



Australian Government
Department of the
Environment and Heritage
Australian Greenhouse Office

AUSTRALIA'S NATIONAL
GREENHOUSE ACCOUNTS



National Inventory Report 2004 (Revised) — Volume 1

The Australian Government Submission to the UN Framework Convention on Climate Change December 2006

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Phone: 1300 130 606 or Fax: 1300 555 606.

This document and supporting methodology workbooks are available on the Internet at the following address:

<http://www.greenhouse.gov.au/inventory>.

The Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories are at:

<http://www.ipcc-nggip.iges.or.jp>.

Suggestions and comments would be appreciated. They should be addressed to the Manager, Australian National Greenhouse Gas Inventory, Emissions Analysis Team, Australian Greenhouse Office, Department of the Environment and Heritage GPO Box 787, Canberra ACT 2601.

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December 2006

Designed by Roar (DEH 3872)

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EXECUTIVE SUMMARY

ES.1 BACKGROUND INFORMATION ON GREENHOUSE GAS INVENTORIES AND CLIMATE CHANGE

The *National Inventory Report 2004 Revised* reports updates to the estimates presented in the *National Inventory Report 2004*, which was submitted by the Australian Government to the UN Framework Convention on Climate Change (UNFCCC) in May 2006. As a party to the UNFCCC Australia has produced national inventories since 1992 and is committed to publishing updated national inventories each year. This report covers the period 1990 to 2004.

This *National Inventory Report 2004 Revised* has been compiled using the methods described in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005* series. The Australian methodologies conform to the international guidelines adopted by the UNFCCC and are available on the Australian Greenhouse Office website. 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).

In addition to this Report, the Australian Greenhouse Office publishes a range of supporting emission estimates that, together, constitute the *Australian National Greenhouse Accounts*. In addition to the *National Inventory Report*, the Australian Greenhouse Office 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 have been prepared under the AGO Emissions Data Management Plan and are available on the AGO website at www.greenhouse.gov.au/inventory. They provide additional information with respect to Australia's emissions on both a regional and industry basis, as well as with respect to Australia's domestic policy commitments.

ES.2 SUMMARY OF THE NATIONAL EMISSION AND REMOVAL RELATED TRENDS

In 2004, net emissions of greenhouse gases in Australia are estimated to have been 525.7 Mt (CO₂-e). By comparison, net emissions were 507.5 Mt in 2003 and 499.9 Mt in 1990. An overview of emission trends at the national level is provided in chapter 2.

ES.3 OVERVIEW OF SOURCE AND SINK CATEGORY EMISSION ESTIMATES AND TRENDS

The combined *energy* subsectors (*stationary energy*, *transport* and *fugitive emissions* from fossil fuel extraction and distribution) were the largest source of net national emissions, contributing 74% of the total in 2004. This proportion, while significant, is nonetheless less than in many countries due to the relatively large contribution from the *agriculture* (17%) sector to Australia's inventory. Other sources of emissions include *industrial processes*, such as from the manufacture of mineral products, emissions from *waste disposal* and *land use, land use change and forestry*. A full overview of emission estimates by source and sink is given in chapter 2. More detailed

¹Separate 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 accounting of forestry sinks. The UNFCCC inventory also includes reporting of indirect greenhouse gases for which Global Warming Potentials are not available.

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.

ES.4 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 SO_2 . 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 SO_2 are presented in chapter 2.

ACKNOWLEDGEMENTS

The following have contributed significantly to the preparation of emission estimates for this inventory:

Sector	Consultant	Organisation
Energy	Dr Hugh Saddler	Energy Strategies Pty Ltd
	Mr Graham Anderson	Energy Strategies Pty Ltd
	Mr George Wilkenfeld	George Wilkenfeld and Associates Pty Ltd
	Mr Steven Oliver	Australian Greenhouse Office
	Mr Charles Jubb	Burnbank Consulting Pty Ltd
Industrial processes, solvents, and waste		
Agriculture	Dr Mick Meyer	CSIRO Marine & Atmospheric Research
	Ms Penny Reyenga	Australian Greenhouse Office
Land Use, Land Use Change & Forestry	Dr Gary Richards	Australian Greenhouse Office
Waste	Mr Mark Hunstone	Australian Greenhouse Office

This report also draws heavily from material published in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Removals by Sinks* series, which required significant input from a large number of contributors who have been identified in those documents.

National Greenhouse Gas Inventory Committee

Ian Carruthers	Australian Government
Matthew Blackmore	New South Wales
Sarah Burrows	Australian Capital Territory
Ian Galbally	CSIRO
Darren Gladman	Victoria
John Isaac	Tasmania
Roman Mandyczewsky	Western Australia
Keryn Oude-Egberink	Queensland
Paul Purdon	Northern Territory
Tom Whitworth	South Australia

Australian Greenhouse Office—Department of the Environment and Heritage

Rob Sturgiss
Mark Hunstone
Steven Oliver
Penny Reyenga
Glen Whitehead
Nicholas Giles

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

CF₄ perfluoromethane (a perfluorocarbon)

C₂F₆ perfluoroethane (a perfluorocarbon)

CH₄ Methane

CO carbon monoxide

CO₂ carbon dioxide

HFCs hydrofluorocarbons

N₂O nitrous oxide

NM VOC non-methane volatile organic compounds

NO_x oxides of nitrogen

PFCs perfluorocarbons

SF₆ sulphur hexafluoride

SO₂ sulphur dioxide

Global Warming Potentials

CO₂ = 1 HFC-23 = 11,700

CH₄ = 21 HFC-125 = 2,800

N₂O = 310 HFC-134a = 1,300

CF₄ = 6,500 HFC-143a = 3,800

C₂F₆ = 9,200 SF₆ = 23,900

Conversion Factors

From element basis to molecular mass

$$\text{C} \rightarrow \text{CO}_2: x \ 44/12 = 3.67$$

$$\text{C} \rightarrow \text{CH}_4: x \ 16/12 = 1.33$$

$$\text{N} \rightarrow \text{N}_2\text{O}: x \ 44/28 = 1.57$$

From molecular mass to element basis

$$\text{CO}_2 \rightarrow \text{C}: x \ 12/44 = 0.27$$

$$\text{CH}_4 \rightarrow \text{C}: x \ 12/16 = 0.75$$

$$\text{N}_2\text{O} \rightarrow \text{N}: x \ 28/44 = 0.64$$

Indicators

In the tables, the following standard indicators are used:

- NO (not occurring) when the activity or process does not occur in Australia
- NA (not applicable) when the activity occurs in Australia but the nature of the process does not result in emissions or removals
- NE (not estimated) where it is known that the activity occurs in Australia but there are no data or methodology available to derive an estimate of emissions
- IE (included elsewhere) where emissions or removals are estimated but included elsewhere in the inventory
- C (confidential) where reporting at a disaggregated level could lead to the disclosure of confidential information

1. INTRODUCTION AND INVENTORY CONTEXT

1.1 BACKGROUND INFORMATION ON GREENHOUSE GAS INVENTORIES

Australia's *National Inventory Report 2004 Revised* provides updates to the estimates of Australia's net greenhouse gas emissions for 2004 submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as part of Australia's reporting obligations under that Convention.

The *National Inventory Report 2004 Revised* 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.

In addition to this Report the Australian Greenhouse Office publishes a range of supporting emission estimates that, together, constitute the *Australian National Greenhouse Accounts*. In addition to the *National Inventory Report*, the Australian Greenhouse Office 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 were prepared under the AGO Emissions Data Management Plan and the most recent issues are available on the AGO website www.greenhouse.gov.au/inventory. They provide additional information with respect to Australia's emissions on both a regional and industry basis, as well as with respect to Australia's domestic policy commitments.

The *National Inventory Report 2004 Revised* 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* (2003) and the *Revised 1996 Intergovernmental Panel on Climate Change (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. The National Inventory Report provides estimates of Australia's total net emissions in 2004 and identifies trends in emissions between 1990 and 2004 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.

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.

A single agency

The compilation of Australia's National Inventory Report is undertaken centrally by a single agency: -the Australian Greenhouse Office (AGO) in the Department of the Environment and Heritage of the Australian Government. The AGO is responsible for all aspects of emissions estimation, the preparation of the reports and for their submission to the UNFCCC on behalf of the Australian Government.

Australia's National Greenhouse Gas Inventory is prepared under the Australian Government's Emissions Measurement and Analysis Programme. The programme supports the Inventory, the AGO's emissions projections activity and the National Carbon Accounting System, which is designed, inter alia, to estimate greenhouse emissions and removals from the Land Use, Land Use Change and Forestry sector.

Support for the AGO inventory staff comprises a pool of 16 expert consultants from which the AGO selects experts to undertake specific inventory preparation and review tasks. The pool is designed to foster a broad base of understanding of Australia's inventory systems.

The Australian Greenhouse Emissions Information System

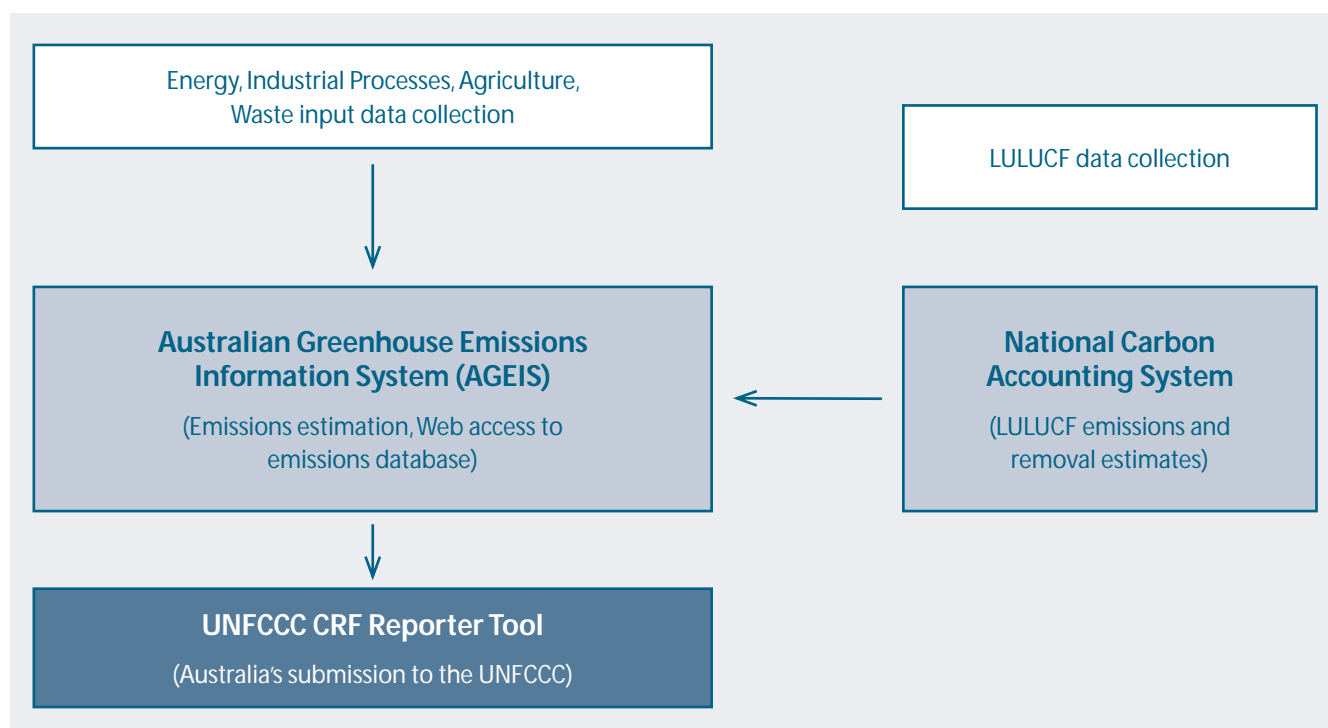
The AGO introduced the Australian Greenhouse Emissions Information System (AGEIS) into the inventory production process in 2005. The AGEIS was designed to meet the requirements for national inventory systems, and is an integral part of the Accounts preparation and publishing processes. In particular, 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 from the AGEIS database for the set of National Inventory accounts publicly accessible through an interactive web interface at www.greenhouse.gov.au/inventory.

The AGEIS is fully integrated with the UNFCCC CRF Reporter Tool enabling the smooth transfer of emissions data to the UNFCCC and reducing data handling with the aim of improving the timeliness and quality of Australia's inventory submissions.

The AGEIS is continuing to be expanded and refined to ensure the support of the range of National Greenhouse Accounts. Investment in 2006-07 will be prioritised to focus on the development of the National Greenhouse Accounts to incorporate State inventories by Economic Sector and both National and State 'Scope 2' electricity end use accounts.

While the AGEIS is used for final preparation of the National Greenhouse Accounts, the National Carbon Accounting System (NCAS) plays a critical role in delivering the emission and removal estimates for the Land Use, Land Use Change and Forestry sector (as illustrated next page).

Figure 1.1 AGO inventory asset structures and relationships

The National Greenhouse Gas Inventory Committee, which comprises representatives of the Australian, State and Territory governments and which has been in place since the early 1990s, is the principal mechanism of review for each new report prior to its release. The 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.

Originally, expert working groups developed the Australian emission estimation methodologies. Their work has been subsequently reviewed by a wide range of technical experts in research institutions, governments and industry on a rolling basis and in accordance with the AGO's Inventory Improvement Plan. Key modifications or refinements to the methodology are adopted following consultation with the National Greenhouse Gas Inventory Committee.

Reliability of data collection processes is an important consideration for inventory preparation to ensure accurate and time series-consistent emissions data. The Australian inventory is well served in this regard. The major sources of activity data are published by key national economic statistics agencies. The Australian Bureau of Statistics (ABS) is the national statistical agency with legislative backing for its collection powers. It is the source of agricultural activity and some energy related data. Energy consumption data are sourced from the Australian Bureau of Agricultural and Resource Economics, which publishes data from a survey of energy use that has operated for 30 years and which are used to fulfill Australia's reporting requirements to the International Energy Agency.

Process for Official Consideration and Approval of the Inventory

The National Inventory Report is prepared by the Australian Greenhouse Office. Prior to finalisation, each new 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 inventory 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 the inventory and submission to the UNFCCC is approved by the Minister for the Environment and Heritage of the Australian Government.

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.

1. Preparation of Evaluation of Outcomes document for the previous year.
2. Preparation of QA-QC and Inventory Improvement plans, taking into account AGO 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)
6. Activity data collection – conducted annually by a panel of external consultants and by the Australian Greenhouse Office (AGO) (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 AGO through predefined data entry templates (August - November).
8. Activity data verification and quality control - the AGO 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) records an assessment of the quality of the activity data in the system, where questions arise.
10. The data quality is checked and internally audited by designated AGO staff (known as the Database Operations Manager DBM) to provide quality control. Only when the DBM is satisfied is the input data transferred to the core database where emissions estimation are undertaken.
11. Emissions estimation – the AGEIS is used to generate emission estimates for all inventory years using time-series consistent methodologies.
12. Emissions estimates verification – the AGO 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 AGO staff to provide QC (DBM and the "Emissions Analysis Team Manager").
14. The compiled inventory is circulated to Australian Government departments and the NGGI Committee of State and Territory government representatives for comment prior to public release (February).
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.greenhouse.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.² 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* (2003) and are comparable with international practice.

The Australian methodologies have been documented in a series of workbooks to ensure transparency. The 2004 Revised inventory relies on the methodologies described in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005*. The essential information reported in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005* is provided under the sectoral chapters of this report.

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.

In the National Inventory Report 2004 Revised key new developments include the enhancement of the methodologies deploying time-dependent capital stock parameters for passenger car and light commercial vehicles (for petrol, LPG and diesel fuels); the extension of the household appliance stock model to stationary air conditioners; the extension of the use of direct measurements at active coal mines; refinements to the fugitives from decommissioned mines methodology; and refinements to the industrial wastewater methodology.

A summary of key emission factors is provided each year in the Australian Greenhouse Office (AGO) Factors and Methods Workbook and is available, along with a compilation of the current methodology for each sector, from the AGO website at www.greenhouse.gov.au/inventory.

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

²An explanation of the 'Tier' concept is provided in the Glossary

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), AGO 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	AGO collection, Australian Government Department of the Environment and Heritage
Agriculture (4)	Australian Bureau of Statistics
Land use, land use change and forestry (5)	National Carbon Accounting System, AGO
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 2004 refers to the Australian fiscal year from 1 July 2003 to 30 June 2004, 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.

1.5 BRIEF DESCRIPTION OF KEY SOURCE CATEGORIES

National greenhouse gas inventory sources and sink categories have been grouped under six sectors that have been defined by the IPCC. These represent the main human activities that contribute to the release or capture of greenhouse gases into or from the atmosphere:

- > Energy
- > Industrial processes
- > Solvent and other product use
- > Agriculture
- > Land use, land use change and forestry
- > Waste.

Inventory sectors are disaggregated into subsectors (e.g. 1.A. *Fuel combustion*, or 4.D. *Agricultural soils*), and sometimes more detailed disaggregations are provided (e.g. 1.A.3.b. *Road transportation* emissions are disaggregated by vehicle type — cars, light commercial vehicles, trucks, motorcycles).

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.

Australia has identified public electricity (solid fuel), enteric fermentation (cattle), road transportation and forest conversion to grasslands as the most significant of the key categories. The most important categories

contributing to the trend in emissions include forest conversion to grasslands, public electricity (solid fuel) and enteric fermentation (sheep). More details are provided in Annex 1.

Gases

The National Greenhouse Gas Inventory Report presents emissions for each gas as carbon dioxide equivalents (CO₂-e). 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. The conversion of emission data to CO₂-e is done using the concept of global warming potentials (GWPs).

GWPs represent the relative warming effect (i.e. cumulative radiative forcing³) of a unit mass of the gas when compared with the same mass of CO₂ over a specific period. The CO₂-e emissions are calculated by multiplying the mass of emissions of each gas by the appropriate GWP. Aggregate emissions are then obtained by summing the emissions of various greenhouse gases.

GWPs are revised from time to time as knowledge about the influence of different gases and processes on climate change increases. GWPs also vary with the time horizon being considered-by international agreement the 100-year horizon is used in policy analyses. To be consistent with the Kyoto and UNFCCC reporting requirements, the 100-year GWPs contained in the 1995 IPCC *Second Assessment Report* (IPCC 1996) are used in this document (e.g. 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).

The indirect effects of a number of gases (e.g. CO, NO_x, and NMVOCs) cannot currently be characterised and these gases do not have GWPs. In accordance with the UNFCCC reporting guidelines, gases that do not have GWPs are reported but they are not included in the inventory total.

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 2006-07. 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 AGO 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 AGO 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 AGO 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 AGO to improve accountability;
- > auditability of QC controls to improve accountability;

³Radiative forcing is a change in the energy balance of the global earth-atmosphere system

- > additional 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
- > additional reconciliation checks for emissions data to ensure completeness of activity data for fossil fuels and carbonates.

Within the Australian Greenhouse Office, 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 (listed as 'AGEIS data verification' checks in Table 1.2). Implementation of new estimation methodologies are undertaken using a dual estimation approach which ensures that AGEIS emission estimates are verified independently.

Systematic Tier 1 checks go beyond the operation of the AGEIS, and comprise systems for:

- > the review of emission estimation methodologies;
- > the pre-processing of input data;
- > the validation of AGEIS estimation processes;
- > and internal reconciliation checks.

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 emissions factors are documented	<i>NIR and Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005</i>
Transcription errors in data input and reference	AGEIS data verification
Emissions are calculated correctly	AGEIS data verification and selected dual estimation process
Parameter and emission units are correctly recorded and that appropriate conversion factors are used	AGEIS data verification and selected dual estimation process
Integrity of database files	AGEIS development phase
Consistency in data between source categories	Mass balance checks for fuel, carbonates and biomass
Movement of inventory data among processing steps is correct	AGEIS data verification
Uncertainties in emissions and removals are estimated or calculated correctly	Independent review by CSIRO completed
Review of internal documentation	Broader QA processes
Methodological and data changes resulting in recalculations	AGEIS data verification
Completeness tasks	Mass balance checks for fuel, carbonates and biomass
Compare estimates to previous estimates	AGEIS data verification
Check time series consistency	Checked with AGEIS
Undertake completeness tasks	Checked through CRF Reporter Tool
Compare estimates to previous estimates	Achieved through AGEIS, CRF Reporter Tool

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

Tier 2 QC checks are sector-specific QC exercises and comprise emission factor and activity data review.

Australia predominantly uses country-specific emission factors. The use of IPCC default emission factors for emissions estimation in some IPCC sectors is not common and is reviewed whenever new country-specific data becomes available.

National level energy activity data are produced by the Australian Bureau of Agricultural and Resource Economics on the basis of its annual Fuel and Electricity Survey. Quality control of the activity data is managed by the source agencies. In addition, 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 AGO 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).

The Australian Bureau of Statistics (ABS) publishes assessments of data quality and quantitative estimates of sampling errors for transport and agricultural activity data. Tier 2 QC checks on domestic wastewater emissions are also performed and reported in the National Inventory Report.

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 2006-07, external consultants were contracted to review the steel, petroleum refining, industrial wastewater and waste incineration methodologies.
- 3) A wide range of QA processes have been employed for the National Carbon Accounting System (see Volume 2);
- 4) Uncertainty estimates were reviewed in 2005 by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research Division according to strict review protocols.
- 5) The transparency of inventory emission estimates and methods published by the AGO 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@greenhouse.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 has sought to have the inventory reviewed by in-country teams where possible, as was the case in 2002 and 2005, while either centralised or desk reviews have been utilised in other years. Principal suggested modifications to the National Inventory Report and cross cutting issues raised by the Review team report published in 2006 are listed in Table 1.3.

In addition, an important QA function is the ongoing review of estimation methodologies used to compile the Australian inventory undertaken in accordance with the AGO'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.

For the National Inventory Report 2004, reviews of Australia's methodology were concluded for liquid fuels, transport, fugitive, agricultural soils, forestry, solid waste disposal and wastewater treatment sectors, which have led to recalculations of emission estimates (reported in chapter 10). Minor reviews have led to the inclusion of additional sources, such as nitrous oxide emissions from aerosols and medical use, the use of acetylene and methane emissions from animal wastes in open pasture management conditions.

For the National Inventory Report 2004 Revised, additional reviews have been completed for transport, steel and petroleum refining, fugitive emissions from decommissioned mines, cement, wastewater treatment and waste incineration emission sources.

Table 1.3 Cross cutting issues for modification identified by both Australia and by the expert review team in the last review report

Reference	Identified areas for inclusion ^(a)	Response
Sectoral chapters	Inclusion of more information from the Australian Methodology Workbooks on methods applied in the respective sectoral chapters	Implemented
Chapter 4	Provision of potential HFC estimates	Implemented
Chapter 10, sectoral chapters, and annex 5.	Planned enhancements (as per Australia's 2003 NIR): Recalculations for refinements to the methodologies for passenger cars, fugitive emissions from coal mines, synthetic gases, agricultural soils, forestry, waste, and new data for the energy and LULUCF sectors.	Implemented
	Identified by Australia in ERT report: Recalculations for refinements to CO ₂ emission factors, refinements to cement methodology, inclusion of solvents.	Implemented
	Identified by ERT: averaging process for prescribed burning of savannas, reallocation of ammonia emissions, revised steel data.	Implemented
	Enhancement of completeness	Inclusion of emissions from aerosols and medical use of nitrous oxide; acetylene use, additional methane sources from manure management; emissions from leaching, CO ₂ from grasslands remaining grasslands; croplands remaining croplands; N ₂ O from soil disturbance.
Annex 1	Two-stage key category analysis	Implemented
Annex 4	Provision of the energy sector reference approach calculations for the years 1991–2002.	Implemented
Annex 7	Greater disaggregation of uncertainty reporting	Implemented
CRF Tables	Inclusion of LULUCF CRF sectoral background data tables	Implemented

(a) UNFCCC, 2006, 'Report of the Individual Review of the Greenhouse Gas Inventory Submitted in the year 2005: Australia', UNFCCC expert review team

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 2004 is estimated at $\pm 4\%$. The reported uncertainty for the trend in emissions is estimated to be $\pm 2\text{--}6\%$. The IPCC approach provides accurate estimates of uncertainty under certain restrictive assumptions that do not always hold for most countries' inventories. Consequently, the Australian Greenhouse Office 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 AGO 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.

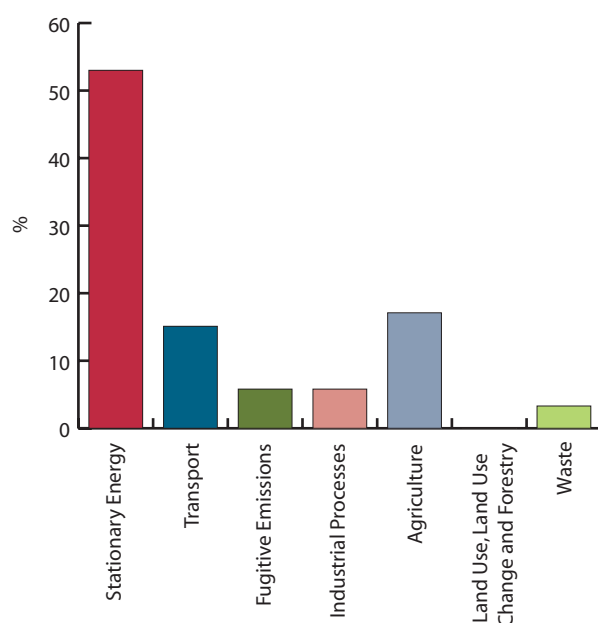
For the National Inventory Report 2004, complete data on methane from decommissioned coal mines; methane from certain livestock wastes; the use of acetylene; and nitrous oxide emissions from aerosols and medical use of nitrous oxide; nitrous oxide emissions from leaching of nitrogen from agricultural soils; and CO₂ emissions from grasslands and croplands were incorporated for the first time. Altogether, these additional sources added around 1% to the inventory in 1990. For the National Inventory Report 2004 Revised, an additional source included is N₂O emissions from soil disturbance, which adds around 0.1% to the inventory in 1990. Completeness is discussed more fully in Annex 5.

2. AUSTRALIA'S NET GREENHOUSE GAS EMISSIONS

2.1 EMISSIONS IN 2004

In 2004, Australia's net greenhouse gas emissions using the UNFCCC accounting provisions were 525.7 million tonnes (Mt), CO₂-equivalent (CO₂-e). The combined *energy* sub-sectors (including *stationary energy*, *transport* and *fugitive emissions*) were the largest source of greenhouse gas emissions comprising 73.9% (388.4 Mt CO₂-e) of emissions (Figure 2.1). This proportion is less than in many countries, however, due to the relatively large contribution from the *agriculture* (17.1%) sector to Australia's inventory. Other relatively minor sources currently include emissions from *industrial processes*, such as from the manufacture of mineral products, emissions from *waste disposal* and *land use, land use change and forestry*.

Figure 2.1 Contribution to total net CO₂-e emissions by sector, 2004



The national emissions from the *energy* sector comprise mainly emissions of carbon dioxide (Table 2.1). Consequently, at the level of individual greenhouse gases, the energy sector is the major contributor to carbon dioxide emissions at 95.3% (359.3 Mt). *Agriculture* is the main contributor of methane (58.5%, 3.3 Mt) and nitrous oxide (82.4%, 0.069 Mt) emissions.

Table 2.1 Australian net greenhouse gas emissions by sector, 2004

Sector and Subsector	CO ₂		CH ₄		N ₂ O		CO ₂ -e	
	Mt	%	Mt	%	Mt	%	Mt	%
1 All energy (combustion + fugitive)	359.3		1.3		0.008		388.4	
Stationary energy	276.2	73.3	0.1	1.1	0.003	3.8	278.5	53.0
Transport	77.3	20.5	0.03	0.5	0.05	5.9	79.5	15.1
Fugitive emissions from fuel	5.7	1.5	1.2	21.1	0.0001	0.1	30.4	5.8
2 Industrial Processes	24.6	6.5	0.003	0.1	0.0001	0.1	30.6	5.8 ^(b)
3 Solvent and other product use^(a)	NA	NA	NA	NA	IE	IE	IE	IE
4 Agriculture	NA	NA	3.3	58.5	0.1	82.4	89.8	17.1
5 Land use, land use change and forestry	-7.0	-1.9	0.3	4.5	0.005	5.6	-0.2	0.0
6 Waste	0.0	0.0	0.8	14.2	0.002	2.2	17.1	3.3
Total net emissions	376.9		5.6		0.084		525.7	

(a) Emissions are included in industrial processes for confidentiality reasons.

(b) HFCs, PFCs and SF₆ are not separately reported here but are included in the CO₂-e totals

Carbon dioxide is the most important of the greenhouse gases in Australia's inventory with a share of 71.7% (376.9 Mt) of the total CO₂-e emissions, followed by methane, which comprises 22.2% (116.9 Mt CO₂-e). The remaining gases make up 6.1% (31.9 Mt CO₂-e) of Australia's greenhouse gas emissions.

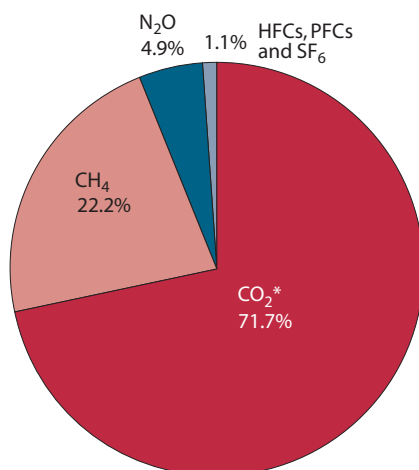
Table 2.2 Australian net greenhouse gas emissions by gas, 2004

Greenhouse gas	Mt	GWP	Mt CO ₂ -e	% of total
CO ₂ ^(a)	376.9	1	376.9	71.7
CH ₄	5.6	21	116.9	22.2
N ₂ O	0.1	310	26.0	4.9
HFCs	(b)	(b)	3.9	0.7
PFCs	(c)	(c)	1.5	0.3
SF ₆	0.00002	23,900	0.5	0.1
NO _x	2.5	NA	NA	NA
CO	26.1	NA	NA	NA
NM VOC	2.5	NA	NA	NA
SO ₂	2.5	NA	NA	NA
Total CO₂-e	NA	NA	525.7	

(a) Includes confidential N₂O emissions from Industrial Processes reported as CO₂-e.

(b) HFC-23 (GWP = 11,700), HFC-125 (GWP = 2,800), HFC-134a (GWP = 1,300) and HFC-143a (GWP = 3,800).

(c) CF₄ (GWP = 6,500) and C₂F₆ (GWP = 9,200).

Figure 2.2 Contribution to total net CO₂-e emissions by gas, 2004

*Includes confidential N₂O emissions from industrial processes reported as CO₂-e.

2.2 EMISSION TRENDS

Australia's net emissions in 2004 were 525.7 Mt, an increase of 18.2 Mt or 3.6% over net emissions recorded in 2003. Contributing sectors to the increase in emissions over this period included *land use, land use change and forestry, stationary energy* (up 2.0%), *transport* (up 5.3%), *fugitive emissions* from fossil fuel (up 0.9%), and *industrial processes* (up 3.2%). Sectors decreasing included, *waste* (down 0.8%) and *agriculture* (down 1.2%).

Net emissions in 2004 were 5.2% (25.8 Mt) above 1990 levels (Figure 2.3). The largest sectoral increase in greenhouse gas emissions over the 1990 to 2004 period, of 42.1% (82.5 Mt CO₂-e), occurred in the *stationary energy* sector, driven in part by increasing population, household incomes and export increases from the resources sector. *Transport* is the next largest growth sector with an increase of 28.4% (17.6 Mt CO₂-e). The main driver for the increase in *transport* emissions is continuing growth in household incomes and numbers of vehicles. Offsetting growth in these sectors has been a strong decline in net emissions from the *land use, land use change and forestry* sector and, in particular, reductions in forest conversion. Trends in emissions from each sector are discussed further in chapters 3-8.

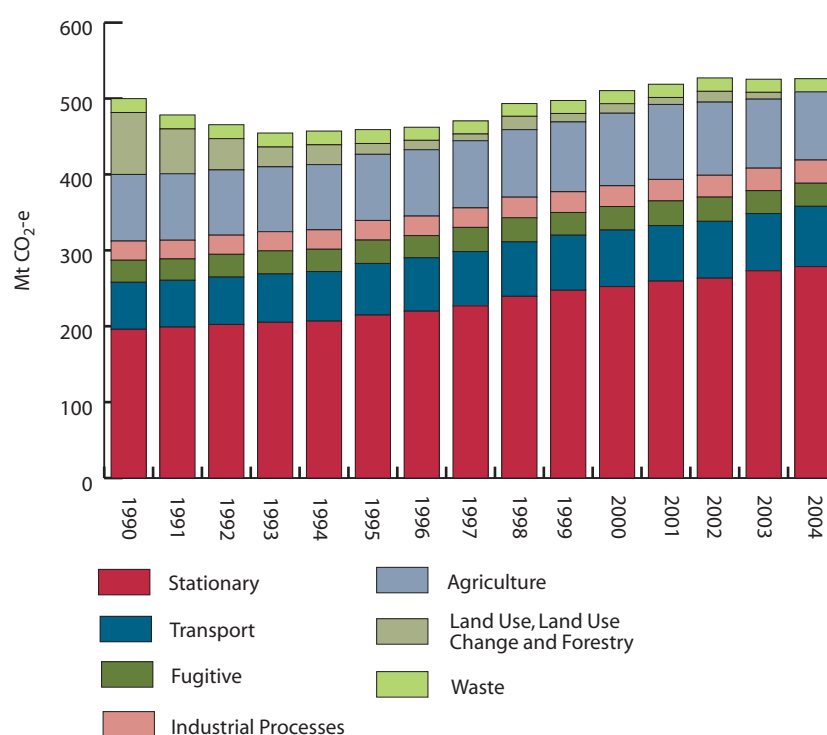
Of the individual greenhouse gases, net emissions of carbon dioxide increased by 6.1% between 1990 and 2004. Methane emissions declined by 1.7%; nitrous oxide emissions increased by 28.6%; HFC emissions increased by 244.9%; and PFC and sulphur hexafluoride emissions fell by 55.0%.

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. The estimated emissions from these gases are shown in Table 2.2, but where the other greenhouse gases have been converted into CO₂-equivalents, the CO₂-equivalents for these gases are shown as NA (not applicable). Compared with 1990, there has been an increase in the emissions of NO_x CO, NMVOC and SO₂ (0.6 Mt (33.3%), 5.5 Mt (26.6%), 0.3 Mt (13.9%) and 0.9 Mt (58.3%) respectively).

Table 2.3 Change in total net CO₂-e emissions by gas, 1990–2004

Greenhouse gases	1990 Mt CO ₂ -e	2004 Mt CO ₂ -e	1990% of Total	2004% of Total	Changes Mt	% Change in emissions
CO ₂ ^(a)	355.1	376.9	71.0	71.7	21.8	6.1
CH ₄	119.0	116.9	23.8	22.2	-2.1	-1.7
N ₂ O	20.2	26.0	4.0	4.9	5.8	28.6
HFCs	1.1	3.9	0.2	0.7	2.8	244.9
PFCs and SF ₆	4.5	2.0	0.9	0.4	-2.5	-55.0
Total CO₂-e	499.9	525.7			25.8	5.2

(a) Includes confidential CO₂ and N₂O data from industrial processes reported as CO₂-e.

Figure 2.3 Trends in CO₂-e emissions and removals by sector, 1990–2004


3. ENERGY

3.1 OVERVIEW

Total emissions from the *energy* sector for 2004 were estimated to be 388.4 Mt CO₂-e (Table 3.1). *Energy industries* were the main contributor, accounting for 55.3% of emissions from the *energy* sector. Other significant contributors to total *energy* emissions were *transport* (20.5%), and *manufacturing industries and construction* (11.0%).

Energy sector emissions increased by 35.3% between 1990 and 2004. Emissions from the sector increased by 9.8 Mt (2.6%) from 378.6 Mt in 2003. The main contributor to the increase in emissions was *energy industries*, which contributed an additional 5.1 Mt CO₂-e.

Table 3.1 Energy sector CO₂-e emissions, 2004

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)			
	CO ₂	CH ₄	N ₂ O	Total
1 ENERGY	359,264	26,593	2,543	388,400
A. Fuel combustion activities	353,534	1,926	2,519	357,979
1 Energy industries	213,878	205	666	214,749
a Electricity and heat production	192,720	172	628	193,521
b Petroleum refining	8,206	2	20	8,228
c Manufacture of solid fuels	12,953	30	17	13,000
2 Manufacturing industries and construction	42,633	47	234	42,914
3 Transport	77,290	620	1,544	79,454
a Civil aviation	4,811	1	46	4,858
b Road transportation	68,464	491	1,469	70,425
c Railways	1,797	2	16	1,815
d Navigation (domestic)	2,171	126	12	2,309
e Other transportation	46	0	0	46
4 Other sectors	18,414	1,053	71	19,538
5 Other	1,318	1	6	1,324
a Lubricants	669	NA	NA	669
b Mobile (military)	649	1	6	656
B. Fugitive emissions from fuels	5,731	24,667	24	30,421
1 Solid fuels	NE	20,454	NA	20,454
2 Oil and natural gas	5,731	4,213	24	9,967

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 278.5 Mt CO₂-e in 2004, equal to 53.0% of net national emissions.

The *energy industries* subsector includes fuel combustion in electricity generation, petroleum refining, gas production and solid fuel manufacture. *Electricity and heat production* (1.A.1.a) contributed 193.5 Mt CO₂-e or 69.5% of *stationary energy* emissions in 2004. 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 21.2 Mt in 2004.

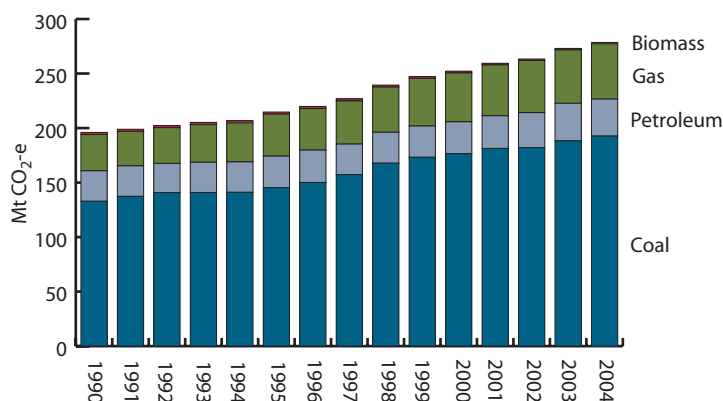
The *manufacturing industries and construction* subsector (1.A.2) emissions were 42.9 Mt CO₂-e in 2004. This subsector includes direct emissions from fuel combustion in manufacturing industries, ferrous and non-ferrous metals production, plastics production, construction and non-energy mining. These calculations do not fully reflect the greenhouse impact of these industries, as the emissions generated from the production of electricity used in these industries are included under electricity and heat production (1.A.1.a).

Estimated emissions from *other* sectors (1.A.4) were 19.5 Mt CO₂-e in 2004. This subsector comprises direct fuel combustion in the residential, commercial and institutional sectors, including energy used in mobile equipment in *agriculture, forestry and fishing* industries. However, as with *manufacturing*, much of the greenhouse impact of these sectors arises from their large consumption of electricity, which is not reflected in this figure alone (reported under 1.A.1.a). *Other* (1.A.5) includes emissions from *lubricants* (0.7 Mt) and *military transport* (0.7 Mt). Emissions from *lubricants* arise from the combustion of engine oil in vehicles.

The use of feedstocks within chemicals production resulted in the equivalent of 2.3 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 4.1 Mt CO₂ was stored in other products, such as lubricants and bitumen while 14.0 Mt CO₂ emissions were reported elsewhere in other sectors within the inventory. Coke and natural gas, used as reductants within iron and steel production, were the most significant non-energy uses of fuels, resulting in the reporting of 10.1 Mt CO₂ within the *industrial processes* sector. There is also a small use of fuels in non-ferrous metals production and natural gas leakage reported as *fugitive* emissions.

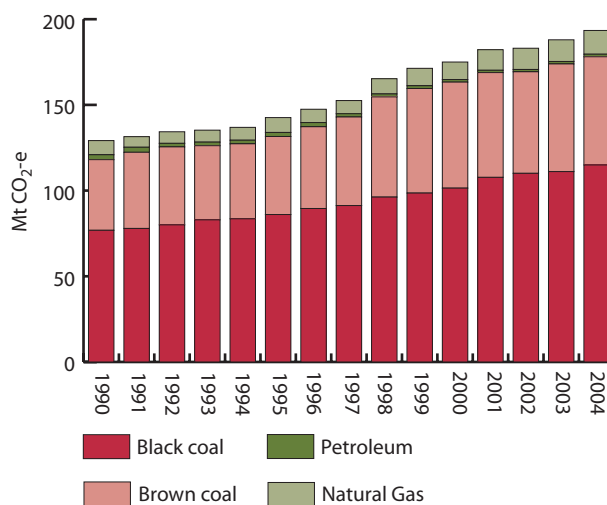
Trends

Emissions from *stationary energy* increased by 42.1% (82.5 Mt) between 1990 and 2004, including an increase in emissions from coal combustion of 45.0% (59.8 Mt) in the same period (Figure 3.1). Although coal accounted for the highest absolute increase in emissions over this period, emissions related to natural gas have shown the largest relative growth, increasing by 52.5% (17.5 Mt) between 1990 and 2004. Emissions from liquid fuels increased by 21.1% (5.9 Mt) in the same period, while biomass emissions decreased by 34.2% (0.7 Mt). The increase in coal-related emissions accounts for 72.5% of the overall increase in emissions, with gas accounting for 21.1% and oil 7.2%. Between 2003 and 2004, emissions from *stationary energy* increased by 2.0% (5.5 Mt).

Figure 3.1 Total CO₂-e emissions from stationary energy combustion by fuel, 1990–2004


Electricity generation emissions increased by 5.3 Mt (2.8%) from 2003 to 2004, and by 64.1 Mt (49.5%) from 1990 to 2004 (Figure 3.2). The 2003 to 2004 *electricity generation* emissions increase (2.8%) was approximately equal to the increase in fuel use (2.8%). The black coal share of energy use increased by 0.1% to 56.5% while the brown coal share decreased by 0.6% to 30.1%. The share of fuel use contributed by gas increased by 0.4% to 12.3% while the proportion of petroleum remained nearly the same at 1.0%.

Emissions from *stationary energy* subsectors, other than *electricity*, increased by 0.2 Mt (0.2%) between 2003 and 2004, and increased overall by 18.5 Mt (27.8%) from 1990 to 2004. Emissions from the *manufacturing industries and construction* subsector increased 3.1% (1.3 Mt) between 2003 and 2004 and increased by 15.7% (5.8 Mt) from 1990 to 2004.

Figure 3.2 CO₂-e emissions from electricity generation by fossil fuels, 1990–2004


3.1.2 TRANSPORT

In 2004 *transport* contributed 79.5 Mt CO₂-e or 15.1% of Australia's net emissions.

The major source of transport emissions in Australia is *road transportation*, which accounts for 88.6% (70.4 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 43.4 Mt and trucks and buses 15.2 Mt. Other sources are far smaller: *domestic aviation* contributed 6.1% (4.9 Mt), *domestic navigation* 2.9% (2.3 Mt), and *railways* 2.3% (1.8 Mt).

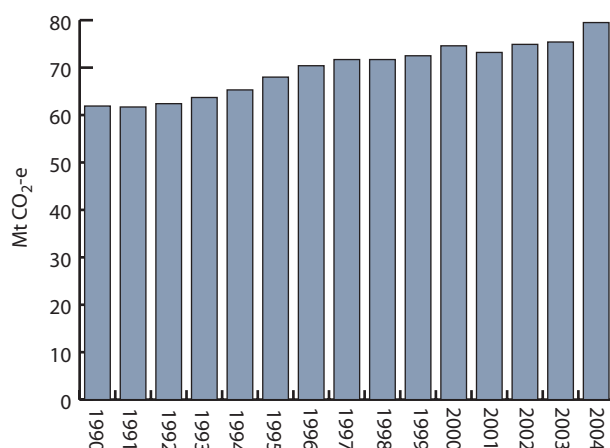
Fuel used in *international transport* (*international aviation and marine 'bunkers'*) is by international agreement reported separately from the national total net emissions. In 2004, international bunker fuels generated 8.9 Mt of emissions.

Trends

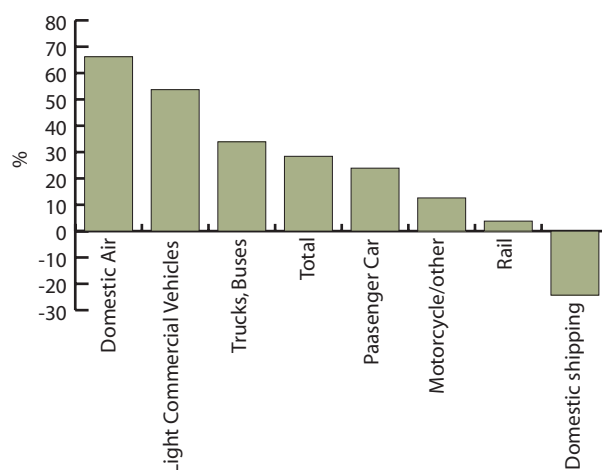
Transport emissions are one of the strongest sources of emissions growth in Australia. Emissions from this sector were 28.4% higher in 2004 than in 1990, and have increased by about 2% annually (Figure 3.3). The strongest period of growth in transport emissions occurred in the early 1990s and since that time the growth rate appears to have slowed.

Emissions from *road transportation* increased by 30.1% (16.3 Mt) between 1990 and 2004 (Figure 3.4). Emissions from *passenger cars* increased by 23.9% (8.9 Mt). The growth in emissions from passenger cars reflects growth in activity but also the influence of technological change, as the importance of vehicles fitted with 3 way catalytic has increased in the overall passenger car fleet (as 3 way catalytic converters reduce NO_x emissions but raise nitrous oxide emissions compared with other technologies). Emissions from Light Commercial Vehicles (LCVs) and heavy duty trucks and buses have also grown strongly (53.7% and 33.9% respectively).

Figure 3.3 Total transport emissions, 1990–2004



Estimates of *civil aviation* (*domestic air transport*) emissions were 66.2% (1.9 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. By contrast, emissions from rail have risen by only 3.8% while shipping emissions have fallen by 24.3%, reflecting improved productivity and changes in activity.

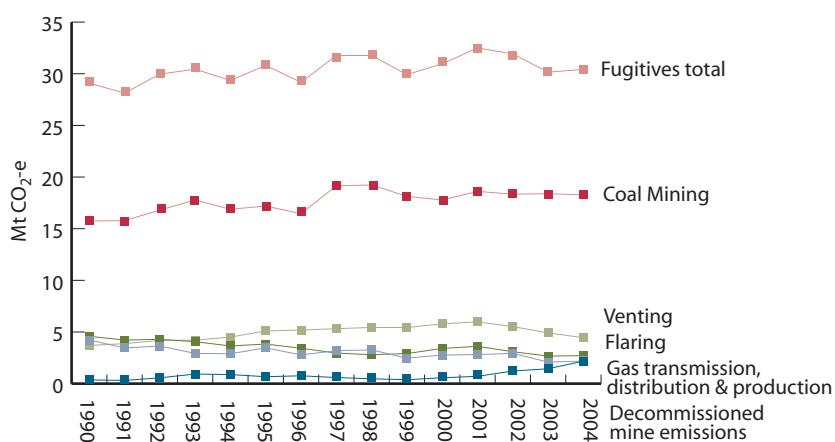
Figure 3.4 Comparison of growth in transport emissions by subcategory, 1990–2004

3.1.3 FUGITIVE EMISSIONS

Total estimated *fugitive emissions* for 2004 were 30.4 Mt CO₂-e, representing 5.7% of net national emissions. Net *solid fuel* emissions, all of which are associated with coal mining and handling, contributed 67.2% (20.5 Mt) of fugitive emissions. *Oil and natural gas production, processing and distribution* account for the remaining 32.8% (10.0 Mt) of *fugitive emissions*.

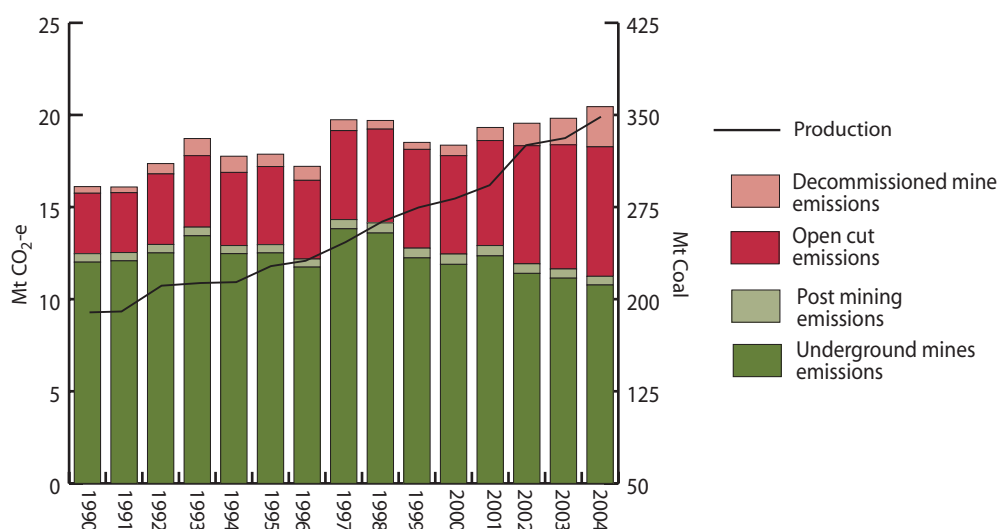
Trends

Overall *fugitive emissions* increased 4.6% (1.3Mt) between 1990 and 2004, and increased by 0.9% (0.3 Mt) from 2003 to 2004 (Figure 3.5). From 2003 to 2004 fugitive emissions from *solid fuels* increased by 0.6 Mt (3.2%) and *oil and natural gas* emissions decreased by 3.5% (0.4 Mt).

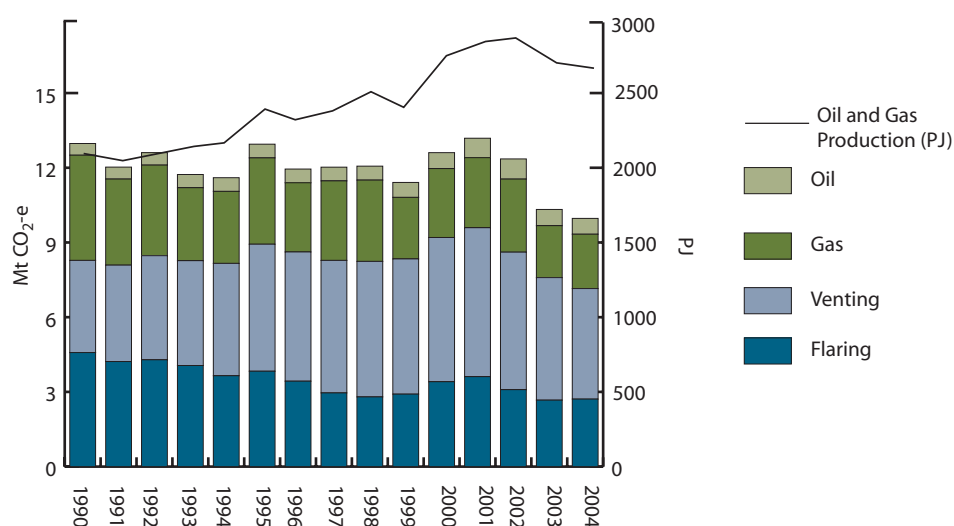
Figure 3.5 CO₂-e fugitive emissions by category, 1990–2004

Solid fuel emissions increased by 26.9% (4.3 Mt) between 1990 and 2004. Between 2003 and 2004, emissions increased 3.2% (0.6 Mt). 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. Mine production of coal has increased from 188 Mt in 1990 to 350 Mt in 2004, an increase of 86%. Since 1990, methane emissions have not grown as fast as activity, and since 1998 there has been a decreasing trend in activity from Class A (gassy) mines, and growth in Class B (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 1.8 Mt between 1990 and 2004, in response to a series a recent gassy mine closures.

Figure 3.6 Fugitive $\text{CO}_2\text{-e}$ emissions from coal mining activities, 1990–2004



Oil and natural gas fugitive emissions decreased by 23.2% (3.0 Mt) between 1990 and 2004 (Figure 3.7). This compares with a 32% increase in production activity. The decrease in emissions relative to the increase in activity is the result of improvements in gas distribution and a reduction in the emissions from flaring. Between 2003 and 2004, emissions from oil-related activities decreased by 2.8% (0.02 Mt) and emissions from gas-related activities increased by 4.6% (0.1 Mt). Emissions from venting decreased by 9.8% (0.5 Mt) from 2003 to 2004 although, compared with 1990, emissions were higher by 20.0% (0.7 Mt). Flaring-related emissions increased by 1.6% (0.04 Mt) from 2003 to 2004. Emissions in 2004 were lower than 1990 levels by 40.8% (1.9 Mt).

Figure 3.7 Fugitive CO₂-e emissions from oil and gas production, 1990–2004

3.2 OVERVIEW OF SOURCE CATEGORY DESCRIPTION AND METHODOLOGY – ENERGY

The *Energy* sector includes emissions from the combustion of fossil fuels (1.A.1 *Energy Industries*; 1.A.2 *Manufacturing Industries and Construction*; 1.A.3 *Transport*; 1.A.4 *Other sectors*; and 1.A.5 *'Other'* as well as fugitive emissions from the extraction of fossil fuels 1.B).

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

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

The data on energy consumption by fuel and economic sector are estimated by the Australian Bureau of Agricultural and Resource Economics (ABARE), which compiles estimates of Australian energy use 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.

Australia's statistical agencies report the national energy statistics in terms of petajoules measured on a gross calorific value (GCV). These energy estimates are the most transparent, consistent and reliable data available and, consequently, the activity data and emission factors are also expressed in terms of GCV. These estimates may be converted into Net Calorific Value equivalents using the International Energy Agency's default conversion factors.

3.2.1 CO₂ EMISSIONS

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 and Coke

Approximately 80% 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 3.8. The variability of these emission factors is illustrated in Figure 3.8. For other uses of coal, such as the steel industry, representative CO₂ emission factors are reported in Table 3.2.

Coal By-Products

Wherever coal by-products are used as a fuel, except in the Basic Chemicals and the Petroleum and Coal Products sector (ANZSIC Codes 253 & 252), it is assumed that the emission factor is the same as for coke oven gas, as advised by the steel industry. The industry has 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. 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

Australia is mostly self sufficient in oil supplies, with principal oil fields located in Bass Strait and on the North West Shelf. 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, taken 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 two sectors, Basic Chemicals (ANZSIC Group 253) and Oil and Gas Mining (ANZSIC Subdivision 12), together with Basic Non-Ferrous Metals (ANZSIC Group 272), after excluding petroleum coke from the latter sector, petroleum products 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.

Solvents, Lubricants, Greases and Bitumen

Australian information on CO₂ emission factors for these products is not available. Default IPCC values of 73.7 Gg/PJ for lubricants and greases and 80.7 Gg/PJ for bitumen has therefore been used (IPCC 1997). The IPCC does not provide an emission factor for solvents. In this workbook, solvents have been given the same emission factor as naphtha, i.e. 69.6 Gg/PJ.

Natural Gas

A national emission factor has been estimated for natural gas for each year, 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 *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Stationary Energy)*).

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 electricity generator values are used. Emission factors for electricity generation are illustrated in Figure 3.8.

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 NGGI was derived based on data within the ASHRAE Handbook Fundamentals 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 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.

Table 3.2 Emission factors for CO₂ 2004

Fuel Type	Fuel	CO ₂ emission factor (Gg CO ₂ /PJ)
Coal derived fuels	Coal used in public electricity generation ^a	86.5 - 96.4
	Coal used in steel industry ^b	91.8
	Black coal used by other industry ^a	90.0
	Brown coal used by industry ^a	94.6
	Coke ^b	119.5
	Coal by-products (gaseous) ^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 ^e	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 ^c	69.7
	Lubricants and greases ^e	73.7
Gases	Bitumen ^e	80.7
	Natural gas ^f	51.4
	Natural gas (Basic chemicals sector) ^f	51.4
	Ethane ^g	56.5
Biomass fuels	Town gas ^c	60.2
	Wood and wood waste ^h	94.0
	For Residential subsector ⁱ	77.5
	Bagasse ^j	91.7

Sources: ^aGWA 2006, ^bBurnbank Consulting 2001, ^cGHD 2006a, ^dABARE, ^eIPCC 1997, ^fAustralian Gas Association 2001, ^gASHRAE 2001, ^hTodd 1993, ⁱTodd 2006, ^jOECD 1991. ^kGHD 2006b

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	Accommodation, Cultural and Personal (Division H, P & Q)	95.0%
	Residential	100%
	All Other Categories	98.0%

Sources: (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 effectively 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.

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.A.4. 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, for which the emission factors are reported in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Transport)*. 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), emission factors for mobile equipment are as reported in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Transport)*.
- > 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 Department of the Environment and Heritage
- > for natural gas and LPG Australian Gas Association

- > for coal (default values)
- > Department of Industry, Technology and Resources.

For the electricity industry specific SO₂ emission data have been obtained from each power station operator. 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 Australian Government Department of Industry, Tourism and Resources.

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	0.006
Motor spirit	0.006
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 Industry, Technology and Resources (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.

A full description of the Australian methodology for the estimation of this inventory is available in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Stationary Energy)*; *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Transport)* and *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Fugitive Emissions)*.

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. An additional reconciliation of years 1990 and 2004 was undertaken for this report in terms of the supply and use of carbon in the economy utilising a number of simplifying assumptions (reported in Table 3.5). For both years it is evident that the reconciliation of supply with uses of carbon is within 1%. 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.

Table 3.5 Reconciliation of the supply and use of carbon from fossil fuels in the Australian economy, 1990 and 2004

1990

Supply and Use of Carbon	kt C
Total Domestic Supply ^(a)	82,035
Total Domestic Use	82,035
1.A CO ₂ emissions from fossil fuel combustion	69,315
1.B Fugitive emissions	275
1.A.2 Non-energy uses as feedstocks	453
2.B, C Industrial process non-energy fuel use	3,227
Carbon stored in other products	1,120
Memo: Biomass sources: wood, bagasse and and biogas	4,025
Memo: International bunkers	1,744
Non-oxidised carbon as ash and soot	1,204
Net balance and statistical discrepancy	670

Note: (a) derived from ABARE 2006a.

2004

Supply and Use of Carbon	kt C
Total Domestic Supply ^(a)	109,482
Total Domestic Use	109,482
1.A CO ₂ emissions from fossil fuel combustion	96,418
1.B Fugitive emissions	201
1.A.2 Non-energy uses as feedstocks	616
2.B, C Industrial process non-energy fuel use	3,605
Carbon stored in other products	1,129
Memo: Biomass sources: wood, bagasse and and biogas	4,551
Memo: International bunkers	2,391
Non-oxidised carbon as ash and soot	1,545
Net balance and statistical discrepancy	-974

Note: (a) derived from ABARE 2006a.

3.3 SOURCE CATEGORY 1.A.1 – ENERGY INDUSTRIES

3.3.1 SOURCE CATEGORY DESCRIPTION

This category includes emissions from fuel combustion within electricity generation, petroleum refining and other energy manufacturing industries such as coke ovens, briquette production, coal mining oil and gas extraction, and natural gas production, transmission and distribution. 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 3.6.

Table 3.6 Relationship between IPCC source categories and ANZSIC sectors: Energy Industries

IPCC Source Category	ANZSIC Subdivision/Group/Class			
	Division	Sub-division	Group/Class	Description
1.A.1 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. Accounting for all fossil fuel combustion associated with 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 3.7).

Table 3.7 Summary of estimation methods and emission factors: Energy Industries

Categories	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A1a Public electricity	T2	CS	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.

Electricity Generation (ANZSIC Group 361) (1.A.1.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.

There are between 45 and 55 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 2004 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.

Table 3.8 CO₂ and non-CO₂ emission factors and oxidation factors for major power stations 2003–2004

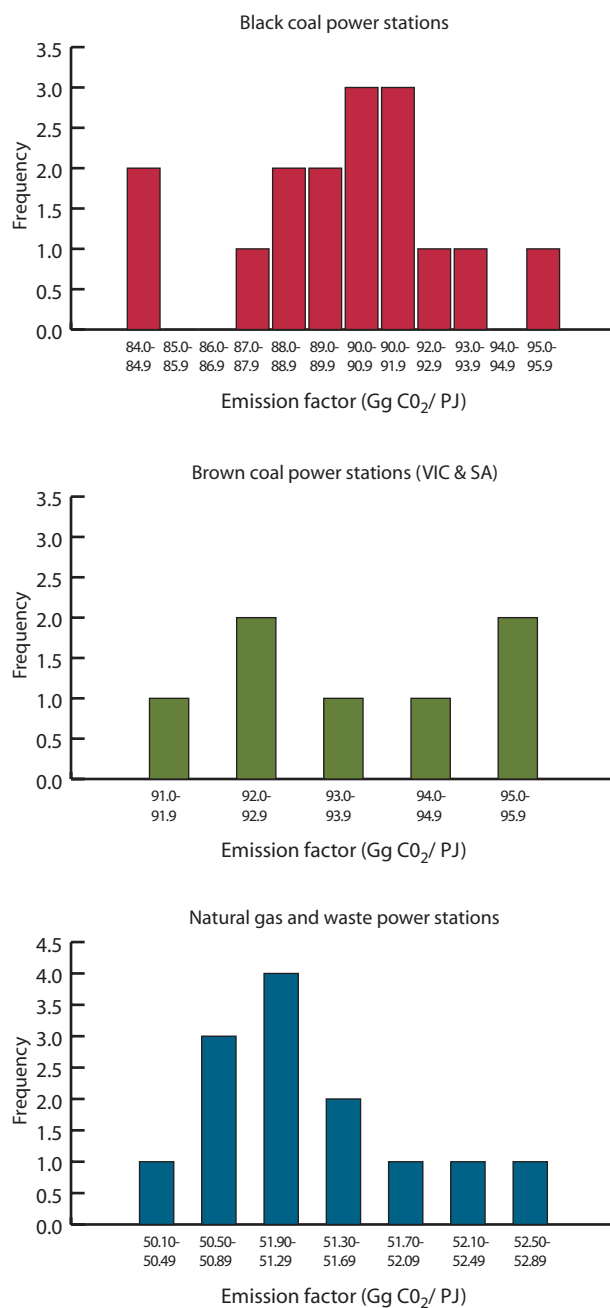
Power Station	Fuel	Gg CO ₂ /PJ		Emission Factor Mg/PJ						Oxidation Factor
		Main Fuel	Oil	CH ₄	N ₂ O	NO _x	CO	NMVOC	SO ₂	
NSW										
Bayswater	BC	94.66	73.30	0.9	0.8	215	11	1.7	566	99.3%
Eraring	BC	90.92	70.85	0.9	0.8	241	11	1.7	336	99%
Mt Piper	BC	89.44	69.37	0.7	0.8	306	11	1.7	439	100%
Liddell	BC	90.50	70.16	0.9	0.8	306	11	1.7	370	100%
Munmorah	BC	91.01	68.64	0.7	0.8	190	11	1.7	260	100%
Vales Point	BC	90.05	69.48	0.7	0.8	236	11	1.7	330	100%
Wallerawang	BC	87.22	70.31	0.7	0.8	203	11	1.7	443	100%
Appin/Tower	WG	51.40	-	236.4	0.9	346	304	80.0	2.3	99.5%
Smithfield	NG	51.40	-	8.0	0.1	23	46	2.4	2.3	99.5%
Redbank	BC	92.00	73.60	0.9	0.8	55	11	1.7	175	99%
Victoria										
Hazelwood	BrC	94.40	59.40	0.5	1.4	136	17	1.7	62	99.7%
Loy Yang A	BrC	93.76	-	0.9	1.4	145	4	1.7	259	99%
Loy Yang B	BrC	92.68	-	0.7	1.4	136	17	1.7	310	100%
Morwell	BrC	94.20	68.00	0.9	1.4	136	17	1.7	150	99.7%
Yallourn	BrC	96.29	73.60	0.5	1.4	81	55	0.0	113	98.8%

AUSTRALIA'S NATIONAL GREENHOUSE ACCOUNTS

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	
Anglesea	BrC	91.51	78.80	0.9	1.4	213	5	1.6	2453	99.9%
Yarra	NG	51.00	-	0.1	0.1	97	35	0.6	150	99.5%
Jeeralang A & B	NG	50.60	78.80	5.4	0.1	130	29	0.6	2.3	99.5%
Queensland										
Callide	BC	96.13	69.00	0.9	0.8	380	11	0.6	170	99.5%
Gladstone	BC	92.10	70.10	0.9	0.8	523	11	1.7	370	99%
Stanwell	BC	90.80	44.90	0.7	0.8	316	9	1.7	377	99%
Swanbank	BC	86.50	69.00	0.9	0.8	245	5	0.6	395	98%
Collinsville	BC	89.40	70.70	0.9	0.8	523	11	1.7	370	99%
Tarong	BC	89.64	64.96	0.9	0.8	378	12	1.5	232	98.9%
Millmerran	BC	85.50	71.10	0.9	0.8	142	11	1.7	370	99%
Mica Creek	NG	52.06	-	0.1	0.1	32	1	0.6	0.1	99.5%
Western Australia										
Muja A/B	BC	93.80	69.70	0.9	0.8	462	11	1.7	370	99%
Muja C/D	BC	93.80	69.70	0.9	0.8	306	11	1.7	370	99%
Cockburn	NG	51.80	-	8.0	0.1	39	10	2.4	2.3	99.5%
Kwinana A	BC	93.80	-	0.9	0.8	306	11	1.7	370	99%
Kwinana C	BC	93.80	-	0.9	0.8	306	11	1.7	370	99%
Collie	BC	93.80	69.70	0.9	0.8	462	11	1.7	370	99%
Kwinana B	NG	51.80	-	0.1	0.1	226	16	0.6	2.3	99.5%
Kwinana GT	NG	51.80	-	8.0	0.1	190	46	2.4	3.9	99.5%
Geraldton	NG	52.50	-	8.0	0.1	190	46	2.4	3.9	99.5%
Kalgoorlie	NG	52.50	-	8.0	0.1	190	46	2.4	3.9	99.5%
Mungarra	NG	51.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
Pinjar	NG	51.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
TiWest	NG	51.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
Worsley	NG	51.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
South Australia										
Northern/Playford	BrC	96.40	73.60	0.9	1.4	136	17	1.7	150	99%
Torrens Island	NG	51.40	73.60	0.1	0.1	226	16	0.6	2.3	99.5%
Osborne	NG	50.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
Pelican Point	NG	53.1	-	0.1	0.1	190	46	2.4	2.3	99.5%
Ladbroke Grove	NG	50.80	-	8.0	0.1	190	46	2.4	2.3	99.5%
Tasmania										
Bell Bay	NG	51.80	73.60	0.1	0.1	226	16	0.6	3.9	99.5%
Northern Territory										
Channel Island	NG	51.40	-	8.0	0.1	190	46	2.4	2.3	99.5%

BC = Black Coal, BrC = Brown Coal, NG = Natural Gas, WG = Waste Gas.

Source: GWA (2006)

Figure 3.8 Emission factors for CO₂ in electricity generation, 2004


Source: GWA (2006).

 Notes: Values are the product of the respective CO₂ emission factors and oxidation factors.

The full time series of factors used by individual power station are reported in NGGI Committee 2006a *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Stationary Sources)*.

Petroleum Refining (ANZSIC Group 251) (1.A.1.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.A.1. 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.

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, as estimated by this means, is reduced by the quantity of energy flared and vented, as advised by 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)⁴. 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.

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

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

- > Coke Oven Operation (ANZSIC 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.A.1.

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.

⁴Department of the Environment and Heritage, www.npi.gov.au.

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.A.1 are set out below:

1.A.1.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 byproducts – coke oven gas as a fuel (with a low relatively low emission factor of 37 Gg/PJ) at the expense of black coal.

1.A.1.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 Table 3.5, provide quality control checks for this sector.

Fuel and generation data for 1.A.1.a Public Electricity, based on AGO survey data, company annual reports and ABARE energy data, are checked and reconciled against the alternative data sources of the Energy Supply Association of Australia (ESAA) and data for the East Coast and Western Australian electricity grids. 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 2004 INVENTORY

Recalculations for the 1990–2004 period were performed following the release of updated ABARE national energy statistics, and their application in all sub-sectors. For 1.A.1 Energy Industries the revisions since the 2004 Inventory resulted in a change of 0.01 Mt CO₂-e in 1990 and less than one Mt CO₂-e for all years except 2001, 2002, 2003 and 2004 where the changes are 1.2, 1.1, 1.4 and 2.0 Mt CO₂-e respectively.

3.3.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

3.4 SOURCE CATEGORY 1.A.2 – MANUFACTURING INDUSTRIES AND CONSTRUCTION

3.4.1 SOURCE CATEGORY DESCRIPTION

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

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 3.9.

Table 3.9 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.e.c.
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.A.2 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.A.2.c Chemicals, black coal within 1.A.2.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.A.2. More detail is provided for the metal and chemicals industries.

Table 3.10 Summary of estimation 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.A.2.a)

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

- > The operation of Coke Ovens is considered to be an energy transformation industry, and hence must be reported separately to the rest of the iron and steel emissions.
- > The production of coke yields a variety of by-products, including coke oven gas, coal tar, 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.C.3 rather than the Energy sector.

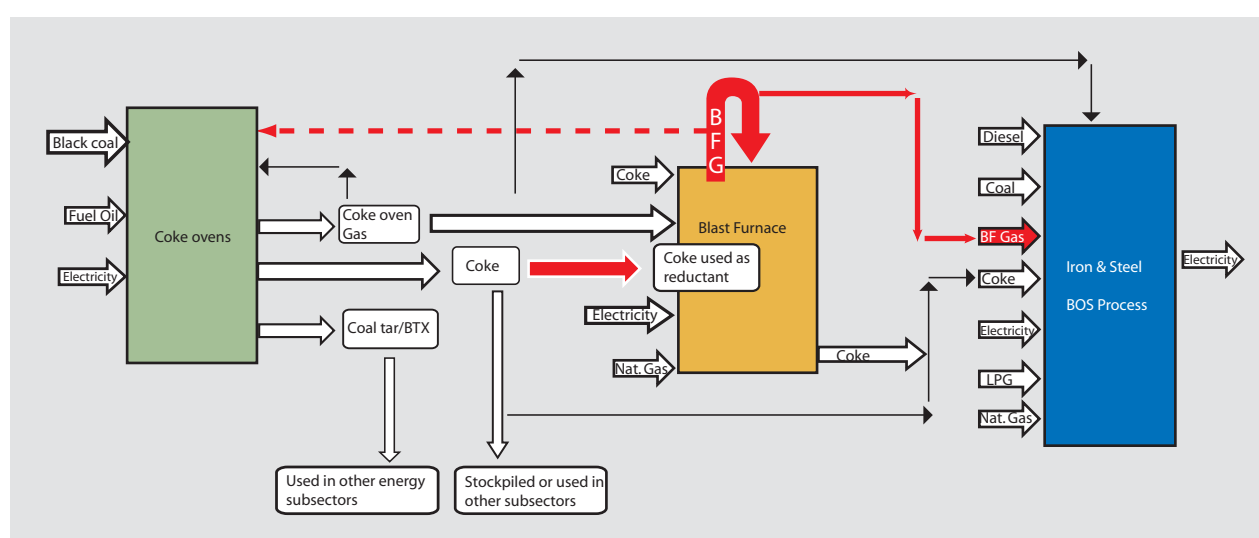
Although Coke Ovens (ANZSIC code 2711) are in operation in the Iron and Steel industry, they are considered an energy transformation industry under the IPCC methodology. Therefore Coke Ovens must be separated from the other parts of the iron and steel industry, so that it can be reported under IPCC category 1.A.1.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 Iron and Steel sector is shown below in Figure 3.9. The components associated with coke used for reduction are reported in the Industrial Processes sector and are indicated in (dark) red. 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, no emissions are re-allocated to the electricity sector.

Figure 3.9 Iron and Steel input-output energy flow chart



Non-Ferrous Metals (ANZSIC Group 272) (1.A.2.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.C.3. The quantity of petroleum coke consumed in this sector, as advised by ABARE special analysis 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.

Black coal used for non-energy purposes in the production of synthetic rutile is reported in UNFCCC category 2.B.5.

Chemicals (ANZSIC Subdivision 25) (1.A.2.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, but is now made at one plant in Victoria.

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 3.11 and 3.12.

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 3.11 Feedstock assumptions in basic chemicals

Feedstock	Carbon Fraction	Calorific Value (GCV)
Ethane	0.80	(a)
Propylene	0.88	52.2
Naphtha (Benzine)	12/13	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 3.12 Product assumptions in basic chemicals

Product	Carbon Fraction
Polyethylene	0.85
Polypropylene	0.85
BR / SBR	0.85
Styrene	0.85
Carbon black	1.00

Notes: All products, other than carbon black, are assumed to contain a carbon fraction of approximately 85% based on the assumption that this is the average carbon content of long chain carbon polymers.

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.A.2 are set out below:

1.A.2.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. This leaves two solid fuels: coal and coke oven gas, of which coke oven gas is now the dominant fuel used, and has a low CO₂ emission factor of 37Gg/PJ. This had the effect of producing a relatively low 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.

1.A.2.c Chemicals: Emissions and IEFs for Chemicals are influenced by the mix of end products which sequester carbon. The production mix of the Australian chemicals industry 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 2004 INVENTORY

Recalculations for the 1990–2004 period were performed following the release of updated ABARE national energy statistics. The above recalculations resulted in the following changes in 1A2 Manufacturing:

- > 2004 Inventory – 37.0 Mt in 1990 – 42.5 Mt in 2004
- > 2004 Revised Inventory – 37.1 Mt in 1990 – 42.9 Mt in 2004

3.4.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

3.5 SOURCE CATEGORY 1.A.3 – TRANSPORT

3.5.1 SOURCE CATEGORY DESCRIPTION

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

Activity data on fuel consumption is based on ABARE 2006a. A number of mobile source categories have been allocated to the stationary source inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. In particular, emissions from miscellaneous off-road vehicles used in specific ANZSIC classifications (such as tractors and other farm vehicles, forestry vehicles, quarry trucks and front-end loaders, construction equipment, and forklifts), are allocated to the corresponding ANZSIC group and accounted for in sectors 1.A.2 and 1.A.4. Emissions from mobile utility engines (such as lawn-mowers, chain-saws, portable generators and mobile compressors) and military transport are reported in sectors 1.A.4 and 1.A.5 using the methodologies detailed in this sector. Emissions from other off-road mobile sources, however, such as unregistered trail bikes and recreation vehicles, competition vehicles are reported under 1.A.3.

3.5.2 METHODOLOGY

Like other energy sub-sectors, the methodology for 1.A.3 is based on the application of 'bottom up' approaches to the estimation of emissions. Tier 2 approaches are employed for the estimation of 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 kilometers travelled, vehicle fleet characteristics and vehicle operating modes.

Table 3.13 Summary of methods and emission factors used to estimate emissions for the Transport sector

Greenhouse gas source and sink	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Categories: Transport						
1A3a Civil Aviation	T1	CS	T2	CS/D	T2	CS/D
1A3b Road Transportation – passenger and light commercial vehicles	T1	CS	T3	CS/D	T3	CS/D
1A3b Road Transportation - other	T1	CS	T2	CS/D	T2	CS/D
1A3c Railways	T1	CS	T1	D	T1	D
1A3d Navigation (Domestic)	T1	CS/D	T1	D	T1	D
1A3e Other Transport	T1	CS	T1	D	T1	D
1A4 Other sectors	T1	CS	T1	D	T1	D
1A5b Military	T1	CS/D	T1	D	T1	D

Notes: T1 = Tier 1. T2 = Tier2. T3 = Tier3. 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 vehicle 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 CO_2 and SO_2 , and grams of gas l emitted per kilometre travelled (g/km) for other non- CO_2 gases.

Fuel consumption data for the transport sector are taken from ABARE 2006a. The main assumptions applied to ABARE energy consumption data allocate petrol to off-road and military fuel uses (reported in Table 3.A.10).

Civil Aviation (1.A.3a)

The estimation of carbon dioxide emissions from civil aviation is undertaken using a Tier 1 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 3.14). 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 3.15).

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 2006a. Cruise emission factors are taken from IPCC (1997) (Table 3.16).

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 and therefore on non- CO_2 emission estimates. 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 2006a.

Table 3.14 The Australian aircraft fleet, 2004, and emission factors by type of aircraft

Type of aircraft	Number	Emission Factors				
		CH ₄ kg/LTO	N ₂ O kg/LTO	NO _x kg/LTO	CO kg/LTO	NMVOC kg/LTO
Major inter-state						
DHC-8-100	34	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	10	0.06	0.10	9.01	6.19	0.51
A330-200/300	11	0.13	0.20	35.57	16.20	1.15
BAE 146	25	0.14	0.00	4.07	11.18	1.27
B717	14	0.01	0.10	10.96	6.78	0.05
B727-200	6	0.81	0.10	11.97	27.16	7.32
B737-300/400/500	25	0.08	0.10	7.19	13.03	0.75
B737-700	20	0.07	0.10	9.12	8.00	0.78
B737-800	54	0.33	0.10	12.30	7.07	0.65
B767-200	1	0.10	0.10	23.76	14.80	2.99
B767-300	29	0.09	0.20	28.19	14.47	1.07
Regional						
SAAB 340	28	0.00	0.02	1.51	2.24	0.00
SA227	59	0.00	0.02	1.51	2.24	0.00
SA226	11	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	3	0.14	0.10	5.63	8.88	1.23
EMB 110	11	0.06	0.01	0.30	2.97	0.58
EMB 120	19	0.00	0.02	1.51	2.24	0.00
Cessna 525	5	0.33	0.03	0.74	34.07	3.01
Beech 200	81	0.06	0.01	0.30	2.97	0.58
F27	26	0.03	0.02	1.82	2.33	0.26
International						
747-300	6	0.27	0.40	65.0	17.8	2.46
747-400	30	0.22	0.30	42.9	26.7	2.02

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

Table 3.15 Weighted average emissions factors per Landing and Take Off cycle

Fleet	CH ₄ (kg/LTO)	N ₂ O (kg/LTO)	NO _x (kg/LTO)	CO (kg/LTO)	NMVOC (kg/LTO)
Domestic/Interstate Fleet	0.09	0.09	11.39	9.06	0.82
Regional Fleet	0.03	0.02	1.12	3.26	0.32
International Fleet	0.23	0.32	46.6	25.24	2.09

Source: AGO estimates

Table 3.16 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

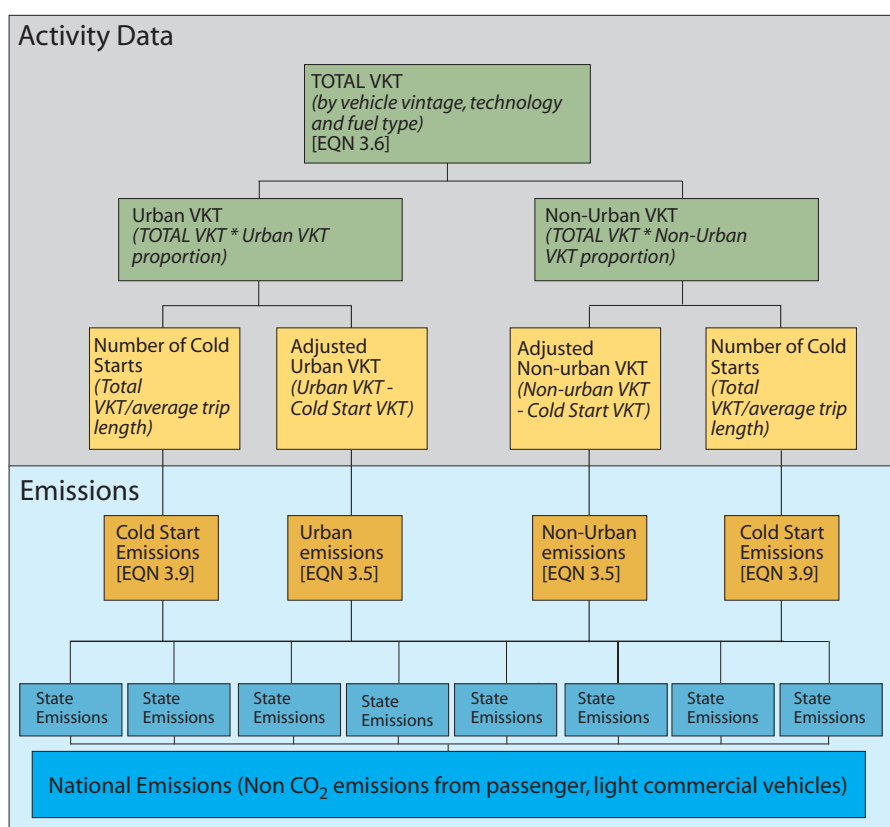
Source IPCC (1997).

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.A.3.b)

Like the aviation sector, the estimation of carbon dioxide emissions from the road transport sector is based on a Tier 1 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).

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



Passenger and Light Commercial Vehicles (1.A.3.bi & 1.A.3.bii)

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.

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

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 passenger and light commercial vehicles consuming automotive gasoline, diesel and LPG, non-CO₂ emissions for each fuel are estimated based on vehicle kilometres traveled (VKT) in each State or Territory; the profile and age of the vehicle capital stock in each State; the penetration of catalytic control technology; mode of operation and road type; and vehicle and fuel specific emission factors.

It is assumed that all passenger and light commercial 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 NSW EPA (2000)). A cold-start duration of 3km (as cited in IPCC 2006) is used to determine the total distance travelled in the cold start phase of operation.

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 2006.

Passenger and light commercial vehicles using automotive gasoline, diesel and LPG are further classified by age of vehicle (using data contained in ABS 2006a). 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. Vehicles manufactured and sold during 1976-1985 use a variety of non-catalytic control (such as exhaust gas recirculation); vehicles sold in 1985-1997 use a mix of 2-way and 3-way catalytic control while vehicles sold post-1997 use 3-way catalytic control.

In general, non-carbon dioxide exhaust emissions from passenger and light commercial 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:

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

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; and

R_{ijk} is the average rate of fuel consumption (in l/km, given in Tables 3.A.12-3.A.14) 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

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

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

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

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;

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 2006a and ABS (2006b and various issues). The data on fuel consumption rates are taken from ABS (2006b, and various issues). The profile and age of the passenger vehicle stock in each State required for equation 3.7 is taken from ABS (2006a, and various issues). Data required to estimate VKT for individual vehicle and age classes for 2004 are given in Tables 3.A.11 to 3.A.15.

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 3.17). The use of disaggregated, country-specific emission factors expressed in terms of emissions per kilometre travelled is consistent with the IPCC tier-3 methodology.

Table 3.17 Country specific CH_4 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 (EPA VIC 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 CH_4 . 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 CH_4 . 3. Bureau of Transport and Regional Economics 2002 - based on NISE study 1 (FORS 1996), MAQS Emissions Inventory (NSWEPA 1995), NGGIC (1996), Air emissions inventory Port Phillip Bay Control Region (EPAV 1991).

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 (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 (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 and post-1997), IPCC default (US EPA) emission factors were 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.

Emission factors for diesel and LPG are derived from relative emission factors reported in IPCC (2006) - which rely on US EPA data. Emission factors for urban and rural driving conditions are derived from the relative emission factors reported in IPCC 2006 - based on COPERT IV values.

A summary of the emission factors used to estimate CH₄ emissions from the Australian petrol, diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in appendix Table 3.A.5.

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.A.8.

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. The emission factors in Weeks et al are comparable to those reported in IPCC (2000) and by the US EPA and COPERT IV and reflect the range of emissions control technology currently used in Australia to meet vehicle exhaust emissions standards. 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 2003. 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.

Emission factors for diesel and LPG are derived from relative emission factors reported in IPCC (2006) - which report US EPA data. Emission factors for urban and rural driving conditions are derived from the relative emission factors reported in IPCC 2006 - based on COPERT IV values.

A summary of the emission factors used to estimate N₂O emissions from the Australian petrol, diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in appendix Table 3.A.6.

Heavy Vehicles and Motorcycles (1.A.3biii- vi)

More generally, the estimation of emissions for heavy road transport and motorcycles is given by equations 3.4 and 3.5. Fleet average emission factors for light medium and heavy duty trucks, buses and motorcycles are provided in appendix Table 3.A.9.

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

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

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

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.A.16.

Railways (1.A.3c)

Emissions are estimated using Tier 1 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 3.18. 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 2006a.

Table 3.18 Non- CO₂ emission factors for non-road sources

Source Category		CH ₄	N ₂ O	NO _x	CO	NM VOC
		(g/MJ)				
Rail Transport ^a						
ADO		0.003	0.002	1.53	0.202	0.071
IDF		0.003	0.002	1.53	0.202	0.071
Coal		0.032	0.001	0.19	0.22	0.26
Marine Transport ^b						
<i>Domestic</i>						
Petrol						
	Small Craft	0.36	0.0009	0.254	20.3	3.24
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	1.58	0.163	0.046
IDF		0.007	0.002	1.58	0.163	0.046
Fuel Oil		0.003	0.002	2	0.044	0.063
NG		0.243	0.001	0.243	0.095	0.029
Coal		0.032	0.001	0.19	0.22	0.26
<i>International</i>						
ADO		0.007	0.002	1.58	0.163	0.046
IDF		0.007	0.002	1.58	0.163	0.046
Fuel Oil		0.003	0.002	2	0.044	0.063

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

Navigation (1.A.3d)

Emissions are estimated using Tier 1 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 3.18.

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 2006a.

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.

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 Australian Greenhouse Office 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 (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).

3.5.5 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations for the 2004 Inventory were performed following:

- a) the release of updated ABARE national energy statistics for the period 1990–2004; and
- b) the adoption of a revised methodology for passenger and light commercial vehicles non-CO₂ emissions from the consumption of automotive gasoline, diesel and LPG which included country-specific emission factors for N₂O and CH₄ emissions disaggregated into urban and non-urban, and hot and cold modes of operation.

The net effect of the recalculations was to increase emissions for this sector by 0.2 Mt in 1990 and 3.3 Mt in 2004 (the latter principally reflecting changes in activity data).

3.5.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

3.6 SOURCE CATEGORY 1.A.4 – OTHER SECTORS

3.6.1 SOURCE CATEGORY DESCRIPTION

The source category—*1.A.4 Other Sectors*—is an aggregation of the following sources:

- > Commercial/Institutional—a diverse category which includes direct emissions from water utilities, accommodation, communications, finance, insurance, property and business services, government and defence, education, health and wholesale and retail trade.
- > Residential—emissions from fuel combustion in households, including lawnmowers.
- > 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 3.19.

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.A.3.

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 2006a. Non-CO₂ emission factors for this sector, by ANZSIC Division, are reported in appendix Table 3.A.3.

Table 3.19 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
	Residential		
	Division A	01	Agriculture
B Residential	Division A	02	Services to agriculture, hunting and trapping
	Division A	03	Forestry and logging
	Division A	04	Commercial fishing

Table 3.20 Summary of methods and emission factors used to estimate emissions for 1.A.4 Other Sectors

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, D= IPCC default.

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.

Residential firewood use in Australia is substantial and is the largest source of CH₄ emissions within the Stationary Energy sector. Around 15% of households choose firewood as their main heating fuel and a further 7% using it for secondary heating. Approximately 4.5 million tonnes of firewood is burnt annually in the residential sector (ABARE). The proportion of 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 have been gradually replacing older, non-certified heater models. Poor user behaviour, which significantly increases in emissions, has been the target of education campaigns and, in the past few years, programs are aimed specifically at households with excessive visible smoke. This has led to improved appliance use.

The methodology for emissions from this source is presented in Todd 2003. The approach incorporates technology factors such as appliance type and certification, as well as wood type, moisture content and user behaviour. The methodology is 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

Table 3.21 Residential biomass emission factors

Inventory Year	Greenhouse Gas Emission Factor (Mg/PJ)						
	CO ₂	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
1990	70374	1100.1	2.3	11751.6	16.9	1393.5	1.1
2000	76245	782.4	1.9	9421.7	21.1	991.0	1.1
2001	76561	765.2	1.9	9296.0	21.4	969.3	1.1
2002	76877	748.2	1.9	9170.7	21.6	947.7	1.1
2003	77191	731.1	1.9	9045.9	21.8	926.1	1.1
2004	77505	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 3.22.

There are no fuel consumption statistics for these activities, instead allocation factors are used to derive this data from known consumption statistics. Lawn mowers are powered by small 2-stroke or 4-stroke engines and assumed to be utilised in the ratio of 60:40 (EPA NSW, 1995).

For the 1.A.4.c *Agriculture, Forestry & 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 3.22). For the derivation of emission factors for different engine types, see *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005, Energy (Transport)*.

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.

Table 3.22 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 (1995), F.Carnovale personal communication, 1995.

Residential - Biomass Combustion (1.A.4)

This category is characterised by the use of wood in residential woodheaters. Emissions are modeled 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 CO₂ IEF has an increasing trend over time. This is due to both the gradual update in later model heaters and improved user operation arising from awareness campaigns. Both these factors result in improved combustion and less ash/soot, which acts to increase the CO₂ EIF, but also results in more efficient use of fuel. In addition, these factors also produce a declining trend in non-CO₂ IEFs as evident for CH₄.

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 2004 INVENTORY

Recalculations for the 1990–2004 period were performed following:

- the release of updated ABARE national energy statistics.
- Recalculations for the 1990–2004 period were performed as a result of a change in the petrol allocation to utility engines such as lawnmowers.

The above recalculations resulted in the following changes in 1A4 Other Sectors:

- > 2004 Inventory—14.6 Mt in 1990—19.4 Mt in 2004
- > 2004 Revised Inventory—14.7 Mt in 1990—19.5 Mt in 2004.

3.6.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review

3.7 SOURCE CATEGORY 1.A.5 – 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 3.23 Summary of methods and emission factors used to estimate emissions for the other (not elsewhere classified) sector

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 = Tier 2, T3 = Tier 3, CS= Country-specific.

3.7.1 SOURCE CATEGORY DESCRIPTION

The source category *Other 1.A.5* 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 2006a. 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. There is also assumed to be a quantity of re-used lubricating oil that is not accounted for in the ABARE statistics. An estimation of this quantity is therefore added to the activity level for lubricant combustion.

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.A.9.

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 NGGI, 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 2004 INVENTORY

Recalculations for the 1990–2004 period were performed as a result of a change in the petrol allocation to Military Transport.

The above recalculations resulted in the following changes in 1A5 Other :

- >2004 Inventory—1.1 Mt in 1990—1.4 Mt in 2004
- >2004 Revised Inventory—1.0 Mt in 1990—1.3 Mt in 2004.

3.7.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

3.8 SOURCE CATEGORY 1.B.1 – SOLID FUELS

3.8.1 SOURCE CATEGORY DESCRIPTION

This source category covers fugitive emissions from the production, transport and handling of coal, and emissions from decommissioned mines. It does not include emissions arising from the conversion of coal into coke.

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 negligible. Sub-bituminous coal is mined in Western Australia and South Australia. In both States the coal is close to brown coal in its characteristics, and CH₄ emissions are negligible.

3.8.2 METHODOLOGY

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 3.24 Summary of estimation methods and emission factors used for 1B1 Solid Fuels

Category	CO ₂		CH ₄		N ₂ O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1B1 Solid Fuels	-	-	T2, T3	CS	-	-

Notes: T2 = Tier 2, T3 = Tier 3, 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.B.1ai)

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. For mines where measured data is not available, an empirical 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 Saghaifi (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').

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 account 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 ; the average in-situ methane content of coal reported in the two studies (IN-SITU, 5.09 m³/tonne) and the volume to mass conversion factor (C_a , equal to 0.616):

$$E_{a1} = (4.48 \cdot QTY_a \cdot \text{IN-SITU} + 2.79) \cdot C_a \quad (1B1_1)$$

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 Saghafi (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).

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

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.B.1aii)

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 3.25.

Table 3.25 CH₄ emission factors for open cut black coal mining

Coal source	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

(a) Source: Williams et al. (1993) and confirmed by Australian Coal Association.

(b) Source: D Cain, Australian Coal Association, pers. comm. (1993).

(c) These factors are derived by treating CH₄ as an ideal gas, ie 16 g (1 gmole) occupies 23.645 l at 15 °C and 1 atmosphere.

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

$$E_o = (QTY_{NSW} \cdot EF_{NSW} + QTY_{QLD} \cdot EF_{QLD} + QTY_{TAS} \cdot EF_{TAS}) \cdot C_{oc} \quad (1B1_4)$$

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.B.1.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 the 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

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

Non-gassy mines

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

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

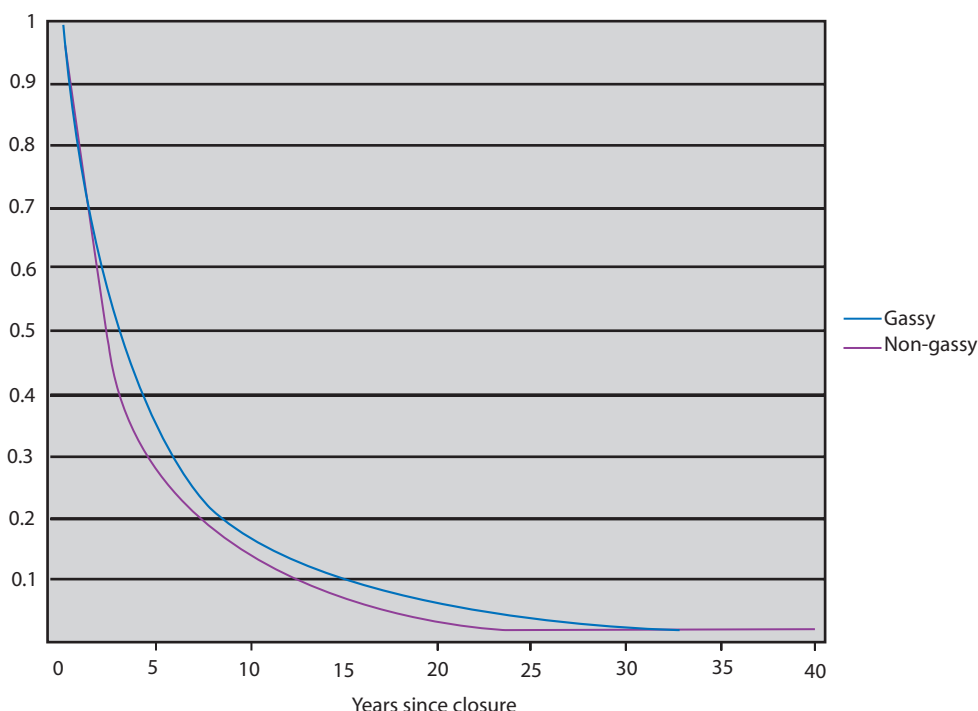
T is the time elapsed since decommissioning of mine.

A , b and C are coefficients unique to the decline curve.(see table below):

Coefficients used in Australian EDCs

Mine category	Coefficients		
	A	b	C
Gassy Mines	0.23	-1.45	0.0242
Non-Gassy mines	0.35	-1.01	0.0881

Figure 3.10 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 2005, and
- > Queensland Department of Natural Resources, Mines and Energy, from 1979 to 2005.

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 the 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.B.1ai). Final mine production at closure is taken as the last full year of production.

Decommissioned mines are defined as Class A (gassy) or Class B (non-gassy) based on existing classifications used to calculate previous National Greenhouse Gas Inventories. For earlier mines, for which class tends to be unknown, mines were classified according to their geological proximity to other mines for which class was known.

Adjustment of EDC for flooding mines

It is common for decommissioned mines to become flooded over time. The flooding of mines is known to result in a very rapid decline in the release of 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 multiplying the total tonnage by 1.425, representing the specific gravity of an average Australian worked coal seam Lunarzewski (2006).

Mine water production data are difficult to obtain on a mine by mine basis, particularly for older, decommissioned mines. The approach taken is to develop a set of basin/state average mine water inflow rates based on available data.

The primary source of mine water production rates for individual mines were obtained from publicly available Environmental Impact Statements (EIS) for mining development projects. EIS provides a good coverage of ground water hydrology, providing data on mine water production rates for proposed mines, extensions, nearby existing mines and the flooding status of surrounding mines.

Water production rates for three regions were calculated. The Southern NSW region mine water production rates ranged 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 mines flood 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

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

3.8.5 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations were required due to the inclusion of a revised method for decommissioned mines. Mining activity emissions were also recalculated due to the inclusion of measured mine emissions for a number of mines, as well as the gassy class reclassification of several mines.

Recalculations resulted in the following changes in 1B1 Solid Fuels:

- > 2004 Inventory—17.1 Mt in 1990—21.3 Mt in 2004
- > Revised 2004 Inventory—16.9 Mt in 1990—19.9 Mt in 2004.

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 closure, where available.

3.9 SOURCE CATEGORY 1.B.2 – 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 Industry Tourism and Resources monthly series, *Australian Petroleum Statistics*.

The relationship between the National Inventory subcategories and the corresponding relationship with APPEA source categories are shown in Table 3.26.

Table 3.26 Relationship between NGGI 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.B.2a)

Oil (and Gas) Exploration (1.B.2ai)

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 3.27.

Table 3.27 Oil exploration and production fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / combustion (kt)					
		CO ₂	CH ₄	NM VOC	N ₂ O	NO _x	CO
Exploration (for both oil and gas)	Offshore testing:						
	- Gas Flared	2750	35.0	50.0	0.081	1.5	8.7
	- Diesel Flared	3200	0.14	1.9	0.22	70.0	19.0
	Onshore Production testing:						
	- Gas Flared	2750	35.0	15.0	0.081	1.5	8.7
		Emissions (t) / throughput (kt)					
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	0.001	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.B.2aii)

Emissions of CH₄ and NMVOCs may occur during oil production, including field processing, as a result of:

- > flaring or venting of gases produced during oil production, either 1) where there is no market for the gas, for example in some offshore floating facilities or in some remote onshore fields, or 2) where flaring of a small amount of gas is necessary for the safe operation of processing facilities
- > leakages at seals in flanges, valves, and other components in a variety of process equipment
- > accidental events
- > controlled releases of pressurised pipe and component contents (blowdown) during routine maintenance activities, including well workovers, pipeline testing, process equipment maintenance etc
- > incomplete combustion of flare gas.

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 3.27.

Crude Oil Transport (1.B.2aiii)

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, 1995), 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.B.2aiv)

Crude oil is refined to numerous products via a wide variety of physical and chemical processes. During such processing, fugitive emissions of NMVOCs and 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 (Environment Protection Authority Victoria, 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 (1995).

In previous years, information on the quantity of gas flared at Australian refineries has been determined using the single national figure derived from the national energy consumption statistics (ABARE 2006a). 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 publically 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 3.28.

Table 3.28 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: AGO estimates, following methodology of E&P Forum (1994)

Petroleum Product Distribution (1.B.2av)

The distribution of petroleum products represents a significant source of fugitive NMVOC emissions. Emission sources include motor vehicle refuelling, service station tank filling and breathing losses, major fuel-terminal storage 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 (see *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Energy (Fugitive Emissions)* (NGGIC 2006c).

Natural Gas (1.B.2b)*Natural Gas Production and Processing (other than venting and flaring) (1.B.2bi)*

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.A.1. Emission factors are reported in 3.29.

Table 3.32 Gas emission factors used for emissions based on APPEA inventory

Inventory category	Operation/source	Emissions (t) / Output (kt)					
		CO ₂	CH ₄	NMVOC	N ₂ O	NO _x	CO
Venting and Flaring		M	M	M	0	0	0
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.B.2bii)*Natural Gas Transmission

Australia has an extensive system of long distance natural gas transmission pipelines. As with oil and gas production, emissions may occur as a result of compressor starts (for which gas expansion is typically used to start gas turbine power units), blowdowns for maintenance at compressor stations, maintenance on pipelines, leakage and accidents.

The Australian high pressure gas transmission system is of relatively recent vintage (the oldest line dates from 1969), has been built to high quality standards and is well maintained. Work undertaken by the Pipeline Authority (the organisation formerly responsible for operation of the Moomba to Sydney pipeline) concluded that losses from a typical gas transmission pipeline in Australia are 0.005% of throughput.

The factor of 0.005% and the throughput data are used in conjunction with national average pipeline gas composition figures for each year, as given in Table 3.30. 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 Australian Gas Association (AGA) series *Gas Distribution Industry Performance Indicators*
- > annual gas utility sales in each State and Territory, published in the AGA series *Gas Industry Statistics*; 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 3.30).

Table 3.30 Natural gas composition and emission factors, 2000 to 2004^(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			

(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.B.2c)

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 AGO 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 3.29, 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 2004 INVENTORY

A recalculation was made for Crude Oil Refining due to revised activity data for flaring. This resulted in the following changes in 1B2 Oil and Natural Gas :

- > 2004 Inventory—13.0 Mt in 1990—9.8 Mt in 2004
- > Revised 2004 Inventory—13.0 Mt in 1990—10.0 Mt in 2004.

3.9.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

APPENDIX 3.A ADDITIONAL INFORMATION ON ACTIVITY DATA

Table 3.A.1 Non- CO₂ Emission Factors 1.A.1 Energy Industries

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
1.A.1.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
1.A.1c 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	1390
Briquette Manufacture (ANZSIC Class 1103, part)						
Brown Coal	1.3	0.8	105.0	287.0	1.0	150
Coal Mining (ANZSIC Subdivision 11, remainder)						
LPG	0.1	0.6	13.0	154.0	5.0	2.3
ADO	0.1	0.6	13.0	154.0	5.0	85
Fuel Oil	0.1	0.6	13.0	154.0	5.0	1390
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
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
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.A.4.

Table 3.A.2: Non-CO₂ Emission Factors 1.A.2 Manufacturing and Construction

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NM VOC	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
1.A.2.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
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
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

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NM VOC	SO ₂
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.A.2.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.A.2.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
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	85
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
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

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NM VOC	SO ₂
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.A.2.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
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
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

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NMVOC	SO ₂
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
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.A.2.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
IDF	1.1	0.6	44.8	330.9	0.8	57.0
Fuel oil	0.8	0.6	44.8	330.9	0.8	1,282.1
Petroleum products nec	1.1	0.6	44.8	330.9	0.8	57.0

Source: Derived from Table 3.A.4.

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

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NM VOC	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
Div. M Government Administration and Defence						
Black coal	1.3	0.8	105.0	287.0	1.0	370.0

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH ₄	N ₂ O	CO	NO _x	NM VOC	SO ₂
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.A.4.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 3A.4.

(a) See table 3A4 for residential biomass emission factors

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

			Emission Factors (Mass/Mass or Volume or Energy)						Conversion Factors		Emission Factors (Mass/Gross Energy Use)				
Sector	Fuel	Equipment	CH ₄	N 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]													
4	Natural Gas	Turbine[h]	7.95		190	46	2.37	ng/J	1.0		0.9	1.4	136	17	1.7
7	Natural Gas	Internal Combustion[i]	240		1,331	340	80	ng/J	1.0		8.0	0.1	190	46	2.4
8	Fuel Oil	Internal Combustion[j]	4		1,322	349	45	ng/J	1.0		240	0.1	1,331	340	80
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		6.85	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
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

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
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 (1995) 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 (1995) 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 (1995) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration (tangentially fired boiler). [f] USEPA (1995) 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 (1995) 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 (1995) Pg 3.4-3. Assume dual fuel emission factors. [j] USEPA (1995) Pg 3.4-3. [k] USEPA (1995) 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 (1995) 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 (1995) 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 (1995) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for spreader stoker firing configuration. [p] USEPA (1995) 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 NO_x 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 (1995) 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 (1995) 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 (1995) 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 (1995) Pg 1.1-6 and 1.1-23. Uncontrolled emissions for overfeed stoker firing configuration. [w] USEPA (1995) 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 (1995) 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 (1995) Pg 1.1-7 and 1.1-23. Uncontrolled emissions for hand fired units. [z] USEPA (1995) Pg 1.9-3. Assume CH₄ constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion). [aa] USEPA (1995) Pg 1.10-3. Assume CH₄ constitutes 38% of total organic emissions for fireplace (USEPA recommendation for wood combustion). [ab] USEPA (1995) 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 (1995) 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.A.5 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
Petrol												
Post 97	0.0070	USEPA (as cited in IPCC 2006)	0.0550		0.0047	Hot urban EF x Copert IV (IPCC 2006)	0.0100	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.0820		0.0090	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.0390		0.0340		0.0298		0.0400		0.0720		0.0300	
1985 – 1997 (2-way cat)	0.1120	FORS 1996	0.0090		0.0627	non-urban to urban ratio	0.1100		0.0990	USEPA (as cited in IPCC 2006)	0.0850	
1976 – 1985	0.1250	Carnovale 1991	0.0590		0.0650	Carnovale 1991	0.1400		0.0670		0.0870	
Pre 76	0.1330		0.0620		0.1120		0.1500		0.0710		0.1000	
LPG												
Post 97	0.0240		0.0240		0.0105	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.0240	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.0240	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.0110	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.0240	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.0240		0.0105		0.0240		0.0240		0.0110	
1985 – 1997 (2-way cat)	0.0328		0.0328		0.0143		0.0330		0.0330		0.0140	
1976 – 1985	0.0313		0.0313		0.0137		0.0310		0.0310		0.0140	
Pre 76	0.0316		0.0316		0.0138		0.0320		0.0320		0.0140	
ADO												
Post 97	0.0010		0.0000		0.0000		0.0010	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.0000	USEPA (as cited in IPCC 2006)	0.0000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.0010	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.0000		0.0004	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.0010		0.0000		0.0004	
1985 – 1997 (2-way cat)	0.0014		0.0000		0.0011		0.0014		0.0000		0.0011	
1976 – 1985	0.0013		0.0000		0.0006		0.0013		0.0000		0.0006	
Pre 76	0.0013		0.0000		0.0006		0.0013		0.0000		0.0006	

Sources (as indicated in table): FORS (1996) Carnovale (1991) IPCC (2006)

Table 3.A.6 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	Source	Hot	Cold	Source	Hot	Cold	Source	Hot	Cold	Source
Petrol	EF (g/km)	EF (g/start)	Source	EF (g/km)	EF (g/start)	Source	EF (g/km)	EF (g/start)	Source	EF (g/km)	EF (g/start)	Source
Post 97	0.0288	0.1130		0.0048	0.0800	Hot urban EF	0.2000	0.0800		0.0800		Hot urban EF
1985 – 1997 (3-way cat)	0.0288	0.0920		0.0054	0.0480	x Copert	0.1530	0.0480		0.0480		x Copert
1985 – 1997 (2-way cat)	0.0113	0.0720		0.0021	0.0150	IV (IPCC 2006)	0.0930	0.0150	USEPA (as cited in IPCC 2006)	0.0150		IV (IPCC 2006)
1976 – 1985	0.0042	0.0280	Weeks et al 1993	0.0019	0.0050	non-urban to urban ratio	0.0320	0.0050		0.0050		non-urban to urban ratio
	0.0027	0.0280		0.0018	0.0030		LCV to car EF ratio	0.0020		0.0020		
LPG												
Pre 76												
Post 97	0.0160	0.0160		0.0064	0.0160	Hot urban EF	0.0160	0.0060		0.0060		Hot urban EF
1985 – 1997 (3-way cat)	0.0055	0.0055		0.0013	0.0055	x Copert	0.0060	0.0010	Hot EF x Copert	0.0010		x Copert
1985 – 1997 (2-way cat)	0.0028	0.0028	Petrol EF x USEPA 2006	0.0017	0.0028	IV (IPCC 2006)	0.0030	0.0020	USEPA 2006 LPG to petrol EF ratio	0.0020		IV (IPCC 2006)
1976 – 1985	0.0026	0.0026		0.0000	0.0026	non-urban to urban ratio	0.0030	0.0000		0.0000		non-urban to urban ratio
	0.0017	0.0017		0.0000	0.0017		0.0020	0.0000	2006 cold to hot ratio	0.0000		2006 non-urban to urban ratio
ADO												
Pre 76												
Post 97	0.0032	0.0000		0.0014	0.0032	Hot urban EF	0.0000	0.0010		0.0010		Hot urban EF
1985 – 1997 (3-way cat)	0.0011	0.0000		0.0017	0.0011	x Copert	0.0000	0.0020		0.0020		x Copert
1985 – 1997 (2-way cat)	0.0006	0.0000	Petrol EF x USEPA 2006	0.0011	0.0006	IV (IPCC 2006)	0.0000	0.0010	USEPA (as cited in IPCC 2006)	0.0010		IV (IPCC 2006)
1976 – 1985	0.0005	0.0000		0.0000	0.0005	non-urban to urban ratio	0.0000	0.0000		0.0000		non-urban to urban ratio
	0.0003	0.0000	petrol EF ratio	0.0000	0.0003		EF ratio	0.0000		0.0000		

Sources (as indicated in table): Weeks (1993) IPCC (2006)

Table 3.A.7 Passenger and light commercial vehicles: emission factors for indirect gases

Fuel type	Passenger Car			LCV		
	NOx	CO	NM VOC	NOx	CO	NM VOC
Petrol						
<i>Post 97</i>	0.225	0.869	0.077	0.459	1.516	0.236
<i>1985 – 1997 (3-way cat)</i>	0.450	3.850	0.294	0.917	6.712	0.894
<i>1985 – 1997 (2-way cat)</i>	0.930	5.460	0.260	1.895	9.519	0.791
<i>1976 – 1985</i>	1.400	14.900	1.419	2.853	25.977	4.314
<i>Pre 76</i>	2.460	24.000	2.275	5.014	41.842	6.914
LPG						
<i>Post 97</i>	0.472	2.327	0.199	0.472	2.327	0.199
<i>1985 – 1997 (3-way cat)</i>	0.942	10.305	0.755	0.942	10.305	0.755
<i>1985 – 1997 (2-way cat)</i>	1.947	14.614	0.669	1.947	14.614	0.669
<i>1976 – 1985</i>	2.931	39.881	3.647	2.931	22.875	3.647
<i>Pre 76</i>	5.150	64.238	5.846	5.150	36.846	5.846
ADO						
<i>Post 97</i>	0.250	0.116	0.062	0.250	0.116	0.062
<i>1985 – 1997 (3-way cat)</i>	0.500	0.515	0.237	0.500	0.515	0.237
<i>1985 – 1997 (2-way cat)</i>	1.034	0.731	0.210	1.034	0.731	0.210
<i>1976 – 1985</i>	1.556	1.994	1.144	1.556	1.994	1.144
<i>Pre 76</i>	2.734	3.212	1.833	2.734	3.212	1.833

Table 3.A.8 Passenger and light commercial vehicles: non-carbon dioxide emission factor deterioration rates (g/km/km)

	Passenger Vehicle Age Class				
	Pre '76	'76-'85	'85-'97 ^a	'85-'97 ^b	Post '97
CH ₄	6.35E-07	4.76E-07	8.43E-07	1.49E-06	8.43E-07
N ₂ O	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;

Sources: NSW EPA 1995

Table 3.A.9 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						
	Petrol	0.026	0.009	2.524	10.871	1.043
	ADO	0.157	0.025	5.200	6.438	1.152
	LPG	0.220	0.020	4.830	24.000	4.210
	NG ^e	0.504	0.005	5.985	0.948	0.05
Heavy Trucks						
	Petrol	0.026	0.009	2.524	10.871	1.043
	ADO	0.157	0.025	5.200	6.438	1.152
	LPG	0.22	0.02	4.83	24	4.21
	NG ^e	1.68	0.02	19.96	3.33	0.17
Buses						
	Petrol	0.15	0.005	3.91	48.61	3.47
	ADO	0.03	0.025	4.9	2.88	1.56
	LPG	0.12	0.011	2.76	24	2.41
	NG ^e	1.41	0.014	16.756	2.793	0.14
Motorcycles						
	Petrol	0.15	0.002	0.21	19.27	4.58
Passenger Cars						
	NG ^e	0.968	0.004	0.704	0.408	0.074
Light Commercial Vehicles						
	NG ^e	1.006	0.004	0.732	0.424	0.077

Sources: (a) Hoekman (1992); (b) Weeks et al. (1993); (c) Carnovale (1991); (d) NSW EPA (1995); (e) de Maria (1992).

Table 3.A.10 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%			

Sources: Derived from Farrington 1988 and ABS 2006c..

Table 3.A.11 Shares of total road fuel consumption by vehicle and fuel type 2004

Vehicle Type	Fuel Type			
	Automotive Gasoline	ADO	LPG	NG _a
Passenger cars	0.845	0.108	0.715	0.053
Light commercial vehicles	0.146	0.179	0.261	0.053
Medium duty trucks	0.002	0.254	0.005	0.006
Heavy duty trucks	-	0.403	-	-
Buses	0.002	0.05	0.019	0.889
Motor cycles	0.005	-	-	-

Source: ABS 2006b. (a) Apelbaum 2006

Table 3.A.12 Australian petrol-fuelled passenger and light commercial vehicle stock age distribution and fuel consumption rates: 2004

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles	
	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2004	347557	0.111	47350	0.130
2003	697069	0.108	91810	0.130
2002	635619	0.108	74456	0.130
2001	618439	0.111	68677	0.130
2000	630776	0.113	64555	0.130
1999	599718	0.112	69387	0.130
1998	641976	0.114	65076	0.130
1997	568311	0.110	54620	0.130
1996	482881	0.110	54557	0.130
1995	488132	0.110	52361	0.130
1994	455414	0.110	53577	0.130
1993	402280	0.110	42189	0.130
1992	373723	0.110	43960	0.130
1991	348316	0.110	38594	0.130
1990	396525	0.111	46686	0.130
1980 – 1989 a	1790437	0.117	296589	0.128
1979 and earlier	384312	0.122	127589	0.129

 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 2006a, 2006b.

Table 3.A.13 Australian diesel-fuelled passenger and light commercial vehicle stock age distribution and fuel consumption rates: 2004

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles	
	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2004	16376	0.125	3018	0.130
2003	29065	0.125	6282	0.130
2002	24268	0.125	6908	0.130
2001	20932	0.125	12404	0.130
2000	19702	0.125	16313	0.130
1999	16886	0.125	11328	0.130
1998	16227	0.125	8368	0.130
1997	54620	0.125	14440	0.130
1996	54557	0.125	17630	0.130
1995	52361	0.125	20430	0.130
1994	53577	0.125	16292	0.130
1993	42189	0.125	20774	0.130
1992	43960	0.125	22207	0.130
1991	38594	0.125	25055	0.130
1990	46686	0.125	24116	0.130
1980 – 1989 a	174760	0.118	344569	0.123
1979 and earlier	2123	0.095	5607	0.110

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 2006a, 2006b.

Table 3.A.14 Australian LPG-fuelled passenger and light commercial vehicle stock age distribution and fuel consumption rates: 2004

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles	
	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2004	2035	0.170	912	0.158
2003	5456	0.170	1945	0.158
2002	4026	0.170	2051	0.158
2001	5045	0.170	2544	0.158
2000	2420	0.170	1542	0.158
1999	977	0.170	248	0.158
1998	875	0.170	158	0.158
1997	13337	0.170	154	0.158
1996	11628	0.170	250	0.158
1995	12249	0.170	171	0.158
1994	13580	0.170	286	0.158
1993	13432	0.170	205	0.158
1992	16393	0.170	213	0.158
1991	14448	0.170	239	0.158
1990	13876	0.170	324	0.158
1980 – 1989 a	38780	0.169	2954	0.154
1979 and earlier	2144	0.288	2205	0.160

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 2006a, 2006b.

Table 3.A.15 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	0.212	0.279	0.275
Heavy duty trucks	0.341	0.55	0.40
Buses	0.145	0.274	0.442
Motor Cycles	0.063	NA	NA

Source: ABS 2006b. (a) Refer to Table 3.A.12 - 3.A.14.

Table 3.A.16 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 30.6 Mt CO₂-e in 2004, or 5.8% of net national emissions (Table 4.1).

Table 4.1 Industrial processes sector CO₂-e emissions, 2004

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	19,530	69	19	5,356	30,571
A Mineral products	5,593	NA	NA	NA	5,593
B Chemical industry	848	9	IE	NA	857
C Metal production	13,088	61	19	1,486	14,654
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	4,405	4,405
G Other ^(a)	C	C	C	NA	5,062

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

Metal production contributed 47.9% (14.7 Mt CO₂-e) of the sector's emissions, *mineral products* contributed 18.3% (5.6 Mt CO₂-e), *chemical industries* contributed 2.8% (0.9 Mt CO₂-e), and the *consumption of halocarbons* (HFCs) contributed 14.4% (4.4 Mt CO₂-e).

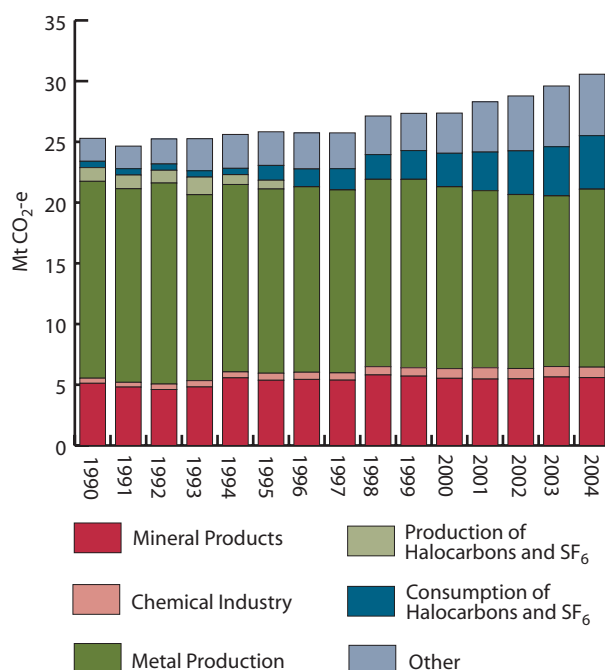
Activity data for soda ash production and use, magnesia production, nitric acid production ammonia production, acetylene use, titanium production and N₂O use in aerosols and anesthesia are commercial-in-confidence and, due to the direct relationship between activity and emissions, emissions estimates by gas species are also confidential. These emissions are aggregated and reported as CO₂-e emissions. Total emissions from this subsector are 5.1 Mt CO₂-e.

The main gas emitted by *industrial processes* is carbon dioxide, contributing 63.9% (19.5 Mt) of the sector's emissions in 2004. PFCs contributed 4.9% (1.5 Mt), HFCs contributed 12.7% (3.9 Mt), SF₆ contributed 1.7% (0.5 Mt), nitrous oxide contributed 0.1% (0.02 Mt), and methane 0.2% (0.1 Mt). CO₂-e emissions from the subsectors where data are confidential contributed 16.6% (5.1 Mt).

Trends

Net emissions from *industrial processes* increased by 20.9% (5.3 Mt CO₂-e) from 1990 to 2004 and increased by 3.2% (1.0 Mt CO₂-e) from 2003 to 2004 (Figure 4.1). The increases in sectoral emissions observed 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 2004 is shown in Figure 4.1.

Figure 4.1 Emissions from industrial processes by subsector, 1990–2004



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 used to estimate emissions from 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	T2	CS	T2	CS	T1	D	M,T1	D	T1c	CS	T2	CS
A. Mineral Products	T2	CS	NA	NA	NA	NA						
1. Cement Production	T2	CS	NA	NA	NA	NA						
2. Lime Production	T2	CS	NA	NA	NA	NA						
3. Limestone and Dolomite Use	T2	CS	NA	NA	NA	NA						
4. Soda Ash Production and Use	T2	CS	NA	NA	NA	NA						
6. Road Paving with Asphalt	NE	NA	NA	NA	NA	NA						
7. Other (please specify)												
Magnesia production	T2	CS	NA	NA	NA	NA						
B. Chemical Industry	T1,T2	CS,D	T2	D	T2	CS	NA	NA	NA	NA	NA	NA
1. Ammonia Production	T1b	D	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
2. Nitric Acid Production	NA	NA	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
5. Other (please specify)												
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	T1b	CS	T2	CS	T2	CS			T1c	CS	T2	CS
1. Iron and Steel Production	T1b	CS	T2	CS	T2	CS			NA	NA	NA	NA
3. Aluminium Production	T1b	CS	NA	NA	NA	NA			T1c	CS	NA	NA
4. SF ₆ Used in Aluminium and Magnesium Foundries	NA	NA	NA	NA	NA	NA			NA	NA	T2	CS
5. Other (please specify)												
Other Metals	IE	IE	NA	NA	NA	NA			NA	NA	NA	NA
D. Other Production	NA	NA										
E. Production of Halocarbons and SF₆							T1	D	NA	NA	NA	NA
1. By-product Emissions							NA	NA	NA	NA	NA	NA
Production of HCFC-22							T1	D	NA	NA	NA	NA
Other							NA	NA	NA	NA	NA	NA
F. Consumption of Halocarbons and SF₆							M	D	NA	NA	T2	CS
1. Refrigeration and Air Conditioning Equipment							M	D	NA	NA	NA	NA
2. Foam Blowing							M	D	NA	NA	NA	NA
3. Fire Extinguishers							M	D	NA	NA	NA	NA
4. Aerosols/ MDIs							NE	NE	NA	NA	NA	NA
5. Solvents							M	D	NA	NA	NA	NA
6. Semiconductor Manufacture							NO	NO	NA	NA	NA	NA
7. Electrical Equipment							NA	NA	NA	NA	T2	CS
8. Other (please specify)							NA	NA	NA	NA	NA	NA
G. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: EF = Emission Factor, T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS= Country-specific, D= IPCC default, NE = not estimated, NA= not available, IE = included elsewhere, NO = not occurring.

Data Sources

The inventory for the Industrial Processes sector relies on an annual survey of industries conducted by Burnbank Consulting for the Australian Greenhouse Office. 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

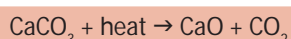
Industrial Processes Sector	Activity data
2.A.1. Cement clinker	Cement Industry Federation
2.A.2. Lime	Pacific Lime, Blue Circle Southern Cement, Adbri (Adelaide Brighton Cement and Cockburn Cement), Loongana Lime, Unimin, Hyrock and Queensland Alumina
2.A.3. Limestone and dolomite	BlueScope Steel, OneSteel, ACI, Amcor, Temmco, MIM, Smorgon, Zinifex
2.A.4. Soda ash	Penrice Soda Products
2.A.6. Bitumen	ABARE Commodity Statistics
2.A.7. Magnesia Production	Qmag, Causmag
2.B.1. Ammonia	Incitec, Wesfarmers CSBP, BHP Billiton, Queensland Nitrate
2.B.2. Nitric acid	Incitec, Wesfarmers CSBP, Queensland Nitrate
2.B.5. 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.B.5 Synthetic Rutile and Titanium Dioxide	WA Department of Minerals and Energy, Ti-west, Iluka Resources Milenium Chemicals
2.C.1. Iron and steel	BlueScope Steel, OneSteel and Smorgon Steel
2.C.3. Aluminium	Australian Aluminium Council
2.C.4. SF ₆ used in metal production	CSIRO, Brisbane
2.C.5. Other (sulphur dioxide)	ABARE Commodity Statistics for various metals
2.D.2. 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 and Heritage 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, flyash 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 et al 1992). A value of 0.66 had been adopted, based on industry 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).

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

Table 4.4 Australian cement clinker production and emissions 1990:2000–2004

Year	Clinker production (kt)	Cement Kiln Dust (kt)	Emissions (GgCO 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

Source: Burnbank 2006.

4.3.2 LIME PRODUCTION (2.A.2)

Source Category Description

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

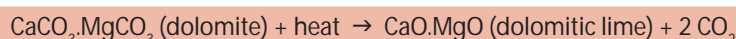
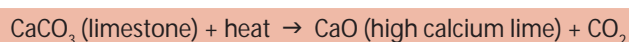
CO₂ emissions associated with the production of commercial and in-house lime are accounted for under this category. In-house lime production is undertaken by the steel and alumina industries, although only the

emissions from alumina are reported under this category (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.A.3). 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.A.3 (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: 2000–2004

Year	Lime production (kt)	Emissions (GgCO 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

Source: Burnbank 2006.

4.3.3 LIMESTONE AND DOLOMITE USE (2.A.3)

Source Category Description

Apart from use in clinker and lime production, limestone (CaCO₃) and dolomite (CaCO₃.MgCO₃) 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 CO₂ 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.A.3).

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 CO₂ 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 CO₂; 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 CO₂ emissions E are estimated from total limestone A_{ls} and dolomite use A_d and the relevant fractional purities and emission factors:

$$E = A_{ls} \cdot F_{ls} \cdot EF_{ls} + A_d \cdot F_d \cdot EF_d$$

Table 4.6 Limestone and dolomite consumption and emissions 1990:2000–2004

Year	Limestone Use (kt)	Limestone Use Emissions (Gg)	Dolomite Use (kt)	Dolomite Emissions (GgCO 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

Source: Burnbank 2006.

4.3.4 SODA ASH PRODUCTION AND USE (2.A.4)

Source Category Description

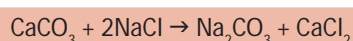
Soda ash (sodium carbonate, Na₂CO₃) is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper manufacture and water treatment. Coke used in soda ash manufacture is commercially purchased and the CO₂ emissions associated with its use are 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, magnesium and nitric acid production and reported under '2.G Other: Confidential emissions reported as CO₂-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 CO₂ 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 CO₂ 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 CO₂ is emitted. The mass of CO₂ 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 CO₂ and 105.99 is the molecular weight of Na₂CO₃).

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

Table 4.7 Soda Ash use and emissions

Year	Soda ash use (kt)	Emissions (GgCO ₂)
1990	450	186
2004	C	C

Source: Burnbank 2006.

4.3.5 ASPHALT ROOFING (2.A.5)

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

4.3.6 ROAD PAVING WITH ASPHALT (2.A.6)

Source Category Description

Cutback bitumen is the most common form of primer used in Australia to protect roads from excessive wear. Cutback bitumen primers and primer binders are manufactured from refined bitumen which are 'cutback' (i.e. blended) with petroleum solvents. NMVOC emissions occur during the mixing of bitumen batches, stockpiling, application and curing of the road surface.

Methodology

According to Treadrea (1995), for a system in equilibrium where the quantity of NMVOC used is constant each year and the average temperature conditions do not vary significantly from year to year, the quantity of flux and cutter lost to the atmosphere will be approximated by the quantity used each year.

It is assumed that the quantity of fluxed bitumen is negligible; the fraction of total bitumen consumption used in cutback bitumen is approximately 42 per cent (Australian Asphalt Pavement Association 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 2005).

4.3.7 OTHER (2.A.7) MAGNESIA AND GLASS PRODUCTION

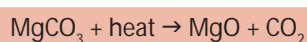
Source Category Description

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.A.3 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 2004

	Raw material(kt)	CaCO ₃ (kt)	Emissions (GgCO ₂)	Carbon (kt)
<i>Limestone use</i>				
2.A.1 Cement – clinker	8,712	7,841	3,450 c	941
2.A.2 quicklime production – in-house lime	109	102	45	12
2.A.2 quicklime production – commercial lime	2,722	2,341	1,030	281
2.A.3 Limestone use	1,615	1,453	639	174
Change in stocks, statistical discrepancy, and residual available for agriculture and non-pyro processes	3,570	-	-	-
Total Use ^(a)	17,125			1,718
<i>Limestone supply</i>				
Production	16,911			
Net imports	214			
Total supply ^(b)	17,125			

Source: a) AGO b) ABARE b) ABARE 2005a c) Clinker emissions excluding those from the calcination of magnesium carbonates

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 2003 INVENTORY

Recalculations for the 2004 inventory were performed following:

- a) a revision to the cement clinker CO₂ emission factor to take into account the calcination of magnesium carbonate;
- b) revised activity data for in-house lime production and limestone and dolomite use.

The above recalculations resulted in a 0.12 Mt increase in 1990 and a 0.13 increase in emissions in 2004 in 2.A Mineral Products.

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.B.1)

Source Category Description

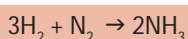
The overall manufacturing process for ammonia production involves a series of stages to remove impurities such as sulphur, carbon monoxide, carbon dioxide and water from the natural gas feedstock and the generation and reaction of hydrogen and nitrogen. The multi stage process involved in ammonia production (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.

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.B.2)

Source Category Description

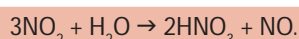
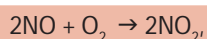
The manufacture of nitric acid (HNO₃) generates nitrous oxide (N₂O) as a by-product of the high temperature catalytic oxidation of ammonia (NH₃). Nitric acid is used as a raw material mainly in the manufacture of nitrogenous agricultural fertiliser.

Nitric acid is produced by three producers in Australia; Wesfarmers, Incitec and QLD Nitrate. All companies provided data for the 2004 Inventory. Nitric acid production data and emissions are confidential and are

reported under '2.G Other: confidential emissions reported as CO₂ 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 N₂O and nitrogen dioxide (NO₂) at high pressures for temperatures in the range of 30 to 50°C.

The emission factor for N₂O 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 N₂O, E_n, from the manufacture of nitric acid production A_n is calculated according to:

$$E_n = A_n \cdot EF_n$$

4.4.3 ADIPIC ACID PRODUCTION (2.B.3)

There is no adipic acid production occurring in Australia.

4.4.4 CARBIDE PRODUCTION (2.B.4)

Silicon carbide and calcium carbide are not produced in Australia. Minor quantities of acetylene are produced from imported calcium carbide and used in welding applications. Data are reported by one company, BOC, and have been included in '2.G Other: confidential emissions reported as CO₂ 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.B.5) 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 (TiO₂).

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.

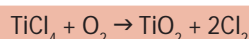
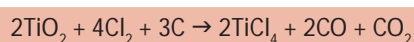
Synthetic rutile is produced in Australia by Iluka Resources and the Ti-West Joint Venture.

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 TiO_2 in Australia that lead to process greenhouse gas emissions are synthetic rutile production using the Becher process, and rutile TiO_2 production via the chloride route.

The Becher process reduces the iron oxide in ilmenite to metallic iron and then reoxidises it to iron oxide, and in the process separates out the titanium dioxide as synthetic rutile of about 91 to 93 per cent purity. Rutile TiO_2 is produced through the carbothermal chlorination of rutile ore or synthetic rutile to produce titanium tetrachloride (TiCl_4) and oxidation of the TiCl_4 vapours to TiO_2 according to the following reactions (Kirk-Othmer, 1999; p.2017):



Based on stoichiometry and assuming complete conversion of the input C to CO_2 through further conversion of CO in excess air, the CO_2 emission factor cannot be less than 0.826 tonnes of CO_2 per tonne of TiO_2 (based on 1.5 moles of CO_2 per mole of TiO_2).

Emissions from rutile and TiO_2 respectively may be calculated by:

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

Data on synthetic rutile production were obtained from various Statistics Digests published by the WA Department of Minerals and Energy. TiO_2 production is provided by Ti-West and Millennium Chemicals. Cefic (the European Chemical Industry Council) provided an emission factor for TiO_2 production which is applied to Millennium's TiO_2 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.

Emissions from the production of TiO_2 are confidential. For reporting purposes, emissions estimates from TiO_2 production are aggregated with confidential emissions from soda ash, ammonia, magnesia, nitric acid production and N_2O from aerosols and anaesthesia and reported under '2.G Other: Confidential emissions reported as CO_2 -equivalent'.

Table 4.9 Australian synthetic rutile production and emissions 1990–2004

Year	Synthetic Rutile production (kt)	Emissions (Gg CO_2)
1990	284	407
2000	553	791
2001	643	921
2002	586	839
2003	597	855
2004	592	848

Source: Burnbank 2006.

4.4.6 OTHER (2.B.5) POLYMERS AND OTHER CHEMICALS

Source Category Description

The manufacture of organic chemicals results in process emissions of NMVOC. Other gases such as CO_2 , CH_4 , N_2O , NO_x and CO may also be generated depending on the manufacturing process.

Complete time series of emissions of CH_4 and NMVOCs are included in the inventory for 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 and sources for organic chemicals

Subsector	CO ₂ (kg/tonne)	CH ₄ (kg/tonne)	NM VOC (kg/tonne)
Acetylene ^a	1,692 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: Burnbank 2006.

Notes: (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:

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

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.

4.4.9 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations for the 2004 inventory were performed following:

- a) reallocation of emissions from the production of titanium dioxide to 2.G Confidential emissions reported as CO₂-e.

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.C.1)

Source Category Description

Iron and Steel production is a key source in the Australian inventory. Emission sources relate to the in-house production of metallurgical coke and lime, the use of limestone and dolomite as flux in iron, steel and ferro-alloy production and fugitive gas leaks associated with the distribution of coke oven gas and other products within industrial premises. In-house lime production as well as limestone and dolomite use is accounted for under 2.A.3.

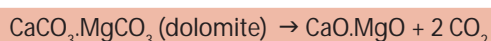
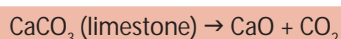
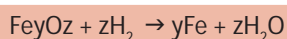
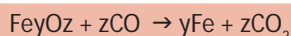
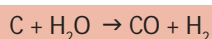
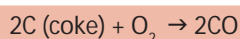
Metallurgical coke is an essential material in iron and steel production where it serves a number of major functions including the provision of a porous support for furnace ingredients, as a combustion ingredient producing the reducing atmosphere required for ore refinement and as a chemical reductant. 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.A.1 while the emissions generated by the combustion of coke oven gas to produce energy are reported under the industry category of sector 1.A.2.

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 hot briquetted iron (HBI) plant that used natural gas as a reductant in Western Australia is no longer in operation. Both 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)	119.5
Natural Gas	99.5 ^(b)	51.4

(a) IPCC (1997) default value.

(b) IPCC (1997) default value.

(c) All CO₂ emission factors are sourced from BlueScope Steel's predecessor, BHP Steel, and the Australian Gas Association.

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

Fuel Type	F: 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

Source: NGGIC 2006a

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 (J. Deslandes, pers. comm.), the average carbon content of raw steel is estimated to be 0.2%.

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 (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 from the Department of Industry, Tourism, and Resources, company websites, and company survey.

Table 4.13 Australian steel production, coke consumption and emissions

Year	Steel production (kt)	Coke consumption (kt)	Hot Briquetted Iron production (kt)	Natural Gas consumption (PJ)	Total emissions from iron and steel production (GgCO ₂ -e)
1990	6,223	87	NO	NO	10,255
2000	6,345	92	558	6	11,098
2001	6,027	77	1,223	22	10,162
2002	5,933	74	1,142	23	9,835
2003	6,282	67	1,670	34	9,580
2004	6,312	72	1,592	32	10,146

Source: Burnbank 2006, AGO.

4.5.2 FERROALLOYS PRODUCTION (2.C.2)

There is no ferroalloys activity occurring in Australia.

4.5.3 ALUMINIUM PRODUCTION (2.C.3)

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.

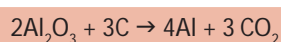
Alumina is calcined at about 1200°C to eliminate chemically and physically bound water from the alumina, and to impart crystalline properties which are advantageous for aluminium production.

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.A.2).

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 2004 Inventory and production data were obtained from ABARE 2005a.

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 (Na₃AlF₆) 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 CO₂ 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% CO₂ 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 CO₂ immediately above the electrolyte.

Carbon emitted during electrolysis is reported as if all the carbon is oxidised to CO₂ (at a rate of 1.514 tonnes of CO₂ 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:

$$E_{al} = A_{Al} \cdot EF_{Alap} + A_{Al} \cdot EF_{Alac}$$

The perfluorinated carbon compounds (PFC), tetrafluoromethane (CF₄) and hexafluoroethane (C₂F₆) 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 CF₄ and C₂F₆ 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).

Table 4.14 Emission factors: kg per tonne of aluminium production

Year	CO ₂	CF ₄	C ₂ F ₆
1990	1633.54	0.414	0.054
2000	1584.71	0.083	0.011
2001	1601.34	0.113	0.015
2002	1645.05	0.108	0.014
2003	1626.36	0.103	0.013
2004	1611.24	0.103	0.013

Source: Burnbank 2006.

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 2005a.

Table 4.15 Aluminium: production and emissions

Year	Aluminium production (kt)	Emissions (GgCO ₂ -e)
1990	1,235	5,956
2000	1,742	3,874
2001	1,788	4,414
2002	1,809	4,482
2003	1,855	4,474
2004	1,877	4,508

Source: Burnbank 2006.

4.5.4 SF₆ USED IN ALUMINIUM AND MAGNESIUM FOUNDRIES (2.C.4)

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.C.5)

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.A.3. Other industries that consume limestone include copper smelting, foundries, ferromanganese 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	2.018
Lead	0.295
Nickel	1.093
Silver	0.297
Zinc	0.980

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.

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 between 1990 and 2004 has mirrored the decline internationally (75%), whereas the International Aluminium Institute 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.

Table 4.17 Emission factors: tonnes PFCs per tonne of aluminium production

Year	Tonnes PFCs (CO ₂ -e)/ tonne Al	
	Australia	IAI Survey
1990	3.2	4.03
2000	0.67	1.60
2001	0.87	1.25
2002	0.83	1.25
2003	0.79	1.09
2004	0.80	

Source: Burnbank 2006. International Aluminium Institute 2005.

4.5.8 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations for the 2004 inventory were performed following:

a) revision to the CO₂ and PFC emission factors in aluminium production.

The above recalculations resulted in a 0.01 Mt decrease in emissions in 2004 in 2.B Metal Production.

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. In accordance with IPCC guidelines, the fermentation of sugar by industry is not considered to be a net source of CO₂ emissions. 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 (2005a).

4.6.2 METHODOLOGY

Food and drink emissions are based on tier 2 methods and IPCC default and country specific methodologies. Generally the methods involve the product of activity level data (the amount of material produced or consumed) and an associated emission factor per unit of production or consumption.

A full description of the methodologies and emission factors is presented in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Industrial Process Emissions* (NGGIC 2006d).

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 2004 INVENTORY

Nil.

4.6.6 PLANNED IMPROVEMENTS

Activity data and emission factors are kept under review.

4.7 SOURCE CATEGORY PRODUCTION OF HALOCARBONS AND SF₆ (2.E)

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 CONSUMPTION OF HALOCARBONS AND SF₆ (2.F)

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 Environment and Heritage 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 2005 financial year are shown in Table 4.18.

Table 4.18 Quantities of HFCs imported in bulk in 2005

Total Imports, Mt CO ₂ -e	2005
HFC-134a	2.96
Other HFC	3.06
Exotic HFC	0.03
SUM HFC	6.04

Source: Australian Government Department of the Environment and Heritage

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 4.19.

Table 4.19 End-use allocation of bulk and pre-charged HFCs (2005)

End Use Breakdown	Bulk Imports 2005 (Mt CO ₂ -e)	Pre-charged imports 2005 (Mt CO ₂ -e)
Refrigeration	3.228	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	0.441	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	2.045	0.38
Cars	1.494	0.34
Trucks	0.550	0.04
Foam	0.102	-
Aerosols/solvents	0.159	-
Fire equipment	0.069	-
TOTAL	6.044	1.477

Source: Australian Government Department of the Environment and Heritage

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 4.19, information on the transition into HFC use has been used to determine a time-series of HFC consumption.

Refrigeration and Air conditioning (2.F.1)

The refrigeration and air-conditioning sector accounts for the majority of HFC consumption in Australia.

Emissions from any piece of equipment include both the amount of chemical leaked during 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 2005a), 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 4.20. 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 4.20.

Table 4.20 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 charged
			Initial	Operation		
Domestic refrigeration	0.157	15	0.6	0.3	95	70
Split System airconditioners	1.90	15	0.6	5.5	60c	81
Packaged system airconditioners	0.99	15	0.6	5.5	60c	81
Refrigerated-portable systems	0.60	15	0.6	5.5	60c	81
Mobile airconditioners	0.69	12	0.5	15	25c	37

Sources: a) AGO 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 4.21 and 4.22.

Table 4.21 Refrigerator/freezer stocks and the associated bank and emissions of HFC-134a

Year	Total fridge Population ^a	Domestic Production ^b	Imports ^{b,c}	Disposals ^e	Bank (Mt CO ₂ -e) ^d	Emissions (Mt CO ₂ -e) ^d
1994	8,382,200	372,200	194,200		0.115	0.001
1995	8,578,400	349,600	226,400		0.232	0.001
1996	8,774,600	378,500	207,300		0.351	0.002
1997	8,970,900	338,400	257,200		0.473	0.002
1998	9,167,100	329,700	275,700		0.596	0.002
1999	9,363,300	301,500	313,700	28,300	0.715	0.006
2000	9,538,800	175,600	428,800	57,100	0.827	0.010
2001	9,714,300	84,900	529,200	86,400	0.935	0.015
2002	9,889,800	161,900	462,100	116,200	1.038	0.019
2003	10,162,100	203,000	527,700	146,400	1.157	0.024
2004	10,434,500	170,600	569,900	177,200	1.271	0.028

Sources: a) ABS 2005a; b) Burnbank 2002; c) Department of the Environment and Heritage; d) AGO Estimates; e) Disposal of units containing HFC 134a.

Table 4.22 Stationary airconditioner stocks and the associated bank and emissions of HFCs as CO₂ equivalent

Year	Total AC Population ^a	Sales ^c	Disposals ^c	Bank (Mt CO ₂ -e) ^b	Emissions (Mt CO ₂ -e) ^b
1995	8,518,700	39,700		0.10	0.01
1996	8,626,000	78,500		0.30	0.02
1997	8,733,400	116,300		0.59	0.04
1998	8,840,700	153,000		0.98	0.06
1999	8,948,100	188,800		1.46	0.09
2000	9,012,200	235,000	1,900	2.78	0.17
2001	9,076,400	274,200	5,900	4.36	0.26
2002	9,140,500	313,300	11,700	6.14	0.36
2003	9,418,200	462,600	19,300	8.15	0.48
2004	9,695,800	517,900	28,800	10.37	0.62

Sources: a) ABS 2005a; b) AGO 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 2006a data on the stock of motor vehicles have been used to construct a capital stock model. In Table 4.23 the 2004 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 4.23 Vehicle stocks and assumed air-conditioner penetration 1995-2004

Year of Manufacture	New vehicle population (2004) ^a	Percentage of vehicles with air-conditioning ^b
1995	532,839	95%
1996	533,809	95%
1997	561,958	95%
1998	657,817	100%
1999	677,482	100%
2000	607,036	100%
2001	685,835	100%
2002	666,672	100%
2003	704,170	100%
2004	755,338	100%

Source: a) ABS 2005a; 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 4.24.

Table 4.24 Estimated bank of HFC 134a contained in passenger vehicles 1995–2004 and associated emissions

Year	Bank(Mt CO ₂ -e)	Emissions(Mt CO ₂ -e)
1995	3.06	0.56
1996	3.55	0.65
1997	4.16	0.76
1998	4.85	0.89
1999	5.53	1.02
2000	6.39	1.12
2001	6.88	1.22
2002	7.33	1.31
2003	7.70	1.40
2004	7.94	1.49

Source: Australian Greenhouse Office.

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.F.2)

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.F.3)

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).

Aerosols/Metered Dose Inhalers and Solvents (2.F.4 and 2.F.5)

Emissions from these sectors come from two sources: product use and fugitive emissions associated with product manufacture. Emissions from solvent and aerosol product use can be assumed to be 100 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.

Semiconductor Manufacture (2.F.6)

There is no semiconductor manufacture activity occurring in Australia.

Electrical Equipment (2.F.7)

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 Environment and Heritage 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.

4.8.5 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations for the 2004 inventory were performed following:

- a) the development of a capital stock model for the estimation of HFC emissions from domestic stationary airconditioners; and,
- b) a revision to bulk HFC import and pre-charged equipment data.

The above recalculations resulted in a 0.5 Mt increase in emissions in 2004 in 2.F Consumption of Halocarbons and SF₆.

4.8.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

4.9 SOURCE CATEGORY CONFIDENTIAL EMISSIONS REPORTED AS CO₂-E (2.G)

4.9.1 SOURCE CATEGORY DESCRIPTION

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

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, 4.4.5, 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 2004 INVENTORY

Recalculations for the 2004 inventory were performed following:

- a) revision to nitric acid, ammonia and titanium dioxide production data;
- b) revised and N₂O emission factor in nitric acid production and CO₂ emission factor in titanium dioxide; and,
- c) the inclusion of CO₂ emissions from the production of titanium dioxide in confidential emissions reported as CO₂-e.

The above recalculations resulted in a 0.003 Mt increase in emissions in 1990 and a 0.2 Mt increase in 2004 in 2.G Confidential emissions reported as CO₂-e.

4.9.6 PLANNED IMPROVEMENTS

All relevant data are kept under constant review.

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 0.2 Mt NMVOC in 2004 (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 2004

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	68
B Degreasing and dry cleaning	NA	36
C Chemical products manufacture and processing	NA	1
D Other	IE	48

Paint application contributed 44.4% (0.07 Mt NMVOC) of the sector's emissions, *degreasing and dry cleaning* contributed 23.6% (0.04 Mt NMVOC), *chemical products manufacture and processing* contributed 0.6% (0.001 Mt NMVOC), and *other* contributed 31.4% (0.05 Mt NMVOC).

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

Notes: (a) Australian Paint Manufacturers Federation (1995).

5.3.2 DEGREASING AND DRY CLEANING (3.B)

Surface cleaning or degreasing operations involve the removal of materials such as oils, grease, waxes and moisture from surfaces. In the commercial/industrial sectors, surface cleaning/degreasing is normally conducted in preparation for other treatment such as painting and electroplating.

There are three basic types of surface cleaning operations, which are used by commerce and industry. These operations are referred to as cold cleaning, vapour cleaning and in-line or conveyorised cleaning. 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

Notes: (a) US EPA (1991)

(b) ICI (1994).

5.3.3 CHEMICAL PRODUCTS MANUFACTURE AND PROCESSING (3.C)

Chemical products manufacture and processing covers paint and ink manufacturing.

Emissions associated with the refining and storage of petroleum products are not accounted in this chapter (see *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005: Fugitive Fuel Emissions*).

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

Notes: (a) Dulux (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 Anesthesia

Emissions of N₂O from aerosol products and anesthesia 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, 1994) have been used for Domestic/Commercial Aerosol Products and US data for aerosol spray products and miscellaneous non-aerosol spray products (USEPA 1997) have been adopted for estimating NMVOC emissions from Other Domestic/Commercial products and Consumer Cleaning Products.

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

Notes: (a) Aerosol Association of Australia (1994)

(b) USEPA (1997)

NMVOC emissions from general solvent use and consumer cleaning products are reported in table 5.5. The mean population for the financial year is multiplied by the 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 2004 INVENTORY

Nil

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 89.8 Mt CO₂-e emissions or 17.1% of net national emissions in 2004 (Table 6.1). The agriculture sector is the dominant national source of both methane and nitrous oxide-accounting for 58.5% (68.4 Mt CO₂-e) and 82.4% (21.4 Mt CO₂-e) respectively of the net national emissions for these two gases.

Greenhouse gas emissions from *livestock*, which are the sum of the *enteric fermentation* and *manure management* subsectors, declined by 6.5% (4.3 Mt) between 1990 and 2004, and by 0.7% (0.4 Mt) from 2003 to 2004. In contrast, there has been a 29.2% (6.4 Mt) increase in emissions from the remaining *agriculture* subsectors between 1990 and 2004. The net result of these trends is an increase of 2.4% (2.1 Mt) in greenhouse gas emissions from *agriculture* between 1990 and 2004, but a 1.2% (1.1 Mt) decrease from 2003 to 2004.

Table 6.1 Agriculture sector CO₂-e emissions, 2004

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)			
	CO ₂	CH ₄	N ₂ O	Total
4 AGRICULTURE	NA	68,397	21,368	89,794
A Enteric fermentation	NA	58,248	NA	58,248
B Manure management	NA	1,952	1,432	3,384
C Rice cultivation	NA	237	NA	237
D Agricultural soils	NA	NA	16,572	16,572
E Prescribed burning of savannas	NA	7,728	3,290	11,018
F Field burning of agricultural residues	NA	230	104	334

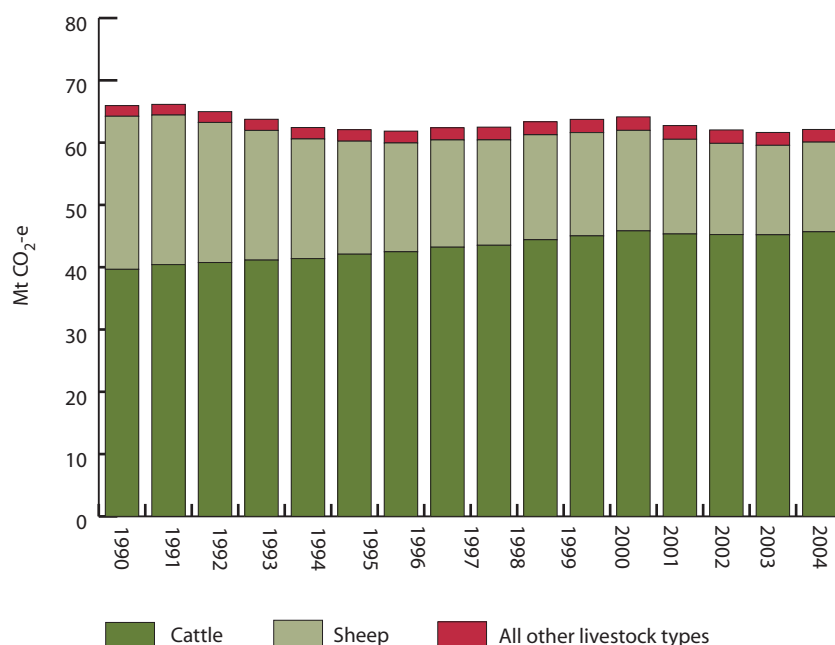
6.1.1 LIVESTOCK

Livestock emissions were 61.6 Mt CO₂-e in 2004, which represents 68.5% of the *agriculture* sector's emissions and 11.7% of net national emissions.

Trends

Livestock related emissions in 2004 were 6.5% (4.3 Mt) lower than in 1990 and 0.7% (0.4 Mt) lower than in 2003 (Figure 6.1). Between 1990 and 2004, cattle numbers have gradually increased from 24.8 million to 27.2 million (9.5%). This growth in cattle numbers is tending to drive up livestock emissions, particularly as emissions per head from cattle are about 12 times that per head of sheep. Against this trend, sheep numbers, after having peaked in 1990 at 173 million, have declined to 101 million (-41.7%) in 2004 due largely to reduced returns to the industry. The combined effect of these two trends is that *livestock* emissions peaked in 1991, declined between 1991 and 1996 and subsequently rose until 2001. The decline since 2001 is due to the widespread drought conditions in this period and the related declines in most animal populations. With an easing of drought conditions in some regions most populations had begun to increase in 2004.

N₂O emissions from Livestock increased by 172% (0.9 Mt CO₂-e) from 1990 to 2004 due to increasing intensification of the livestock industries (principally in feedlots). However, this results in little change to aggregate emissions because N₂O is such a small component (2%) of livestock emissions.

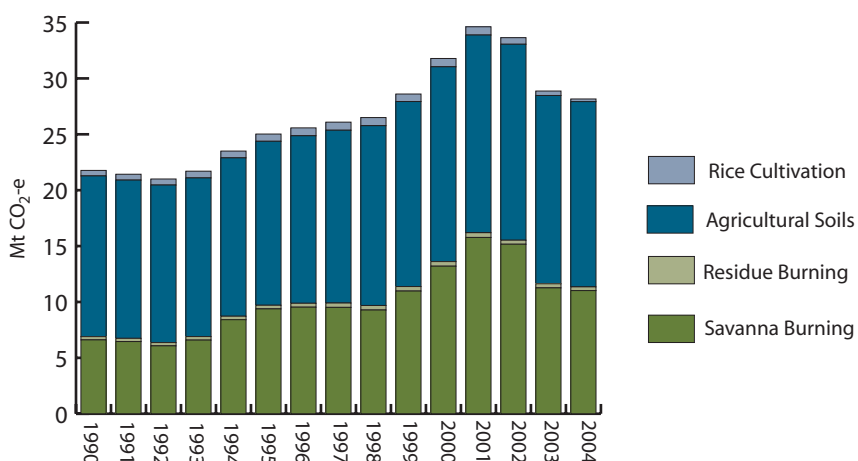
Figure 6.1 CO₂-e emissions from livestock, 1990–2004


6.1.2 OTHER AGRICULTURE

Total estimated emissions from the *other agriculture* subsectors in 2004 were 28.0 Mt CO₂-e. These include emissions from *rice cultivation* (0.2 Mt), *agricultural soils* (16.5 Mt), *prescribed burning of savannas* (11.0 Mt) and *field burning of agricultural residues* (0.3 Mt) (see Table 6.1).

Trends

Emissions from *other agriculture* in 2004 were 29.2% (6.4 Mt) higher than in 1990 but 2.6% (0.8 Mt) lower than in 2003. The increase since 1990 is principally a result of larger areas of savanna burnt since the mid-1990s compared to earlier years, and an increase in emissions from agricultural soils due to the growing use of synthetic fertilisers. The decrease from 2001 is due to the widespread drought conditions in this period and the related declines in agricultural production and the availability of water for irrigation so that emissions from agricultural soils and rice cultivation in particular fell.

Figure 6.2 Total emissions of other agriculture subsectors, 1990–2004


Savanna burning emissions are estimated to have increased by 66.7% (4.4 Mt) between 1990 and 2004. The higher emissions reflect higher fire activity (area burnt) rising from low levels early 1990s to a cyclical peak in 2001, followed by decreases over 2002–2004. The cause of the upward trend in fire activity to 2001 has been an increase in annual rainfall in the preceding seasons that promoted vegetation growth and fuel accumulation, and is most probably the result of natural variability within a long term climate cycle (Meyer, 2004).

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).

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.

Table 6.2a Methods and emission factors used to estimate agriculture emissions

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
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			T1	CS
b. Animal Wastes Applied to Soils			T1	CS
c. N-fixing crops			T1	IPCC
d. Crop Residues			T1	IPCC
e. Cultivation of Histosols			T1	IPCC
2 Animal Production			T1	CS
3 Indirect Emissions				
a. Atmospheric Deposition			T1	IPCC
b. Leaching and Run-off			CS	CS
4 Other			T2	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.A.1)

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 feed cattle in temperate Australia. This approach was selected as it has been widely used in methane inventories and is capable of reflecting the effect of feed quality on methane emissions. Although based on animals fed on diets representative of those in the UK, the digestibility of the feeds studied are within the ranges found in temperate Australia.

The equations derived by Blaxter and Clapperton (1965) do not reflect the breeds and feed types used in the tropics and sub-tropics of Australia. In a study of *Bos indicus* (Brahman) cattle on tropical feeds conducted in Australia, Kurihara et al. (1999) 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 energy⁵ 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 a country-specific method (Minson and McDonald 1987) based on research in Australia is used instead. Minson and McDonald (1987) have derived an equation that estimates feed intake relative to liveweight and liveweight gain of cattle. This relationship includes data for cattle on both tropical and temperate feeds. By setting the liveweight gain component of their equation to zero to calculate maintenance intake, it is possible to estimate the relative feed intake of cattle.

Lot Fed

Moe and Tyrrell (1979) devised equations for predicting methane emissions from dairy cattle fed diets consisting mostly of high digestibility grains and concentrates and high quality forages. The Moe and Tyrrell (1979) equation used relates methane production to the intake of three components of the dietary carbohydrate. These are: soluble residue, hemicellulose and cellulose. As feedlot cattle in Australia are fed diets consisting of high digestibility grains and concentrates, the Moe and Tyrrell (1979) equations were considered appropriate for estimating emissions.

Dairy Cattle

The large volumes of milk produced by dairy cattle under modern management regimes, nearly 5000 litres per annum, 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		

Notes: (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.

⁵It 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.

The equation presented in Minson and McDonald (1987) calculates feed intake of non-lactating cattle from liveweight and liveweight gain data. For lactating cattle the additional intake for milk production (MI_{ijk}) is included to give total intake (I_{ijk} kg dry matter/head/day):

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

Where: W_{ijk} = weight in kg (Appendix 6.A.1)

LWG_{ijk} = liveweight gain in kg/day (Appendix 6.A.2)

MR_l = increase in metabolic rate when producing milk (SCA 1990) 1.1 for milking and house cows and 1 for all other classes

The additional intake required for milk production (MI_{ijk} kg DM/head/day) is calculated by:

$$MI_{ijk} = MP_{ijk} \times NE / k_l / q_{m,ijk} / 18.4 \quad (4A.1a_2)$$

Where: MP_{ijk} = milk production (kg/head/day) from Dairy Australia State statistics

NE = 3.054 MJ net energy/kg milk (SCA 1990)

k_l = 0.60 efficiency of use of metabolizable energy for milk production (SCA 1990)

$q_{m,ijk}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ijk}). So using the equation of Minson and McDonald (1987), $q_{m,ijk} = 0.00795 DMD - 0.0014$; (where DMD is expressed as a %).

The gross energy intake (GEI_{ijk}) is the sum of the intake (I_{ijk}) converted into energy terms assuming a gross energy content of 18.4 MJ/kg (SCA 1990):

$$GEI_{ijk} = I_{ijk} \times 18.4 \quad (4A.1a_3)$$

The intake of the animals relative to that needed for maintenance (L_{ijk}) is calculated as actual intake divided by maintenance intake (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.A.3)

L_{ijk} = intake relative to that needed for maintenance

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

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

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:

$$E = \sum_{i=1}^3 7.3 \sum_j (365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \sum_{i=2}^3 \sum_j \sum_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (4A.1a_7)$$

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.B.1)

LWG_{ijkl} = live weight gain in kg/head/day (Appendix 6.B.2)

Feed intakes can increase by up to 60% during lactation (ARC 1980). For this study, the intake of all breeding cattle was increased by 30% during the season in which calving occurs and by 10% in the following season based on relationships presented in SCA (1990).

The additional intake for milk production ($MA_{ijkl=5}$) is calculated by:

$$MA_{ijkl=5} = (LC_{ijkl=5} \times FA_{ijkl=5}) + ((1-LC_{ijkl=5}) \times 1) \quad (4A.1b_2)$$

Where: $LC_{ijkl=5}$ = proportion of Cows >2 lactating (Appendix 6.B.5)

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

As feed dry matter has, on average, a gross energy content of 18.4 MJ/kg (SCA 1990), the dry matter intake is converted into gross energy intake (GEI_{ijkl} MJ):

$$GEI_{ijkl} = I_{ijkl} \times 18.4 \quad (4A.1b_3)$$

The intake of the animals relative to that needed for maintenance (L_{ijkl}) is calculated as actual intake divided by maintenance intake (ie. intake of non-lactating animal with liveweight gain is set to zero).

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

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

$$Y_{ijkl} = 1.3 + 0.112DMD_{ijkl} + L_{ijkl}(2.37 - 0.050DMD_{ijkl}) \quad (4A.1b_5)$$

Where: DMD_{ijkl} = digestibility of feed (expressed as a %) (Appendix 6.B.3)

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

The total daily production of methane (M_{ijkl} , kg CH_4 /head/day) for animals on temperate pastures is thus:

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

For animals on tropical pastures total daily production of methane (M_{ijkl} , kg CH_4 /head/day) is given by Kurihara

et al. (1999) 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

$F = 55.22 \text{ MJ/kg CH}_4$ from Brouwer (1965)

Feedlot cattle are assumed to originate entirely from the steers > 1 year old beef cattle class. To ensure these cattle are not double counted, it is necessary to subtract feedlot cattle numbers from beef cattle numbers in the steers > 1 year class in that State for the same year. Because feedlot cattle, on average, spend between 75 and 250 days on feedlots prior to slaughtering, an annual equivalent number is derived to represent the figure for feedlot cattle which is subtracted from steers > 1 year old - beef cattle numbers - to calculate emissions. The emissions from the feedlot cattle are calculated in section 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.

$(l=7) - \text{total feedlot numbers}$ = from Table 3, $l=7$ corresponds with steers > 1 year old. In order to calculate total beef cattle numbers in this class, total feedlot numbers, adjusted to annual equivalence must be subtracted from $l=7$. For WA 99 per cent of feedlot cattle are assumed to be sourced from the South-West region and the balance from the Pilbara and Kimberley.

Annual Australian methane production (Gg) for all classes of beef cattle across all seasons can then be calculated as:

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

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 CH₄/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.C.2), the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C.3) and the soluble residue, hemicellulose and cellulose fractions of each of these components (Appendix 6.C.4).

The total daily production of methane (M_{ij} kg CH₄/head/day) is thus:

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

Where: $F = 55.22$ MJ/kg CH₄ (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.A.3)

Estimated emissions are based on Howden et al. (1994) who report a close relationship between dry matter intake and methane production based on an analysis of Australian respiration chamber experiments with sheep fed diets typical of the range found in Australia (Margan et al. 1985, 1987, 1988 and Graham 1964a,b, 1967 and 1969). Howden et al. (1994) found that feed intake alone explained 87% of the variation in methane production.

The Agriculture and Food Research Council (AFRC) (1990) equation for intake is used here, as it corresponded well with intakes reported by State experts for seasonal digestibilities common in their State.

The methodology for estimating emissions from sheep has been independently verified. Leuning et al. (1999) found close agreement between the methane emissions estimated by the inventory methods and direct field measurements made using micrometeorological mass-balance and SF₆ tracer techniques. Using the inventory methods and default values Leuning et al. (1999) estimated CH₄ emissions to be 12.6 g/head/day compared with 11.9 and 11.7 g/head/day measured by the mass-balance and SF₆ tracer techniques respectively.

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 (kg CH₄ = 0.0187 x kg DMI - 0.0003) to that reported in Howden et al. (1994).

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.D.1)

$q_{m,ijk}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ijk}) so, using the equation of Minson and McDonald (1987), $q_{m,ijk} = 0.00795 DMD - 0.0014$ (DMD is expressed as a %)

However, the actual feed intake of animals is often less than the potential intake. This can be caused by many factors, especially by low feed availability. Relative intake is defined as the proportion of potential intake that the animal will consume. The relative intake due to feed availability is given by White *et al.* (1983) as:

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

Where: DMA_{ijk} = dry matter availability tonnes/hectare (Appendix 6.D.3)

Note: Actual feed intake will be less than potential intake only when feed availability is less than 1.63 tonnes/hectare.

The actual intake (I_{ijk} kg DM/head/day) of a sheep is thus:

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

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.D.6)

$FA_{ijk=4}$ = feed adjustment (assumed to be 1.3)

Methane production (M_{ijk} kg/head/day) is calculated using daily intake figures (I_{ijk}) via the relationship of Howden *et al.* (1994):

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

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.A.8)

Pigs are non-ruminant animals, and convert a smaller proportion of feed energy intake into methane than do ruminants. The OECD (1991) estimated that, depending on diet, pigs typically convert around 1% of gross energy intake into methane, compared with around 6–7% for cattle and sheep.

Whittemore (1993) suggests that the output of methane by a 60 kg pig is about 0.2 MJ/day. Assuming that, on

average, a 60 kg pig consumes 1.95 kg DM/day of a diet containing 18.6 MJ GE/kg, the GE intake was 36.3 MJ GE. Thus pigs would convert around 0.6% of gross energy into methane.

Other values in the literature suggest methane conversions of 1.2% of gross energy (Christensen and Thorbek 1987), 0.6 to 0.8% of gross energy (Moss 1993) and 0.4% gross energy (Kirchgessner et al. 1991).

A methane conversion of 0.7% of gross energy intake is used for Australia.

Table 6.7 Symbols used in algorithms for pigs

State (i)	Pig Classes (j)
i = 1 NSW/ACT	j = 1 Boars
i = 2 Tasmania	j = 2 Sows
i = 3 Western Australia	j = 3 Gilts
i = 4 South Australia	j = 4 Others
i = 5 Victoria	
i = 6 Queensland	
i = 7 Northern Territory	

The relationship for enteric fermentation in pigs gives the total daily production of methane (M_{ij} kg 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.E.1)

F = 55.22 MJ/kg CH₄ (Brouwer 1965)

18.6 = MJ GE/kg feed DM

The annual production of methane (G_g) 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.F.1)

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

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 AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6. As described in section 6.2.2.2, independent verification has been undertaken on the emission estimates for sheep.

6.3.9 RECALCULATIONS SINCE THE 2004 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. Emissions from tropical beef cattle are now based on Kurihara et al. (2006) replacing Kurihara et al. (1999). In addition, as part of ongoing QA/QC, changes have been made to a number of dairy cattle, poultry and minor livestock categories to include years where data were missing or to replace preliminary data.

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 x10⁻⁵ kg CH₄/kg DM manure

Warm — 5.4 x10⁻⁵ 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 6.9). 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 6.10. The 'other' category includes pig manure treated in a digester and poultry manure with and without bedding.

Table 6.9 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

Notes: (a) IPCC (1997, 2000).

(b) There are no direct emissions from these sources. Emissions from the soil are reported under Agricultural Soils (4D).

Table 6.10 Manure management system to which livestock contribute

Greenhouse gas source and sink categories	Anaerobic lagoon	Liquid system	Daily spread	Solid storage and dry lot	Pasture range and paddock	Other
Non-Dairy Cattle - Free Range	NO	NO	NO	NO	Source	NO
Dairy Cattle	Source	Source	Source	NO	Source	NO
Sheep	NO	NO	NO	NO	Source	NO
Swine	Source	Source	Source	Source	NO	Source
Poultry	NO	NO	NO	NO	Source	Source
Non-Dairy Cattle - Feedlot	NO	NO	NO	Source	NO	NO
Goats, horses, deer, buffalo, donkeys, mules, emus, ostriches, alpacas, camels	NO	NO	NO	NO	Source	NO

Table based on CRF Table 4.B(b)

6.4.2.1 Cattle (4.B.1)

Dairy Cattle

Methane

Dairy cattle are generally kept in higher rainfall areas than other Australian livestock. This, and the disposal of excreta washed from milking sheds, gives opportunities for the generation of methane. However, only a small fraction of the potential methane emissions appears to be released. Williams (1993) measured methane production from dairy cattle manure under field conditions in Australia and found that only about 1% of the methane production potential was achieved. On this basis, the temperate methane conversion factor values for manure voided in the field were reduced to 1% from the IPCC (1997, vol. 3) default value of 1.5%.

Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for dairy cattle (VS_{ijk} kg/head/day) was estimated using the data developed to calculate enteric methane production as this included information on intakes and dry matter digestibility. For dairy cattle, volatile solids were calculated:

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

Where: I_{ijk} = dry matter intake calculated in Section 6.2.2.1

DMD_{ijk} = dry matter digestibility expressed as a fraction (Appendix 6.A.3)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Methane production from manure (M_{ijk} kg/head/day) is then calculated as:

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

Where: B_o = emissions potential - 0.24m³ CH₄/kg VS (IPCC 1997)

MCF = integrated methane conversion factor—based on the proportion of different manure management regimes (Appendix 6.A.4) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.A.5)

ρ = density of methane (0.662 kg/m³)

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

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

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 6.2.2.1

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.A.3)

ME_{ijk} = metabolizable energy (MJ/kg DM) calculated as: $0.1604 DMD_{ijk} - 1.037$ (Minson and McDonald 1987)

I_{ijk} = dry matter intake (kg/day)

$1/6.25$ = factor for converting crude protein into nitrogen

The amount of nitrogen that is retained by the body (NR_{ijk} kg/head/day) is calculated as the amount of nitrogen 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 6.2.2.1

Z_{ijk} = relative size (liveweight / standard reference weight (Appendix 6.A.7))

LWG_{ijk} = liveweight gain (kg/day) (Appendix 6.A.2)

Nitrogen excreted in urine (U_{ijk} kg/head/day) is calculated by subtracting NR_{ijk} , F_{ijk} and dermal protein loss from the nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk} / 6.25) - NR_{ijk} - F_{ijk} - [(1.1 \times 10^{-4} \times W_{ijk}^{0.75}) / 6.25] \quad (4B.1a_7)$$

Where: W_{ijk} = liveweight (Appendix 6.A.1)

The total annual faecal (AFjk Gg) and urinary (AUjk Gg) nitrogen excreted is calculated as:

$$AF_{jk} = (365 \times N_{ij} \times F_{ijk}) \times 10^{-6} + (91.25 \times N_{ijk} \times F_{ijk}) \times 10^{-6} \quad (4B.1a_8a)$$

$$AU_{jk} = (365 \times N_{ij} \times U_{ijk}) \times 10^{-6} + (91.25 \times N_{ijk} \times U_{ijk}) \times 10^{-6} \quad (4B.1a_8b)$$

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:

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

$$\text{Urine}_{\text{MMS}} = (\text{AU}_{ijk} \times \text{MMS} \times \text{EF}_{(\text{MMS})} \times \text{C}_g) \quad (4\text{B.1a_9b})$$

$$\text{Total}_{\text{MMS}} = \sum_i \sum_j \sum_k (\text{Faecal}_{\text{MMS}} + \text{Urine}_{\text{MMS}}) \quad (4\text{B.1a_9c})$$

Where: MMS = the fraction of nitrogen that is managed in the different manure management systems (Appendix 6.A.4).

EF_(MMS) = emission factor (N₂O-N kg/ N excreted) for the different manure management systems (Table 6.9)

C_g = 44/28 factor to convert elemental mass of N₂O to molecular mass

Beef Cattle

Methane

Methane production from the manure (M_{ijkl} kg/head/day) of free-range beef cattle is calculated as:

$$M_{ijkl} = I_{ijkl} \times (1 - \text{DMD}_{ijkl}) \times \text{MEF} \quad (4\text{B.1b_1})$$

Where: I_{ijkl} = dry matter intake calculated in Section 6.2.2.1

MEF = emission factor (kg CH₄ / 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:

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

Where: N_{ijk} = 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:

$$\text{CPI}_{ijkl} = I_{ijkl} \times \text{CP}_{ijkl} + (0.032 \times \text{MC}_{ijkl}) \quad (4\text{B.1b_3})$$

Where: I_{ijkl} = dry matter intake (kg/head/day) as calculated in Section 6.2.2.1

CP_{ijkl} = crude protein content of feed dry matter expressed as a fraction (Appendix 6.B.4)

MC_{ijkl} = milk intake (kg/day) - for areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) considered to be 4 kg/day for animals in the first season after birth and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) considered to be 6 and 4 kg/day (Appendix 6.B.5)

Nitrogen excreted in faeces (F_{ijkl} kg/head/day) is calculated, using equations developed by the SCA (1990) and Freer et al. (1997), as the indigestible fraction of the undegraded protein from solid feed, microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijkl} = \{0.3(\text{CPI}_{ijkl} \times (1 - [(DMD_{ijkl} + 10)/100])) + 0.105(\text{ME}_{ijkl} \times I_{ijkl} \times 0.008) + 0.08(0.032 \times \text{MC}_{ijkl}) + (0.0152 \times I_{ijkl})\} / 6.25 \quad (4\text{B.1b_4})$$

Where: DMD_{ijkl} = dry matter digestibility (expressed as a %) (Appendix 6.B.3)

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.B.5)

1/6.25 = factor for converting crude protein into nitrogen

The amount of nitrogen that is retained by the body (NR_{ijkl} kg/head/day) is calculated as the amount of nitrogen retained as milk and body tissue such that:

$$NR_{ijkl} = \{ (0.032 \times MP_{ijkl}) + \{ 0.212 - 0.008(L_{ijkl} - 2) - [(0.140 - 0.008(L_{ijkl} - 2)) / (1 + \exp(-6(Z_{ijkl} - 0.4)))] \} \times (LWG_{ijkl} \times 0.92) \} / 6.25 \quad (4B.1b_5)$$

Where: MP_{ijkl} = milk production 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.B.5)

L_{ijkl} = relative intake as calculated in Section 6.2.2.1

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

LWG_{ijkl} = liveweight gain (kg/day) (Appendix 6.B.2)

Nitrogen excreted in urine (U_{ijkl} kg/head/day) is calculated by subtracting NR_{ijkl} , F_{ijkl} and dermal protein loss from the nitrogen intake such that:

$$U_{ijkl} = (CPI_{ijkl} / 6.25) - NR_{ijkl} - F_{ijkl} - [(1.1 \times 10^{-4} \times W_{ijkl}^{0.75}) / 6.25] \quad (4B.1b_6)$$

Where: W_{ijkl} = liveweight (Appendix 6.B.1)

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

$$AF_{ijkl} = (N_{ijkl} \times F_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_7a)$$

$$AU_{ijkl} = (N_{ijkl} \times U_{ijkl} \times 91.25) \times 10^{-6} \quad (4B.1b_7b)$$

Where: N_{ijkl} = the number of beef cattle adjusted for feedlot cattle in each State, region, season and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8a)$$

$$Urine_{MMS} = (AU_{ijkl} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.1b_8b)$$

$$Total_{MMS} = \sum_i \sum_j \sum_k \sum_l (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1b_8c)$$

Where: MMS = the fraction of AE that is managed in the different manure management systems. In the case of beef cattle all manure is voided at pasture ($MMS = 5$).

$EF_{(MMS)}$ = emissions factor (N_2O -N kg/ N excreted) for the different manure management systems (Table 6.9)

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.C.2)

DMD_{ij} = digestibility expressed as a fraction (assumed to be 80%)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Methane production from the manure (M_{ij} kg/head/day) is then calculated as:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad (4B.1c_2)$$

Where: B_o = emissions potential - $0.17 \text{ m}^3 \text{ CH}_4/\text{kg VS}$ (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/m^3)

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.C.2) of the animals as the proportion of the diet that is grass, legume, grain (including molasses) and other concentrates (Appendix 6.C.3) and the nitrogen fraction of each of these components (Appendix 6.C.4).

Nitrogen excreted in faeces (F_{ij} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer et al. (1997), as the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein plus the endogenous faecal protein, such that:

$$F_{ij} = \{0.3(CPI_{ij} \times (1 - [(DMD_{ij} + 10)/100])) + 0.105(ME_{ij} \times I_{ij} \times 0.008) + 0.0152 \times I_{ij}\} / 6.25 \quad (4B.1c_5)$$

Where:

DMD_{ij} = digestibility expressed as a percentage (assumed to be 80%)

ME_{ij} = metabolizable energy (MJ/kg DM) calculated as: $0.1604 DMD_{ij} - 1.037$ (Minson and McDonald 1987)

I_{ij} = feed intake (kg/day) (Appendix 6.C.1)

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.C.5 - steers > 1)

LWG_{ij} = liveweight gain (Appendix 6.C.5)

Nitrogen excreted in urine (U_{ij} kg/head/day) is calculated by subtracting NR_{ij} , F_{ij} and dermal protein loss from the nitrogen intake such that:

$$U_{ij} = (CPI_{ij} / 6.25) - NR_{ij} - F_{ij} - [(1.1 \times 10^{-4} \times W_{ij}^{0.75}) / 6.25] \quad (4B.1c_7)$$

Where: W_{ij} = liveweight (Appendix 6.C.1)

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

$$AF_{ij} = (N_{ij} \times F_{ij} \times 365) \times 10^{-6} \quad (4B.1c_8a)$$

$$AU_{ij} = (N_{ij} \times U_{ij} \times 365) \times 10^{-6} \quad (4B.1c_8b)$$

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:

$$Faecal_{MMS} = (AF_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad (4B.1c_9a)$$

$$Urine_{MMS} = (AU_{ij} \times MMS \times EF_{(MMS)} \times Cg) \quad (4B.1c_9b)$$

$$E_{MMS} = \sum_j (Faecal_{MMS} + Urine_{MMS}) \quad (4B.1c_9c)$$

Where: MMS = the fraction of AE 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 6.9)

$Cg = 44/28$ factor to convert elemental mass of N_2O to molecular mass

6.4.2.2 Sheep (4.B.3)

Methane

Methane production from the manure (M_{ijk} kg/head/day) of sheep is calculated as:

$$M_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times MEF \quad (4B.3_1)$$

Where: I_{ijk} = dry matter intake calculated in Section 6.2.2.2

MEF = manure emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001). The warm factor is used for Qld and NT and the temperate factor is used for all other States.

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

$$\text{Total} = \sum_i \sum_j \sum_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_2)$$

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 6.2.2.2

CP_{ijk} = crude protein content of feed intake expressed as a fraction (Appendix 6.D.4)

MC_{ijk} = milk intake (kg/head/day) – calculated as proportion of lambs receiving milk in each season x milk intake (Appendix 6.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

Nitrogen excreted in faeces (F_{ijk} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer et al. (1997), as the indigestible fraction of the undegraded protein from solid feed, the microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijk} = \{0.3(CPI_{ijk} \times (1 - [(DMD_{ijk} + 10)/100])) + 0.105(ME_{ijk} \times I_{ijk} \times 0.008) + 0.08(0.045 \times MC_{ijk}) + 0.0152 \times I_{ijk}\} / 6.25 \quad (4B.3_4)$$

Where: DMD_{ijk} = digestibility expressed as a percentage (Appendix 6.D.2)

ME_{ijk} = metabolizable energy (MJ/kg DM) calculated as: $0.1604 DMD_{ijk} - 1.037$ (Minson and McDonald 1987)

MC_{ijk} = milk intake (kg/day) – calculated as proportion of lambs receiving milk in each season x milk intake (Appendix 6.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

1/6.25 = factor for converting crude protein into nitrogen

The amount of nitrogen retained by the body (NR_{ijk} kg/head/day) is calculated as the nitrogen retained in milk, wool and body tissue such that:

$$NR_{ijk} = \{(0.045 \times MP_{ijk}) + (WP_{ijk} \times 0.84) + \{[(212 - 4\{(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})\} - 1)] - (140 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})\} - 1]) / \{1 + \exp(-6(Z_{ijk} - 0.4))\}\} \times EBG_{ijk} / 1000\} / 6.25 \quad (4B.3_5)$$

Where: MP_{ijk} = milk production in kg/day - calculated as: proportion of ewes lactating (LE_{ijk}) x milk production (Appendix 6.D.6). 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.D.7

Z_{ijk} = relative size (liveweight / standard reference weight)

Nitrogen excreted in urine (U_{ijk} kg/head/day) is calculated by subtracting the nitrogen retained (NR_{ijk}) and the nitrogen excreted in the faeces (F_{ijk}) from the nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk} / 6.25) - NR_{ijk} - F_{ijk} \quad (4B.3_6)$$

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

$$AF_{ijk} = (N_{ijk} \times F_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_7a)$$

$$AU_{ijk} = (N_{ijk} \times U_{ijk} \times 91.25) \times 10^{-6} \quad (4B.3_7b)$$

Where: N_{ijk} = the number sheep in each State, season and class

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{MMS} = (AF_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.3_8a)$$

$$Urine_{MMS} = (AU_{ijk} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.3_9b)$$

$$E_{MMS} = \sum_i \sum_j \sum_k (Faecal_{MMS} + Urine_{MMS}) \quad (4B.3_10c)$$

Where: MMS = the fraction of AE that is managed in the different manure management systems. In the case of sheep all manure is voided at pasture (MMS = 5).

$EF_{(MMS)}$ = emission factor (N_2O -N kg/ N excreted) for the different manure management systems (Table 6.9)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.4.2.3 Pigs (4.B.8)

Methane

In Australia, pigs are generally housed and the liquid waste slurry produced during cleaning is often channelled into lagoons. These lagoons tend to create anaerobic conditions, resulting in a high proportion of the volatile solids being fermented with the formation of methane.

A significant proportion of feed given to pigs can be wasted (ranging from 5-20%). This waste feed also contributes volatile solids to the manure management system and will result in methane emissions. For completeness emissions are estimated from all waste entering the manure management system.

Casey et al. (1996) have developed a nutrient balance model for intensive piggeries in Australia-PIGBAL. By entering typical animal characteristic, intakes, diet compositions and wastage rates the model calculates the volatile solids in the animal manure and waste feed (Appendix 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:

$$M_{ij} = VS_{ij} \times B_o \times MCF \times \rho \quad (4B.8_1)$$

Where: VS_{ij} = volatile solids production (kg/head/day) - (Appendix 6.E.2)

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.E.3) and MCF values for 'warm' regions for Qld and the NT and MCF values for 'temperate' regions for all other States (Appendix 6.E.4).

ρ = density of methane (0.662 kg/m³)

The annual methane production (Gg) from the wastes of Australian pigs is calculated as:

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

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

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

Nitrous Oxide

The annual nitrogen (AE_{ij} Gg/year) from pig manure and waste feed is calculated as:

$$AE_{ij} = (N_{ij} \times E_{ij} \times 365) \times 10^{-6} \quad (4B.8_3)$$

Where: N_{ij} = numbers of pigs in each class in each State

E_{ij} = nitrogen in waste (kg/head/day) as calculated by PIGBAL (Appendix 6.E.5)

The total emissions of nitrous oxide from the different manure management systems (EMMS 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.E.3).

$EF_{(MMS)}$ = emission factor (N₂O-N kg/ N excreted) for the different manure management systems (Table 6.9)

C_g = 44/28 factor to convert elemental mass of N₂O to molecular mass

6.4.2.4 Other Livestock (Including 4.B.2, 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 - 0.32m³ CH₄/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/m³)

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:

$$M_{ij} = DMM_{ij} \times MEF \quad (4B.3_1)$$

Where: DMM_{ij} = dry matter in manure Appendix 6.F.3

MEF = manure emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001). The warm factor is used for Qld and NT and the temperate factor is used for all other States.

The annual methane production (Gg) from the manure of sheep 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.F.2)

The total emissions of nitrous oxide from the different manure management systems (EMMS Gg) can then be calculated as follows:

$$E_{MMS} = \sum_i \sum_j (AE_{ij} \times MMS \times EF_{(MMS)} \times C_g) \quad (4B.10_5)$$

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.

$EF_{(MMS)}$ = emission factor (N_2O -N kg/ N excreted) for the different manure management systems (Table 6.9)

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

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 AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.4.5 RECALCULATIONS SINCE THE 2004 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, as part of the ongoing QA/QC, changes have been made to a number of dairy cattle, poultry and minor livestock categories to include years where data was missing or to replace preliminary data.

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 and Mosier (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 and Mosier (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 6.11 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 averaged over three years (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 AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.5.5 RECALCULATIONS SINCE THE 2004 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.

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.

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 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 N_2O 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 6.12. 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 6.12 N_2O 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 N_2O from synthetic or animal-source urea (Table 6.12). 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 6.12, and is used to estimate emissions.

Weier (1999) reported some ¹⁵N tracer measurements of N_2O 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 N_2O , or an average of 0.15%. However this loss was additional to a substantial background emission of ¹⁴ N_2O .

Taking the worst case in which the total background N_2O 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 6.12), 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 6.14

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 6.13 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 6.14 Nitrous oxide emissions factors for synthetic fertiliser

Production System	Emission Factor (Gg N_2O -N/ Gg N)
Irrigated pasture	0.004
Irrigated crop	0.021
Non-irrigated pasture	0.004
Non-irrigated crop	0.003
Sugar cane	0.0125
Cotton	0.005
Horticulture/vegetables	0.021

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 averaged over three years (Gg N)

TM_{ij} = Total mass of fertiliser averaged over three years (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 averaged over three years (Gg N)

EF_{ijk} = emission factor (Gg N_2O -N/Gg N applied) (Table 6.14)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.6.2.2 Animal Wastes Applied to Soils and Excreted on Pasture

Nitrous oxide is emitted from soil through the metabolism of urine and faeces deposited directly on pastures by grazing animals, or from animal manure derived principally from dairies, feedlots, piggeries and poultry houses and applied to crops and pastures as organic fertiliser.

Inputs to this subsector are calculated in section 6.3.

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 6.15) 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%), an EF of 1%, is used to estimate manure application emissions.

Table 6.15 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>	<i>0.25</i>	<i>0.04 - 0.57</i>
<i>Pig slurry</i>	<i>0.45</i>	<i>0.17 - 0.95</i>
<i>Poultry litter</i>	<i>0.50</i>	<i>0.50 - 0.50</i>

Source: Bouwman et al. 2002

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 6.16 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.

Table 6.16 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)

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.

In summary, emission factors of 0.01, 0.005 and 0.004 Gg N_2O -N/Gg N deposited are considered to be appropriate for nitrous oxide emissions from, manure spread on pastures and crops, faeces, and urine voided in the field by grazing livestock respectively.

Table 6.17 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 = urine excreted on pastures	2 = beef cattle	2 Liquid systems
3 = WA	3 = faeces excreted on pastures	3 = feedlot cattle	3 Daily spread
4 = SA		4 = sheep	4 Solid storage and drylot
5 = Vic		5 = pigs	5 Digester
6 = Qld		6 = other animals	6 Poultry manure with bedding
7 = NT			7 Poultry manure without bedding
8 = ACT			8 Pasture range and paddock
9 = Australia			

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:

$$MN_{\text{Soil}} = \sum_{MMS=1-7} ((AE_{ij} \times MMS_{=1-7}) - (Total_{MMS=1-7} / C_g) - MN_{\text{atmos}}_{iMMS=1-7}) \quad (4D1_3)$$

And the faecal and urinary nitrogen excreted on pasture range and paddock (4D2) is calculated as:

$$FN_{\text{Soil}} = \sum_{MMS=8} (AE_{ij} \times MMS_{=8} \times PMF) \quad (4D1_4)$$

$$UN_{\text{Soil}} = \sum_{MMS=8} (AE_{ij} \times MMS_{=8} \times PMU) \quad (4D1_5)$$

Where: AE = mass of nitrogen excreted as calculated in section 6.3

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

$Total_{MSS=1-7}$ = total emissions of nitrous oxide from the different manure management systems as estimated in section 6.3

$MN_{atmos_{mms}}$ = mass of animal wastes N volatilised as calculated in section 6.6.2.6 Atmospheric Deposition

PMF = the proportion of waste that is faeces.

PMU = the proportion of waste that is urine.

The above equations present the generalised approach to estimate the quantity of N applied soils. To see the detailed calculations used for each livestock category see NGGIC (2006f).

Annual nitrous oxide production is calculated as:

$$E_{ijkl} = \sum_i \sum_j \sum_k (M_{ijk} \times EF_j \times C_g) \quad (4D1_6)$$

Where: E_{ijk} = annual emission from animal waste (Gg N_2O)

M_{ijk} = mass of manure (MN Soil), urea (UN Soil) or faeces (FN Soil) deposited averaged over three years (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 6.18 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:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \quad (4D1_7)$$

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)

Annual nitrous oxide production is calculated as:

$$E_j = \sum_i \sum_k (M_{ijk} \times EF_{ijk} \times C_g) \quad (4D1_8)$$

Where: E_j = annual emissions from N fixing crops (Gg N_2O)

M_{ijk} = mass of N fixed by crops and pastures averaged over 3 years (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 6.19 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 = Australia		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:

$$M_{ijk} = P_{ik} \times R_k \times DM_k \times CC_k \times NC_k \times (1 - F_{ik} - FFOD_{ik}) \quad (4D1_9)$$

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:

$$E_j = \sum_i \sum_k (M_{ijk} \times EF_j \times C_g) \quad (4D1_10)$$

Where: E_j = annual emissions from N fixing crops (Gg N_2O)

M_{ijk} = mass of N in crop residues averaged over 3 years (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 6.20 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:

$$E_j = \sum_i (A_{ij} \times EF_{ij} \times C_g \times 10^{-6}) \quad (4D1_{11})$$

Where: E_j = annual emissions from cultivation of histosols (Gg N_2O)

A_{ij} = area of cultivated histosols averaged over three years (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 Atmospheric Deposition

The default IPCC *Tier 1* methodology is used to estimate emissions from the atmospheric deposition.

Table 6.21 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:

$$M_{ijk=1} = TM_{ijk=1} \times \text{FracGASF}_j \quad (4D2_{11})$$

Where: $M_{ijk=1}$ = Mass of synthetic fertiliser volatilised averaged over three years (Gg N)

TM_{ijk} = Total mass of fertiliser averaged over three years (Gg N)

$FracGASF_j$ = 0.1 (Gg N/Gg applied) fraction of synthetic fertiliser N that volatilised as NH_3 -N and NO_x -N. IPCC default value.

The mass of animal waste volatilised is calculated as:

$$M_{ijk=2} = \sum_{MMS} (AE \times MMS \times FracGAS_{MMS}) \quad (4D2_2)$$

Where: AE = mass of nitrogen excreted as calculated in section 6.3

MMS = the fraction of AE that is managed in the different manure management systems.

$FracGAS_{MMS}$ = the fraction of N volatilised in each manure management systems (Table 6.22).

The above equation presents the generalised approach to estimate the quantity of N volatilized. To see the detailed calculations used for each livestock category see NGGIC (2006f).

Table 6.22 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 ^a	0.2			0.2
Digester			0	
Poultry manure with bedding				0.4
Poultry manure without bedding				0.55

Source: IPCC 2006

Notes: (a) IPCC 2000.

The mass of savanna burning and field burning of agricultural residue NO_x -N emissions that volatilise is calculated as:

$$M_{ijk=3,4} = (E_{ik=3,4} / (46/14)) \quad (4D2_3)$$

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 averaged over 3 years (Gg NO_x) as estimated in sections 6.6 and 6.7

46/14 = factor to convert elemental mass of NO_x to molecular mass

Annual nitrous oxide production from atmospheric deposition is calculated as:

$$E = \sum_i \sum_k (M_{ijk} \times EF_{jk} \times C_g) \quad (4D2_4)$$

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 N_2O -N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.6.2.7 Leaching and Runoff

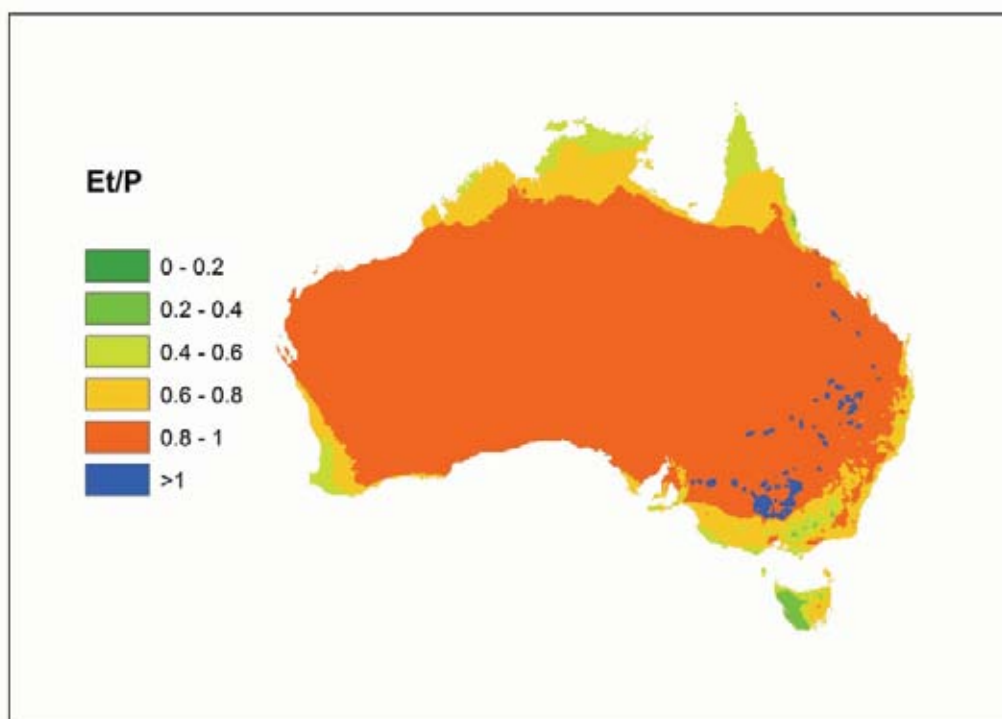
Australia is the driest continent, with substantially less runoff than all other continents. In Australia, much of the cropping takes place in semi-arid regions, or regions of marginal rainfall. The revised 1996 IPCC methodology makes no allowance for reduced rates of leaching in regions of low rainfall 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 $Et/P < 0.8$ or $Et/P > 1$ (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 6.23 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:

$$M_{ijk=1} = M_{ik} \times \text{FracWET}_{ik} \times \text{FracLEACH}_j \quad (4D2_5)$$

Where: $M_{ijk=1}$ = Mass of synthetic fertiliser lost through leaching and runoff (Gg N)

M_{ik} = mass of fertiliser in each production system averaged over three years (Gg N)

FracWET_{ik} = fraction of N available for leaching and runoff (Appendix 6.J.1)

FracLEACH_j = 0.3 (Gg N/Gg applied) fraction of N lost through leaching and runoff. IPCC default value.

The mass of animal waste N applied to soils that is lost through leaching and runoff is calculated as:

$$M_{ijk=2} = (\text{MNsoil}_{ik} + \text{UNsoil}_{ik} + \text{FNsoil}_{ik}) \times \text{FracWET}_{ik} \times \text{FracLEACH}_j \quad (4D2_6)$$

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 averaged over three years (Gg N) as calculated in the section 6.6.2.2

UNsoil_{ik} = mass of urinary N applied to soils averaged over three years (Gg N) as calculated in the section 6.6.2.2

FNsoil_{ik} = mass of faecal N applied to soils averaged over three years (Gg N) as calculated in the section 6.6.2.2

FracWET_{ik} = fraction of N available for leaching and runoff (Appendix 6.J.2)

FracLEACH_j = 0.3 (Gg N/Gg applied) fraction of N lost through leaching and runoff. IPCC default value.

Annual nitrous oxide production from leaching and runoff is calculated as:

$$E = \sum_i \sum_k (M_{ijk} \times \text{EF}_{jk} \times C_g) \quad (4D2_7)$$

Where: E = annual emissions from leaching and runoff (Gg N₂O)

M_{ijk} = mass of N lost through leaching and runoff (Gg N)

EF_{jk} = 0.0125 (Gg N₂O-N/Gg N)

C_g = 44/28 factor to convert elemental mass of N₂O to molecular mass

6.6.2.8 Other: Direct Soil Emissions from Soil Disturbance

Carbon stock changes due to the conversions of Forest Land to Cropland and Forest Land to Grassland are reported under 5.B.2 and 5.C.2 (in Volume 2 of this report). The carbon stock changes all occur on mineral soils and are due to the initial land use change and subsequent management. Mineralised nitrogen due to loss of soil organic carbon can result in N_2O emissions from the process of nitrification and denitrification.

A method for calculating N_2O emissions from this source is provided in IPCC 2006 Guidelines for National Greenhouse Gas Inventories (chapter 11). This method is used for estimation of this emission source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N value used is 18, reflecting the approximate median value extracted from a survey of national estimates (Snowden et al 2005). The same emissions factor as used for fertiliser additions to pasture (0.004) is then applied, as recommended in the 2006 IPCC Guidelines. Also following the methods outlined, nitrogen sequestered into increased carbon stocks is not taken into account, leading to zero emissions for Forest to Cropland conversions where appropriate at the regional level (State).

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 AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.6.5 RECALCULATIONS SINCE THE 2004 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.

The emissions reported under 4.D.4, 'soil disturbance' is a new source that relates to the N_2O emissions generated by the conversion of forest land and subsequent management of that converted land. These emissions add 0.6Mt to the estimates for emissions in 1990. At the same time, new activity data has been used for the estimated area of histosols in Australia. This has reduced the estimated emissions in 1990 and in all subsequent years by around 0.3Mt.

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

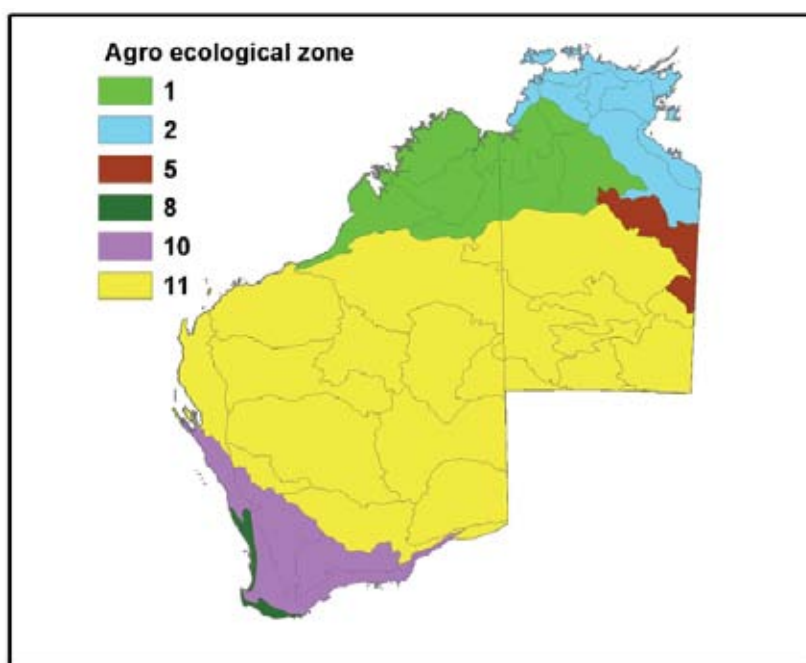
The inventory methodology stratifies the savanna regions of the Northern Territory (NT) and Western Australia (WA) into two broad vegetation classes of woodlands and grasslands. These are defined in terms of the agroecological zones (AEZs) of the Interim Biogeographic Regionalisation for Australia (IBRA)⁶ 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.

⁶IBRA 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.deh.gov.au/parks/nrs/ibra/.

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 (2002) 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 6.24 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 25).

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 26. 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 6.25 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

Sources: (a) Tolhurst (1994) (b) Tolhurst and 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 6.26 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

Sources: (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 6.27 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

Sources: (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 6.28 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 ₂ O	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 6.29 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 averaged over three years (ha)

FL_{ij} = fuel load (dry weight) (Mg/ha)

Z_{ij} = burning efficiency of fires

then for CH_4 , CO and NMVOCs calculate annual emissions:

$$E_{ij} = M_{ij} \times CC_{ij} \times EFL_{ij} \times C_g \quad (4E_2)$$

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

EFL_{ij} = emission factor (Table 6.28)

C_g = factor to convert from elemental mass of gas to molecular mass

and annual emissions for NO_x and N_2O :

$$E_{ij} = M_{ij} \times CC_{ij} \times NC_{ij} \times EFL_{ij} \times C_g \quad (4E_3)$$

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

EFL_{ij} = emission factor (Table 6.28)

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

Data quality used in the inventory is also kept under review by the AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

6.7.5 RECALCULATIONS SINCE THE 2004 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.

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 CH_4 , N_2O , CO , NO_x and NMVOCs into the atmosphere. These gases are formed from carbon and nitrogen in the plant material during the combustion process. As per the IPCC Guidelines (IPCC, 1997) the CO_2 emissions from burning of agricultural residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 is removed by regrowing vegetation in the following year.

Traditionally, burning of agricultural residues in Australia consists of stubble burning (notably for wheat crops), and burning of the sugar cane crop immediately before harvest.

Stubble burning involves firing the standing stalks in either late autumn or spring. Increasingly, as a form of land management, it is being replaced by stubble retention, which reduces erosion and conserves nutrients. In this latter practice the stubble is grazed some weeks after harvest and the next crop is sown by drilling 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 6.28).

Table 6.30 Burning of agricultural residues – emission factors

Gas species	Emission factor ^(a) EF _{ijk} (Gg element in species/Gg element in fuel burnt)	Elemental to molecular mass conversion factor (C _g)
1. CH_4	0.0035	16/12
2. N_2O	0.0076	44/28
3. NO_x	0.2100	46/14
4. CO	0.0780	28/12
5. NMVOC	0.0091	14/12

(a) Hurst et al. (1994 a, b)

Table 6.31 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 = Australia		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 averaged over three years (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 6.30)

C_g = factor to convert from elemental mass of gas to molecular mass

For N₂O 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 6.30)

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

Data quality used in the inventory is also kept under review by the AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6. All activity data for this source categories has been reviewed for this submission.

6.8.5 RECALCULATIONS SINCE THE 2004 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.

6.8.6 PLANNED IMPROVEMENTS

All data and methodologies are kept under review.

APPENDIX 6.A: DAIRY CATTLE

Table 6.A.1. Dairy cattle – liveweight (kg)

State	Milking Cows	Heifers >1	Heifers <1	House Cows – Milk and Dry	Dairy Bulls >1	Dairy Bulls <1
NSW/ACT	550	425	240	450	650	300
Tasmania	500	350	220	400	600	250
Western Australia	550	350	180	450	550	250
South Australia	550	450	260	500	500	350
Victoria	550	450	250	450	600	250
Queensland	580	400	150	500	650	200
Northern Territory	500	350	220	400	550	250

Table 6.A.2. Dairy cattle – liveweight gain (kg/day)

State	Milking Cows	Heifers >1	Heifers <1	House Cows – Milk and Dry	Dairy Bulls >1	Dairy Bulls <1
NSW/ACT	0.04	0.6	0.6	0.04	0.2	0.9
Tasmania	0.04	0.5	0.8	0.04	0.1	1
Western Australia	0.06	0.8	0.8	0.06	0.1	1
South Australia	0.06	0.5	0.8	0.06	0.1	1
Victoria	0.04	0.5	0.6	0.04	0.1	1
Queensland	0.06	0.7	0.7	0.06	0.1	0.7
Northern Territory	0.06	0.5	0.8	0.06	0.1	1

Table 6.A.3. Dairy cattle – dry matter digestibility of feed intake (%)

State	Milking Cows (%)	Heifers >1 (%)	Heifers <1 (%)	House Cows - Milk and Dry (%)	Dairy Bulls >1 (%)	Dairy Bulls <1 (%)
NSW/ACT	75	75	75	75	75	75
Tasmania	75	75	75	75	75	75
Spring	75	75	75	75	75	75
Summer	65	65	65	65	65	65
Autumn	65	65	65	65	65	65
Winter	75	75	75	75	75	75
Western Australia	75	75	75	75	75	75
South Australia	75	75	75	75	75	75
Victoria	78	78	78	78	78	78
Queensland	70	65	65	60	65	65
Northern Territory	75	75	75	75	75	75

Table 6.A.4. Dairy cattle – allocation of waste to manure management systems

State	Milking Cows				Other Dairy Cattle
	Lagoon (%)	Liquid/slurry (%)	Daily Spread (%)	Voided at Pasture (%)	Voided at Pasture (%)
NSW/ACT	6.0	0.5	1.5	92.0	100
Tasmania	6.0	0.5	1.5	92.0	100
Western Australia	2.0	0.0	6.0	92.0	100
South Australia	10.0	0.5	1.0	88.5	100
Victoria	6.0	0.5	1.5	92.0	100
Queensland	3.0	0.0	7.0	90.0	100
Northern Territory	3.0	0.0	7.0	90.0	100

Table 6.A.5. Dairy cattle – Methane Conversion Factors (MCF)

State	Manure Management System– Methane Conversion Factors (MCF)				Integrated MCF	
	Lagoon (%)	Liquid/slurry (%)	Daily Spread (%)	Voided at Pasture (%)	Milking Cows (%)	Other Dairy Cattle (%)
NSW/ACT	90	35	0.5	1.0	6.50	1.0
Tasmania	90	35	0.5	1.0	6.50	1.0
Western Australia	90	35	0.5	1.0	2.75	1.0
South Australia	90	35	0.5	1.0	10.07	1.0
Victoria	90	35	0.5	1.0	6.50	1.0
Queensland	90	65	1.0	2.0	4.57	2.0
Northern Territory	90	65	1.0	2.0	4.57	2.0

Table 6.A.6. Dairy cattle – crude protein content of feed intake (%)

State	Milking Cows (%)	Heifers >1 (%)	Heifers <1 (%)	House Cows - Milk and Dry (%)	Dairy Bulls >1 (%)	Dairy Bulls <1 (%)
NSW/ACT	21	21	21	21	21	21
Tasmania						
Spring	25	25	25	25	25	25
Summer	18	18	18	18	18	18
Autumn	12	12	12	12	12	12
Winter	20	20	20	20	20	20
Western Australia	20	20	20	20	20	20
South Australia	15	15	15	15	15	15
Victoria	23	23	23	23	23	23
Queensland	18	16	16	15	16	16
Northern Territory	15	15	15	15	15	15

Table 6.A.7. Dairy cattle – standard reference weights

State	Milking Cows (kg)	Heifers >1 (kg)	Heifers <1 (kg)	House Cows - Milk and Dry (kg)	Dairy Bulls >1 (kg)	Dairy Bulls <1 (kg)
NSW/ACT	580	580	580	450	770	770
Tasmania	550	550	550	400	770	770
Western Australia	550	550	550	450	770	770
South Australia	550	550	550	550	770	770
Victoria	550	550	550	450	770	770
Queensland	580	580	580	400	770	770
Northern Territory	550	550	550	400	770	770

Based on SCA 1990

APPENDIX 6.B: BEEF CATTLE

Table 6.B.1. Beef cattle – liveweight (kg)

State	Region	Season (kg)	Bulls>1 (kg)	Bulls<1 (kg)	Steers<1 (kg)	Cows (kg)	Cows>2 1 to 2 (kg)	Cows<1 (kg)	Steers>1 (kg)
NSW/ACT		Spring	480	80	75	300	440	75	380
		Summer	520	170	160	360	470	160	420
		Autumn	550	240	220	390	490	220	450
		Winter	560	280	260	410	500	260	460
Tasmania		Spring	700	105	90	300	490	85	480
		Summer	750	480	160	350	530	150	460
		Autumn	725	250	215	360	500	200	490
		Winter	700	260	230	380	460	210	470
Western Australia	South West	Spring	800	340	300	420	550	260	480
		Summer	780	380	340	450	530	300	470
		Autumn	680	100	100	320	480	80	340
		Winter	700	190	170	330	490	150	360
	Pilbara	Spring	450	80	80	260	340	70	370
		Summer	500	150	150	310	360	140	400
		Autumn	550	230	230	330	380	220	420
		Winter	500	250	250	340	360	240	390
	Kimberley	Spring	500	220	210	300	320	180	340
		Summer	550	110	100	220	380	90	390
		Autumn	600	170	160	270	390	140	430
		Winter	550	200	190	280	350	150	400
	South Australia	Spring	800	250	230	400	500	220	420
		Summer	800	320	290	420	500	280	420
		Autumn	700	80	75	300	450	70	400
		Winter	700	160	150	350	450	140	400
Victoria		Spring	820	250	240	410	560	240	510
		Summer	850	280	270	440	550	260	520
		Autumn	700	100	95	300	450	95	410
		Winter	720	150	140	320	470	140	440
Queensland		Spring	750	80	75	300	480	65	350
		Summer	800	170	160	350	500	150	420
		Autumn	760	250	240	390	470	225	470
		Winter	700	320	295	420	450	280	480
Northern Territory		Spring	620	220	210	275	360	190	280
		Summer	650	110	100	240	380	90	260
		Autumn	670	170	160	280	400	140	300
		Winter	660	200	190	290	380	170	285

Table 6.B.2. Beef cattle – liveweight gain (kg/head/day)

State	Region	Season	Bulls>1 (kg/day)	Bulls<1 (kg/day)	Steers<1 (kg/day)	Cows1 to 2 (kg/day)	Cows>2 (kg/day)	Cows<1 (kg/day)	Steers>1 (kg/day)
NSW/ACT		Spring	0.2	0.5	0.5	0.4	0.3	0.5	0.4
		Summer	0.4	1.0	0.9	0.7	0.3	0.9	0.4
		Autumn	0.3	0.8	0.7	0.3	0.2	0.7	0.3
		Winter	0.1	0.4	0.4	0.2	0.1	0.4	0.1
Tasmania		Spring	0.50	1.0	1.0	1.0	0.5	1.0	0.50
		Summer	0.55	0.82	0.77	0.55	0.44	0.71	0.5
		Autumn	0.50	0.77	0.6	0.11	-0.33	0.55	0.33
		Winter	-0.27	0.11	0.16	0.22	-0.44	0.11	-0.22
Western Australia	South West	Spring	1.10	1.64	1.42	0.99	0.66	1.21	1.10
		Summer	-0.22	0.44	0.44	0.33	-0.22	0.44	-0.11
		Autumn	0.00	0.60	0.60	0.22	-0.55	0.60	0.00
		Winter	0.22	0.99	0.77	0.11	0.11	0.77	0.44
	Pilbara	Spring	-0.55	0.70	0.70	0.22	-0.22	0.70	-0.22
		Summer	0.55	0.77	0.77	0.66	0.55	0.77	0.33
		Autumn	0.55	0.88	0.88	0.22	0.22	0.88	0.22
		Winter	-0.55	0.22	0.22	0.11	-0.22	0.22	-0.33
	Kimberley	Spring	-0.55	0.22	0.22	0.22	-0.33	0.33	-0.66
		Summer	0.55	0.80	0.80	0.44	0.66	0.70	0.55
		Autumn	0.55	0.66	0.66	0.55	0.11	0.55	0.44
		Winter	-0.55	0.33	0.33	0.11	-0.44	0.11	-0.33
	South Australia	Spring	1.10	0.99	0.88	0.55	0.55	0.88	0.22
		Summer	0.00	0.77	0.66	0.22	0.00	0.66	0.00
		Autumn	-1.10	0.90	0.80	0.22	-0.55	0.70	-0.22
		Winter	0.00	0.88	0.82	0.55	0.00	0.77	0.00
Victoria		Spring	1.10	1.10	1.10	0.99	0.99	1.10	0.77
		Summer	0.33	0.33	0.33	0.33	-0.10	0.22	0.11
		Autumn	0.20	0.50	0.55	0.44	0.20	0.55	0.20
		Winter	0.22	0.55	0.49	0.22	0.22	0.49	0.33
Queensland		Spring	0.55	1.00	0.90	0.22	0.33	0.80	0.60
		Summer	0.55	0.99	0.93	0.55	0.22	0.93	0.77
		Autumn	-0.44	0.88	0.88	0.44	-0.33	0.82	0.55
		Winter	-0.66	0.77	0.60	0.33	-0.22	0.60	0.11
Northern Territory		Spring	-0.44	0.22	0.22	-0.16	-0.22	0.22	-0.05
		Summer	0.33	0.8	0.8	0.55	0.22	0.8	0.55
		Autumn	0.22	0.66	0.66	0.44	0.22	0.55	0.44
		Winter	-0.11	0.33	0.33	0.11	-0.22	0.33	-0.16

Table 6.B.3. Beef cattle – dry matter digestibility of feed intake (%)

State	Region	Season (%)	Bulls >1 (%)	Bulls <1 (%)	Steers <1 (%)	Cows 1 to 2 (%)	Cows >2 (%)	Cows <1 (%)	Steers >1
NSW/ACT		Spring	55	55	55	55	55	55	55
		Summer	65	65	65	65	65	65	65
		Autumn	60	60	60	60	60	60	60
		Winter	50	50	50	50	50	50	50
Tasmania		Spring	75	75	75	75	75	75	75
		Summer	60	60	60	60	60	60	60
		Autumn	70	70	70	70	70	70	70
		Winter	75	75	75	75	75	75	75
Western Australia	South West	Spring	80	80	80	80	80	80	80
		Summer	58	58	58	58	58	58	58
		Autumn	50	50	50	50	50	50	50
		Winter	75	75	75	75	75	75	75
	Pilbara	Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45
	Kimberley	Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45
		Spring	70	70	70	70	70	70	70
		Summer	55	55	55	55	55	55	55
		Autumn	55	55	55	55	55	55	55
		Winter	75	75	75	75	75	75	75
Victoria		Spring	80	80	80	80	80	80	80
		Summer	55	55	55	55	55	55	55
		Autumn	60	60	60	60	60	60	60
		Winter	76	76	76	76	76	76	76
Queensland		Spring	55	55	55	55	55	55	55
		Summer	65	65	65	65	65	65	65
		Autumn	58	58	58	58	58	58	58
		Winter	52	52	52	52	52	52	52
Northern Territory		Spring	40	40	40	40	40	40	40
		Summer	65	65	65	65	65	65	65
		Autumn	55	55	55	55	55	55	55
		Winter	45	45	45	45	45	45	45

Table 6.B.4. Beef cattle – crude protein content of feed intake (%)

State	Region	Season	Bulls >1 (%)	Bulls <1 (%)	Steers <1 (%)	Cows 1 to 2 (%)	Cows >2 (%)	Cows <1 (%)	Steers >1 (%)
NSW/ACT		Spring	7	7	7	7	7	7	7
		Summer	13	13	13	13	13	13	13
		Autumn	10	10	10	10	10	10	10
		Winter	6	6	6	6	6	6	6
Tasmania		Spring	20	20	20	20	20	20	20
		Summer	10	10	10	10	10	10	10
		Autumn	16	16	16	16	16	16	16
		Winter	20	20	20	20	20	20	20
Western Australia	South West	Spring	20	20	20	20	20	20	20
		Summer	9	9	9	9	9	9	9
		Autumn	6	6	6	6	6	6	6
		Winter	20	20	20	20	20	20	20
	Pilbara	Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	9	9	9	9	9	9	9
		Winter	6	6	6	6	6	6	6
	Kimberley	Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	9	9	9	9	9	9	9
		Winter	6	6	6	6	6	6	6
		Spring	16	16	16	16	16	16	16
		Summer	7	7	7	7	7	7	7
		Autumn	9	9	9	9	9	9	9
		Winter	20	20	20	20	20	20	20
Victoria		Spring	25	25	25	25	25	25	25
		Summer	7	7	7	7	7	7	7
		Autumn	10	10	10	10	10	10	10
		Winter	21	21	21	21	21	21	21
Queensland		Spring	5	5	5	5	5	5	5
		Summer	15	15	15	15	15	15	15
		Autumn	11	11	11	11	11	11	11
		Winter	6	6	6	6	6	6	6
Northern Territory		Spring	4	4	4	4	4	4	4
		Summer	12	12	12	12	12	12	12
		Autumn	7	7	7	7	7	7	7
		Winter	5	5	5	5	5	5	5

Table 6.B.5. Beef Cattle – 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

Note: (a) Based on calving rates provided by ABARE

Table 6.B.6. Beef cattle - standard reference weights

State	Bulls >1 (kg)	Bulls <1 (kg)	Steers <1 (kg)	Cows 1 to 2 (kg)	Cows >2 (kg)	Cows <1 (kg)	Steers >1 (kg)
NSW/ACT	700	700	600	500	500	500	600
Tasmania	770	770	660	550	550	550	660
Western Australia	770	770	660	550	550	550	660
South Australia	770	770	660	550	550	550	660
Victoria	770	770	660	550	550	550	660
Queensland	770	770	660	550	550	550	660
Northern Territory	770	770	660	550	550	550	660

Based on SCA 1990

APPENDIX 6.C: FEEDLOT CATTLE

Table 6.C.1. Feedlot cattle – mean liveweight (kg)

Feedlot Cattle Class/Average time on Feed	1990–1995 ^a	1996+ ^b
domestic/ 75 days	300	360
export/ 140 days	385	490
japan ox/ 250 days	575	565

Notes: (a) Working Group estimates, (b) van Sliedregt et al. (2000)

Table 6.C.2. Feedlot cattle – intake (kg/day)

Feedlot Cattle Class/Average time on Feed	1990–1995 ^a	1996+ ^b
domestic/ 75 days	7.20	9.8
export/ 140 days	8.47	11.7
japan ox/ 250 days	11.50	11.0

Note: (a) Working group estimates based on the assumption that intake is 2.4%, 2.2% and 2.0% of liveweight for domestic, export and Japanese ox markets respectively (b) van Sliedregt et al. (2000)

Table 6.C.3: Feedlot cattle – proportion of feed components

State	Total grain (incl. molasses)	Other Concentrates	Grasses	Legumes
1990–1995 ^a	0.708	0.072	0.118	0.102
1996–2001 ^b	0.779	0.048	0.138	0.035

Note: (a) based on working group estimates, (b) van Sliedregt et al. (2000).

Table 6.C.4. Feedlot cattle – composition of feed components

Diet Components	Concentrates		Roughage	
	grain	other conc.	grass	legume
Cellulose	0.07	0.19	0.31	0.36
Hemicellulose	0.04	0.11	0.31	0.20
Soluble residue	0.68	0.19	0.21	0.21
Nitrogen	0.02	0.05	0.026	0.032

Based on AFIC 1987 and working group estimates

Table E5. 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

Note: (a) Working Group estimates, (b) van Sliedregt et al. (2000)

APPENDIX 6.D: SHEEP

Table 6.D.1. Sheep – liveweight (kg)

State	Season	Sheep > 1					Sheep < 1
		Rams (kg)	Wethers (kg)	Maiden Ewes (intended for breeding) (kg)	Breeding Ewes (kg)	Other Ewes (kg)	Lambs & Hoggets (kg)
NSW/ACT	Spring	75	62	44	54	56	20
	Summer	75	55	42	49	51	27
	Autumn	69	55	43	50	50	32
	Winter	69	55	45	50	51	34
Tasmania	Spring	90	55	45	50	50	14
	Summer	90	55	45	50	50	24
	Autumn	75	50	45	50	50	36
	Winter	75	45	50	55	50	42
Western Australia	Spring	75	60	50	55	55	30
	Summer	65	55	45	50	50	30
	Autumn	65	48	40	45	45	10
	Winter	65	48	45	50	50	20
South Australia	Spring	80	70	52	55	55	40
	Summer	70	65	52	55	55	45
	Autumn	70	60	52	55	55	20
	Winter	70	60	52	55	55	30
Victoria	Spring	70	60	50	55	50	22
	Summer	65	55	45	50	50	28
	Autumn	65	52	43	48	50	33
	Winter	60	50	40	45	50	35
Queensland	Spring	58	50	35	40	45	20
	Summer	61	55	40	45	50	25
	Autumn	63	55	40	45	50	20
	Winter	60	50	35	42	48	25

Table 6.D.2. Sheep – dry matter digestibility of feed intake (%)

State	Season	Sheep > 1					Sheep < 1
		Rams (%)	Wethers (%)	Maiden Ewes (intended for breeding) (%)	Breeding Ewes (%)	Other Ewes (%)	Lambs & Hoggets (%)
NSW/ACT	Spring	75	75	75	75	75	75
	Summer	61	61	61	61	61	61
	Autumn	64	64	64	64	64	64
	Winter	72	72	72	72	72	72
Tasmania	Spring	75	75	75	75	75	75
	Summer	55	55	55	55	55	55
	Autumn	67	67	67	67	67	67
	Winter	70	70	70	70	70	70
Western Australia	Spring	73	73	73	73	73	73
	Summer	55	55	55	55	55	55
	Autumn	50	50	70	70	50	70
	Winter	76	76	76	76	76	76
South Australia	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	55	55	55	55	55	55
	Winter	75	75	75	75	75	75
Victoria	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	65	65	65	65	65	65
	Winter	60	60	60	60	60	60
Queensland	Spring	51	51	51	51	51	51
	Summer	55	55	55	55	55	55
	Autumn	59	59	59	59	59	59
	Winter	58	58	58	58	58	58

Table 6.D.3. Sheep – feed availability (t/ha)

State	Season	Sheep > 1					Sheep < 1
		Rams (t/ha)	Wethers (t/ha)	Maiden Ewes (intended for breeding) (t/ha)	Breeding Ewes (t/ha)	Other Ewes (t/ha)	Lambs & Hoggets (t/ha)
NSW/ACT	Spring	2.90	2.90	2.90	2.90	2.90	2.90
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.60	1.60	1.60	1.60	1.60	1.60
	Winter	1.70	1.70	1.70	1.70	1.70	1.70
Tasmania	Spring	2.50	2.50	2.50	2.50	2.50	2.50
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.30	1.30	1.30	1.30	1.30	1.30
	Winter	0.80	0.80	0.80	0.80	0.80	0.80
Western Australia	Spring	3.50	3.50	3.50	3.50	3.50	3.50
	Summer	1.50	1.50	1.50	1.50	1.50	1.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	1.20	1.20	1.20	1.20	1.20	1.20
South Australia	Spring	4.00	4.00	4.00	4.00	4.00	4.00
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	0.90	0.90	0.90	0.90	0.90	0.90
Victoria	Spring	3.20	3.20	3.20	3.20	3.20	3.20
	Summer	3.00	3.00	3.00	3.00	3.00	3.00
	Autumn	1.80	1.80	1.80	1.80	1.80	1.80
	Winter	1.00	1.00	1.00	1.00	1.00	1.00
Queensland	Spring	1.50	1.50	1.50	1.50	1.50	1.50
	Summer	2.00	2.00	2.00	2.00	2.00	2.00
	Autumn	2.20	2.20	2.20	2.20	2.20	2.20
	Winter	1.70	1.70	1.70	1.70	1.70	1.70

Table 6.D.4. Sheep – crude protein content of feed intake (%)

State	Season	Sheep > 1					Sheep < 1
		Ram (%)	Wether (%)	Maiden Ewes (intended for breeding) (%)	Breeding Ewes (%)	Other Ewes (%)	Lambs & Hoggets (%)
NSW/ACT	Spring	20	20	20	20	20	20
	Summer	10	10	10	10	10	10
	Autumn	12	12	12	12	12	12
	Winter	18	18	18	18	18	18
Tasmania	Spring	20	20	20	20	20	20
	Summer	7	7	7	7	7	7
	Autumn	14	14	14	14	14	14
	Winter	16	16	16	16	16	16
Western Australia	Spring	18	18	18	18	18	18
	Summer	6	6	6	6	6	6
	Autumn	6	6	16	16	6	16
	Winter	21	21	21	21	21	21
South Australia	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	9	9	9	9	9	9
	Winter	20	20	20	20	20	20
Victoria	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	13	13	13	13	13	13
	Winter	10	10	10	10	10	10
Queensland	Spring	8	8	8	8	8	8
	Summer	10	10	10	10	10	10
	Autumn	9	9	9	9	9	9
	Winter	7	7	7	7	7	7

Table 6.D.5. Sheep – liveweight gain (kg/day)

State	Season	Sheep > 1					Sheep < 1
		Rams (kg/day)	Wethers (kg/day)	Maiden Ewes (intended for breeding) (kg/day)	Breeding Ewes (kg/day)	Other Ewes (kg/day)	Lambs & Hoggets (kg/day)
NSW/ACT	Spring	0.07	0.08	0.07	0.04	0.05	0.16
	Summer	0	-0.08	0.00	-0.05	-0.05	0.08
	Autumn	-0.07	0.00	0.00	0.01	-0.01	0.05
	Winter	0.00	0.00	0.02	0.00	0.01	0.04
Tasmania	Spring	0.16	0.11	0.03	-0.02	0.00	0.15
	Summer	0.00	0.00	0.00	0.00	0.00	0.11
	Autumn	-0.20	-0.10	0.00	0.00	0.00	0.13
	Winter	0	-0.10	0.5	0.02	0.00	0.07
Western Australia	Spring	0.11	0.13	0.05	0.05	0.05	0.11
	Summer	-0.11	-0.05	-0.05	-0.05	-0.05	0.00
	Autumn	0.00	-0.08	0.11	-0.05	-0.05	0.11
	Winter	0.00	0.00	0.05	0.05	0.05	0.11
South Australia	Spring	0.11	0.11	0.00	0.00	0.00	0.11
	Summer	-0.10	-0.10	0.00	0.00	0.00	0.05
	Autumn	0.00	-0.10	0.00	0.00	0.00	0.16
	Winter	0.00	0.00	0.00	0.00	0.00	0.16
Victoria	Spring	0.11	0.11	0.16	0.11	0.00	0.15
	Summer	-0.05	-0.05	-0.05	-0.05	0.00	0.07
	Autumn	0.00	-0.03	-0.02	-0.02	0.00	0.05
	Winter	-0.05	-0.02	-0.03	-0.03	0.00	0.02
Queensland	Spring	-0.02	0.00	0.00	-0.02	-0.03	0.20
	Summer	0.03	0.05	0.05	0.05	0.05	0.05
	Autumn	0.02	0.00	0.00	0.00	0.00	0.20
	Winter	-0.03	-0.05	-0.05	-0.03	-0.02	0.05

Table 6.D.6. Sheep – proportion of lambs receiving milk in each season 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

Notes: (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.D.7. Sheep – standard reference weights (kg)

State	Sheep > 1					Sheep < 1
	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
NSW/ACT	78	62	57	57	57	60
Tasmania	77	66	55	55	55	60
Western Australia	84	72	60	60	60	66
South Australia	84	72	60	60	60	66
Victoria	70	60	50	50	50	55
Queensland	70	60	50	50	50	55

Based on SCA 1990

APPENDIX 6.E: PIGS

Table 6.E.1. Pigs – feed intake (kg DM/head/day)

Year	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	2.20	2.20	2.97	1.20
1991	2.20	2.26	2.98	1.23
1992	2.20	2.32	2.98	1.26
1993	2.20	2.38	2.99	1.29
1994	2.20	2.44	2.99	1.32
1995	2.20	2.50	2.99	1.35
1996	2.20	2.56	3.00	1.37
1997	2.20	2.62	3.00	1.40
1998	2.20	2.68	3.01	1.43
1999	2.20	2.74	3.01	1.46
2000+	2.20	2.80	3.02	1.49

Table 6.E.2. Pigs - volatile solids (kg/head/day) entering manure management system

Year	Volatile Solids (kg/head/day)			
	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	0.38	0.40	0.47	0.22
1991	0.38	0.42	0.47	0.23
1992	0.38	0.43	0.47	0.23
1993	0.39	0.44	0.48	0.24
1994	0.39	0.46	0.48	0.24
1995	0.39	0.47	0.48	0.25
1996	0.39	0.48	0.48	0.26
1997	0.39	0.50	0.49	0.26
1998	0.39	0.51	0.49	0.27
1999	0.39	0.52	0.49	0.28
2000+	0.39	0.54	0.49	0.28

Estimate includes volatile solids from waste feed

Table 6.E.3. Pigs - allocation of waste to manure management systems

State	Manure Management Systems				
	Lagoon (%)	Liquid/slurry (%)	Drylot (%)	Daily Spread (%)	Digester (%)
NSW/ACT	73	0	0	27	0
Tasmania	0	0	0	100	0
Western Australia	65	0	30	5	0
South Australia	73	0	0	27	0
Victoria	71	0	0	27	2
Queensland	92	1.5	5	1.5	0
Northern territory	100	0	0	0	0

Table 6.E.4. Pigs – Methane Conversion factor (MCF)

State	Manure Management System MCF					Integrated MCF (%)
	Lagoon (%)	Liquid/slurry (%)	Drylot (%)	Daily Spread (%)	Digester (%)	
NSW/ACT	90	35	1.5	0.5	10	65.84
Tasmania	90	35	1.5	0.5	10	0.50
Western Australia	90	35	1.5	0.5	10	58.98
South Australia	90	35	1.5	0.5	10	65.84
Victoria	90	35	1.5	0.5	10	64.24
Queensland	90	65	5.0	1.0	10	84.04
Northern Territory	90	65	5.0	1.0	10	90.00

Table 6.E.5. Pigs – nitrogen (kg /head/year) entering the manure management system

Year	Boars	Gilts-intended for breeding	Breeding Sow	Other pigs
1990	15.29	16.36	20.76	10.37
1991	15.22	15.95	20.75	10.44
1992	15.15	15.53	20.74	10.51
1993	15.08	15.12	20.74	10.57
1994	15.01	14.71	20.73	10.64
1995	14.94	14.30	20.73	10.71
1996	14.87	13.88	20.72	10.77
1997	14.80	13.47	20.71	10.84
1998	14.73	13.06	20.71	10.91
1999	14.66	12.65	20.70	10.98
2000+	14.59	12.23	20.70	11.04

Estimate includes nitrogen in waste feed

APPENDIX 6.F: OTHER LIVESTOCK

 Table 6.F.1. 'Other livestock' – enteric fermentation emission factors (kg 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.F.2. 'Other livestock' – nitrogen excretion factors (kg N/head/year)

State	Livestock Type									
	Goats	Horses	Deer	Buffalo	Donkeys /Mules	Emus/ Ostriches	Alpacas	Camels	Poultry Meat	Poultry Layers
All States	7.0	39.5	13.2	39.5	13.2	7.0	7.0	39.5	0.7	0.6

Table 6.F.3. 'Other livestock' – Manure production (kg DM/head/year)

State	Livestock Type							
	Goats	Horses	Deer	Buffalo	Donkeys/ Mules	Emus/ Ostriches	Alpacas	Camels
All States	114	957	319	957	319	114	114	957

APPENDIX 6.G: PIGBAL ANALYSIS

The estimation of volatile solids and nitrogen in the waste stream of piggeries was calculated using the nutrient balance model PIGBAL (Casey et al. 1996). Pig industry experts provided information on average intakes and other relevant details for a typical herd in 1990 and 2000. The waste produced for each pig class was then calculated in PIGBAL based on a 1,000 sow herd.

Changes in the herd and feed characteristics are assumed to have occurred gradually from 1990 to 2000. Intake and volatile solids for the years 1991–1999 were, therefore, estimated using a linear regression analysis.

As population statistics are only available for Boars, Gilts, Sow and Other Pigs, weighted averages of intake, volatile solids and nitrogen (as reported in Appendix 6.E) were developed for Sows and Other Pigs based on the herd modelled by PIGBAL.

Table 6.G.1. 1990 feed specification for pigs

Class	Intake (kg/day/pig)	Feed wasted (%)	Crude Protein (%)
Boars	2.20	5.00	13
Gilts	2.20	10.00	18
Gestating sows	2.66	5.00	13
Lactating sows	4.50	5.00	18
Suckers	0.10	20.00	24
Weaner pigs	0.90	15.00	22
Grower pigs	1.50	10.00	21
Finisher pigs	2.20	10.00	18

Table 6.G.2. 2000 feed specifications for pigs

Class	Intake (kg/day/pig)	Feed wasted (%)	Crude Protein (%)
Boars	2.20	5.00	13
Gilts	2.80	10.00	14
Gestating sows	2.66	5.00	13
Lactating sows	5.50	5.00	17
Suckers	0.10	20.00	23
Weaner pigs	1.10	15.00	21
Grower pigs	1.80	10.00	18
Finisher pigs	2.20	10.00	14

Table 6.G.3. Herd characteristics used in PIGBAL

Herd Details		1990	2000
Average lactation length	(days)	28	21
Age out of farrowing accommodation	(days)	28	21
Age out of weaner accommodation	(weeks)	10	10
Age out of grower accommodation	(weeks)	16	16
Age at turnoff	(weeks)	21	24
Age at mating	(weeks)	30	30
Average live pig birth mass	(kg)	1.4	1.4
Average pig weaning mass	(kg)	8.0	6.5
Average pig mass out weaner accom.	(kg)	25	27
Average pig mass out grower accom.	(kg)	55	60
Average pig mass out finisher accom.	(kg)	100	110
Average LW at mating	(kg)	160	170
Average LW at farrowing	(kg)	215	225
Average LW boars at turnoff	(kg)	300	300
Average dressed weight backfatters	(kg)	130	140
Dressing percentage	(%)	76	78
Average dressed weight finishers sold	(kg)	76	86

APPENDIX 6.H: SYNTHETIC FERTILISERS

Table 6.H.1. Fraction of fertiliser N applied to each production system

	NSW	NT	Qld	SA	Tas	Vic	WA		
							1990–1995	1996–2002	2003+
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

APPENDIX 6.I: CROP AND PASTURE ATTRIBUTES

Table 6.I.1 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.I.2	0
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

Source: (a) Robinson and Kirby 2002.

Table 6.I.2 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

APPENDIX 6.J: NITROGEN LEACHING AND RUNOFF

Table 6.H.1. Fraction of fertiliser N available for leaching and runoff (FracWET)

	NSW	NT	Qld	SA	Tas	Vic	WA
Irrigated Pasture	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Irrigated crops	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Non-irrigated pasture	0.334	0.811	0.128	0.708	0.991	0.855	0.508
Non-irrigated crops	0.192	0.777	0.043	0.279	0.985	0.438	0.223
Sugar	0.990		0.656				0.759
Cotton	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.H.2 Fraction of animal waste available for leaching and runoff (FracWet)

State	Region	Dairy Cattle	Free range beef cattle	Feedlot cattle	Sheep	All other categories
ACT		0.96	0.785	0	0.812	0.665
NSW		0.646	0.365	0.192	0.269	0.335
NT		1	0.237	0	0	0.773
QLD		0.348	0.114	0.043	0.018	0.107
SA		0.721	0.691	0.279	0.516	0.415
TASMANIA		1	0.997	0	0.987	0.995
VIC		0.9	0.914	0.438	0.873	0.768
WA		0.996		0.223	0.51	0.668
	South West	0.823				
	Pilbara	0.089				
	Kimberley	0.381				