Average milk production (kg/head/year)

State	1990	2006	2007
NSW/ACT	3603	5039	5039
Tasmania	3775	4581	4581
Western Australia	4202	5369	5369
South Australia	3934	5791	5791
Victoria	3920	5221	5221
Queensland	3123	4076	4076
Northern Territory	3123	4076	4076

Source: Dairy Australia

Appendix 6.B: Beef Cattle

Table 6.B1: Beef cattle – liveweight (kg)

State	Region	Season	Bulls >1	Bulls <1	Steers <1	Cows 1 to 2	Cows >2	Cows <1	Steers >1
			(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(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.B2: Beef cattle – liveweight gain (kg/head/day)

State	Region	Season	Bulls >1	Bulls <1	Steers <1	Cows 1 to 2	Cows >2	Cows <1	Steers >1
			(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(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.B3: Beef cattle – dry matter digestibility of feed intake (%)

State	Region	Season	Bulls >1	Bulls <1	Steers <1	Cows1 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.B4: Beef cattle – crude protein content of feed intake (%)

State	Region	Season	Bulls >1	Bulls <1	Steers <1	Cows1 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.B5: Beef Cattle – proportion of cows >2 lactating, feed intake adjustment and milk production and intake

State	Region	Season	Proportion lactating ^a		Feed adjustment	Milk intake / production (kg/day)
			1990–1995	1996+		
NSW/ACT		Spring	0.88	0.85	1.3	6
		Summer	0.88	0.85	1.1	4
		Autumn	0	0	0	0
		Winter	0	0	0	0
Tasmania		Spring	0.88	0.90	1.3	6
		Summer	0.88	0.90	1.1	4
		Autumn	0	0	0	0
		Winter	0	0	0	0
Western Australia	South West	Spring	0	0	0	0
		Summer	0	0	0	0
		Autumn	0.73	0.8	1.3	6
		Winter	0.73	0.8	1.1	4
	Pilbara	Spring	0.73	0.8	1.3	4
		Summer	0.73	0.8	1.1	3
		Autumn	0	0	0	0
		Winter	0	0	0	0
	Kimberley	Spring	0	0	0	0
		Summer	0.73	0.8	1.3	4
		Autumn	0.73	0.8	1.1	3
		Winter	0	0	0	0
South Australia		Spring	0	0	0	0
		Summer	0	0	0	0
		Autumn	0.83	0.87	1.3	6
		Winter	0.83	0.87	1.1	4
Victoria		Spring	0	0	0	0
		Summer	0	0	0	0
		Autumn	0.9	0.85	1.3	6
		Winter	0.9	0.85	1.1	4
Queensland		Spring	0.73	0.75	1.3	4
		Summer	0.73	0.75	1.1	3
		Autumn	0	0	0	0
		Winter	0	0	0	0
Northern Territory		Spring	0	0	0	0
		Summer	0.6	0.7	1.3	4
		Autumn	0.6	0.7	1.1	3
		Winter	0	0	0	0

Source: a) Based on calving rates provided by ABARE

Table 6.B6: Beef cattle – standard reference weights

State	Bulls >1	Bulls <1	Steers <1	Cows 1 to 2	Cows >2	Cows <1	Steers >1
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(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

Source: Based on SCA 1990

Appendix 6.C: Feedlot Cattle

Table 6.C1: 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

Sources: a) Working Group estimates; b) van Sliedregt et al. (2000)

Table 6.C2: 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

Source: 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.C3: 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

Sources: a) based on working group estimates; b) van Sliedregt et al. (2000)

Table 6.C4: 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

Source: Based on AFIC 1987 and working group estimates

Table 6.C5: 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

Sources: a) based on working group estimates; b) van Sliedregt et al. (2000)

Appendix 6.D: Sheep

Table 6.D1: 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.D2: 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.D3: 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.D4: Sheep – crude protein content 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	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.D5: Sheep – liveweight gain (kg/day)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(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.D6: Sheep – proportion of lambs receiving milk in each season and lambing rates for breeding ewes

State	Season	Proportion of lambs receiving milk ^a	Lambing Rates ^b	
			1990–1995	1996+
NSW/ACT	Spring	0.40	0.78	0.82
	Summer	0.10	0.78	0.82
	Autumn	0.20	0.78	0.82
	Winter	0.30	0.78	0.82
Tasmania	Spring	0.60	0.80	0.82
	Summer	0.00	0.80	0.82
	Autumn	0.10	0.80	0.82
	Winter	0.30	0.80	0.82
Western Australia	Spring	0.15	0.73	0.77
	Summer	0.10	0.73	0.77
	Autumn	0.15	0.73	0.77
	Winter	0.60	0.73	0.77
South Australia	Spring	0.15	0.80	0.85
	Summer	0.05	0.80	0.85
	Autumn	0.30	0.80	0.85
	Winter	0.50	0.80	0.85
Victoria	Spring	0.30	0.80	0.83
	Summer	0.10	0.80	0.83
	Autumn	0.25	0.80	0.83
	Winter	0.35	0.80	0.83
Queensland	Spring	0.50	0.58	0.63
	Summer	0.00	0.58	0.63
	Autumn	0.50	0.58	0.63
	Winter	0.00	0.58	0.63

Sources: a) 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; b) lambing rates provided by ABARE

Table 6.D7: 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.E1: 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.E2: 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

Note: Estimate includes volatile solids from waste feed

Table 6.E3: 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.E4: 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.E5: 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

Note: Estimate includes nitrogen in waste feed

Appendix 6.F: Other Livestock

Table 6.F1: ‘Other livestock’ – enteric fermentation emission factors (kg CH₄/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.F2: ‘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.F3: ‘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.G1: 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.G2: 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.G3: 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.H1: Fraction of fertiliser N applied to each production system, 1990-2005

	NSW	NT	QLD	SA	TAS	VIC	WA		
							1990-95	1996-2002	2003-05
Irrigated Pasture	0.03515	0.02079	0.01932	0.01840	0.09361	0.17074	0.00305	0.00187	0.00182
Irrigated crops	0.08916	0.02560	0.02868	0.00929	0.10052	0.02756	0.00218	0.00133	0.00129
Non-irrigated pasture	0.39740	0.03543	0.01901	0.60105	0.55850	0.44539	0.69458	0.70109	0.70196
Non-irrigated crops	0.23771		0.00447	0.27820	0.01836	0.24182	0.27294	0.27550	0.27584
Sugar	0.01771		0.62038					0.00297	0.00288
Cotton	0.18601		0.23151					0.00054	
Horticultural Vegetable crops	0.03685	0.91818	0.07663	0.09306	0.22901	0.11449	0.02726	0.01670	0.01621

Table 6.H2: Fraction of fertiliser N applied to each production system, 2006+

	NSW	NT	QLD	SA	TAS	VIC	WA
Irrigated Pasture	0.07173	0.02079	0.01763	0.02562	0.05631	0.15474	0.00197
Irrigated crops	0.18194	0.02560	0.02617	0.01294	0.06046	0.02498	0.00141
Non-irrigated pasture	0.24012	0.03543	0.16305	0.51822	0.64542	0.41938	0.68273
Non-irrigated crops	0.15669		0.02841	0.25592	0.01424	0.25513	0.28554
Sugar	0.03664		0.51794				0.00387
Cotton	0.21376		0.14849				0.00004
Horticultural Vegetable crops	0.09911	0.91818	0.09831	0.18729	0.22357	0.14577	0.02444

Appendix 6.I: Crop And Pasture Attributes

Table 6.I1: Crop and pasture attributes

Crop type	Residue: Crop ratio	Fraction of residue remaining at time of burning	Dry matter content	Carbon mass fraction in dry matter	Elemental N:C ratio (by mass)	Fraction burnt	Fraction Removed
I	R _{kl}	S _{kl}	DM _{kl}	CC _{kl}	NC _{kl}		
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 ^(a)	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 ^(a)	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.I2	(b)
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

Sources: a) Robinson and Kirby 2002; b) 0.03 for QLD and zero for WA and NSW

Table 6.I2: Fraction of sugar cane burnt in each State

Year	NSW	WA	QLD	AUSTRALIA
1989	1.000	0.000	0.735	0.750
1990	0.978	0.000	0.686	0.701
1991	0.987	0.000	0.664	0.680
1992	0.987	0.000	0.639	0.662
1993	0.987	0.000	0.641	0.663
1994	0.965	0.000	0.596	0.618
1995	0.949	0.000	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

Appendix 6.J: Nitrogen leaching and runoff

Table 6.J1: 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 vegetable crops	0.599	0.857	0.293	0.667	0.996	0.702	0.911

Table 6.J2: 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
TAS		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				