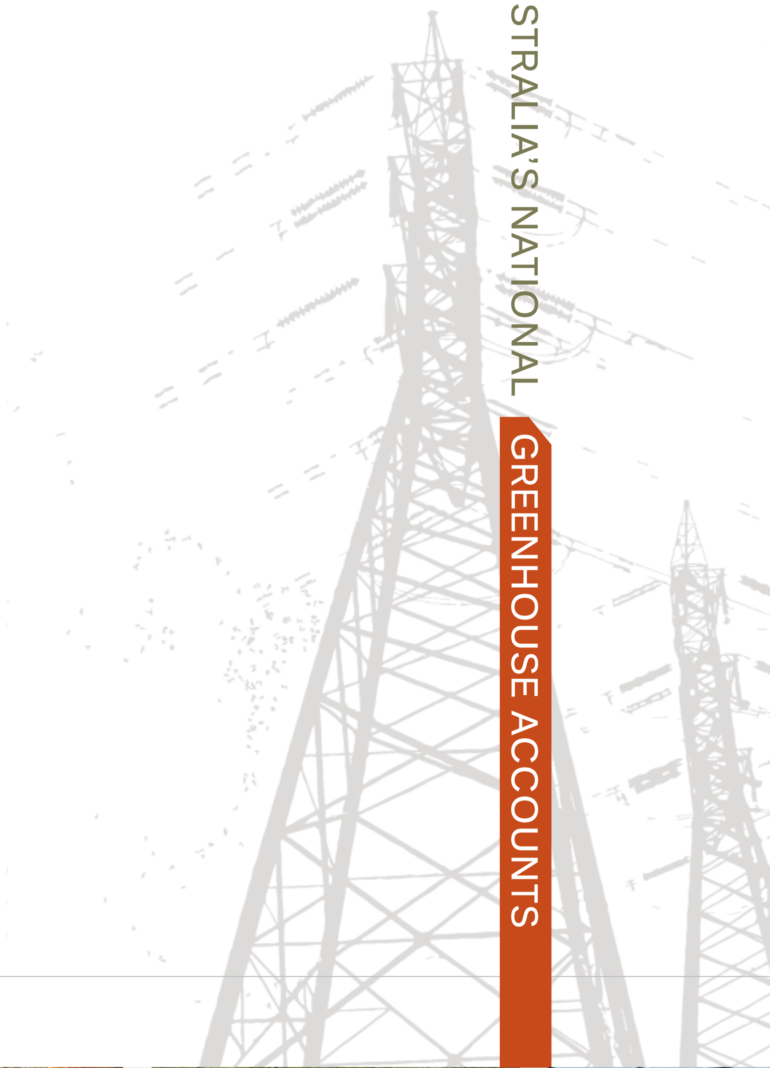
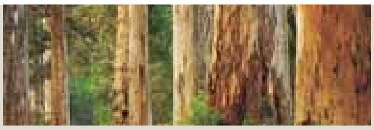
Australian Government

Department of the Environment and Heritage
Australian Greenhouse Office



AUSTRALIA'S NATIONAL GREENHOUSE ACCOUNTS

National Inventory Report 2004 (Revised) — Volume 2

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

APPENDIX 7.E: OVERVIEW OF THE DEVELOPMENT OF AUSTRALIA'S NATIONAL CARBON ACCOUNTING SYSTEM

Introduction

In addition to covering all lands, inventory approaches need to cover all relevant ecosystem components. For monitoring and managing greenhouse gas emissions this needs to consider all relevant carbon pools; biomass, dead organic matter and soil. As both carbon and nitrogen move between these various ecosystem pools, the integration of data over all pools is required for a comprehensive greenhouse gas emissions inventory. Forest and agricultural biomass (above and belowground), soil carbon, litter and debris, and the decay of off-site material (e.g., wood products) represent the major pools for carbon, and each has the potential to be either a source or sink of greenhouse gases.

To develop a comprehensive system to report on Australia's land-based greenhouse gas emissions and removals (from and to the atmosphere) the National Carbon Accounting System (NCAS) was formed. The NCAS provides a complete emissions estimation capability for Australia's international reporting obligations and supports national policy development. The NCAS integrates a wide range of spatially referenced data through a hybrid of process and empirical models that estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools and all principal greenhouse gases (CO_2, CH_4 and N_2O), and can be applied at a variety of scales, from the project level through to regional and continental levels, covering both forest and agricultural land uses.

NCAS was specifically challenged to be relevant to both annual national reporting and supporting location specific management actions. The resulting need to operate at fine temporal and spatial scales, for management relevance, led to a bottom-up approach of aggregating 25 m grid resolution data and modelling into a national account. Even though the land cover change data (the principal driver) and modelling are performed at a 25 m resolution, not all data are available or needed at this fine scale for the bottom-up approach to be effective. A top-down approach to form the national account with a relatively large sample over the entire continent could not provide sufficient samples or resolution to support site specific management decisions or allow project-level estimates.

The terrestrial ecosystem model implemented by the NCAS is the Full Carbon Accounting Model (*FullCAM*) (Richards 2001b; Richards and Evans 2004). *FullCAM* is a carbon:nitrogen (C:N) ratio ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon and nitrogen cycling. As most emissions and removals of greenhouse gases occur on transition between forests and agricultural land-uses, the integration of agricultural and forestry modelling was essential. Model calibration and ongoing refinement programs are completed in parallel to the NCAS science and data collection programs and reporting activity.

The continental spatial and temporal modelling capabilities of *FullCAM* help prevent errors of omission and commission. *FullCAM* also forms the basis of the publicly available National Carbon Accounting Toolbox (NCAT) which allows users to develop project level carbon accounts using the same data as used for deriving national accounts, achieving consistency between national and project level accounting activity.

Although specifically developed to estimate greenhouse gas emissions, the *FullCAM* model and NCAS data have the potential to serve as a valuable framework for a range of land resource inventory and monitoring tasks. The national scale, fine spatial and temporal resolution, and breadth of data (climate, soils, productivity, land cover and management information) provide a comprehensive data and modelling capability not previously available in a single system. This paper reviews the ongoing development of *FullCAM* and NCAS, and presents some of the verification and validation results to date. Particular attention is paid to the forest growth modelling that represents a novel approach.

Methods

Several possible methods were available for the development of the NCAS. These included direct measurement via a range of remote sensing techniques (e.g., optical, radar and lidar sensors), field sampling (e.g., stratified random or plot sampling inventory approaches), process modelling, or an integration of methods (e.g., combination of models, inventory data and remote sensing). The chosen method was an integrated approach using remote sensing, empirical and process models. Landsat images are used to determine changes in land cover. A hybrid of verified empirical and process models are used to estimate the cycling of carbon and nitrogen in plant biomass, dead organic matter, soils and offsite products and the emission and removal of greenhouse gases.

A primary concern was the effect of changes in land cover and land use on greenhouse gas emissions, the modelling framework was designed to accommodate both forest and agricultural land uses, and any transitions between them. The model framework was fully integrated so that mass balance checks could be performed to ensure that all inputs, transfers and emissions were properly reconciled at each time step in the calculation.

A purely measurement approach to developing the NCAS would likely have provided a robust national account, but potentially at greater cost than the model approach chosen. However, a measurement approach would not have supported analysis of either project level estimates or supported management decision making. The process understanding generated through models allows for the development of management practices and land use policies with reliably estimated outcomes. Having such a capacity is fundamental to cost:benefit analysis of mitigation actions and for optimising outcomes for multiple goals (e.g., maintaining production while reducing emissions).

Model Development

The development of the *FullCAM* model started with the 'point-based' Carbon Accounting Model for Forests (*CAMFor*) (Richards and Evans 2000a), that was based on the *CO_2Fix* model (Mohren and Goldewik 1990). *CAMFor* primarily focused on carbon sequestration in trees using basic species information and standard forestry yield tables entered by the user, with limited debris and soil carbon modelling capabilities. After the successful development and testing of *CAMFor* the Carbon Accounting Model for Agriculture (*CAMAg*), was developed to perform similar functions to *CAMFor* but operating in agricultural systems (Richards and Evans 2000b).

To allow for more complete carbon modelling *CAMFor* was integrated with several existing models; *Roth-C* for soil carbon (Jenkinson 1991), *GENDEC* for litter decomposition (Moorehead and Reynolds 1991) and *3-PG* for tree growth (Landsberg and Waring 1997) to form the Full Carbon Accounting Model (*FullCAM*). Other model components (e.g. the *GORCAM* bioenergy and product displacement model of Schlamadinger et. al. (1997)) were also included and a nitrogen cycling capability based on the Century model (Parton et. al., 1987) and the boundary layer approach (Conen et. al., 2000) added to estimate emissions of nitrous oxide.

The model is internally duplicated allowing parallel, but independent, calibration and running of the agricultural and forest systems, and transitions between these land use systems. The integration of the agricultural and forest models helps ensure conservation of mass during carbon and nitrogen cycling by including all pools and transfers between pools, thus ensuring that there are no significant instances of double counting or omissions in accounting. Deforestation at one point, for example, uses the forest model components to estimate the continuing decay and emission of carbon from dead wood, litter, off-site and soil pools while the agricultural model components estimate the changes in pools that result from the introduction of agricultural inputs. This recognises the different cycling rates in the different biomass inputs. The model can report results from any pool or land use, or sum all the results into a single carbon stock estimate. *FullCAM* can be linked to spatial data and run as a grid-based application in addition to its point-based application.

Data sources

An initial task was to bring together all the available data, review its utility, synthesise data of various origins and report the methods and outputs in a series of technical reports. The NCAS Technical Report Series (www.greenhouse.gov.au/ncas; ISSN: 1442 6836) also covers the model development and calibration, and various verification activities. Pre-existing national data, such as the vegetation groups of the National Vegetation Information System (NLWRA 2001) were used where available. Where such national compilations were not available, e.g., on soil carbon content and clay content, national collation and synthesis of available inventory and research data was undertaken (Skjemstad et. al., 2000; Webbnet Land Resource Services Pty. Ltd. 2002).

Climate

Climate variation has a significant effect on emissions in the short term, and as many management and reporting issues also relate to short term changes, it is important to be able to account for this variability. The process based models used in *FullCAM* (*3-PG*, *Roth-C*, *GENDEC*) can use appropriate climate data to reflect this variability. The NCAS has developed monthly climate grids from 1968-2004 for rainfall, minimum, average and maximum temperature, evaporation, vapour pressure deficit and frost (Kesteven et. al., 2004). This climate data is updated as new data becomes available.

Land Cover Change

The importance of land cover change to the pattern of greenhouse gas emissions and removals led to the need to develop a national time series of land cover change showing both where and when change occurs. National coverages of Landsat satellite data (MSS, TM, and ETM+) across fourteen time epochs from 1972 to 2004, have been assembled and analysed for change (Caccetta et. al., 2003). The historic cover and cover change information is important in two ways. First, the effects on greenhouse gas emissions from land cover change are typically long lasting, and historic activities may still contribute to current estimates. Second, the emissions and removals by current activity will be affected by the site history. For example, a current deforestation event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

Individual vegetation species characteristics, management practices and general growth information has also been collated into a set of databases. The databases are relational, i.e., spatially referenced based on set regions (e.g., the Interim- Biographical Regions of Australia (Thackway and Cresswell 1995)) with changes in management varying over time and with species. Historic information on both forest and agricultural management systems was obtained from experts and documented in various technical reports (Swift and Skjemstad 2002; Squire and Raison in press).

Crop Yield

Crop yields are used in the model to determine several factors in the model calibration. In almost all instances where crop yields are used, their impact on carbon and nitrogen cycling is determined in concert with the management approach applied. The uses of the crop yield information include:

> determining plant biomass (crop or grass) at a point in time, via the use of 'harvest indices' that relate total plant biomass to the yield commodity of interest (e.g., grain);
> determining how much plant biomass is removed from the site as product;
> determining the amount of root slough as input to soil from plant growth coupled with management practices; and,
> determining the post harvest/grazing resides burnt, decomposed on soil surface or incorporated into soil.

Data on crop yield and management practice are jointly collected because management practices will determine the crop yields as well as the fate of crop residues. Initial data collection from 1970 onwards is supplemented annually. Data are drawn from a variety of sources including statistical and industry holdings, crop growth modelling and expert opinion. One of the planned future developments in the modelling framework will be to incorporate generic crop and pasture yield models into *FullCAM*. Initial testing indicates that this can be achieved through a small number of generic model forms for broad crop classes.

Forest Growth

Providing a dynamic, disturbance and management responsive forest growth model for all of Australia's forests was particularly challenging. Eventually, a novel spatial modelling approach was used that combines the strengths of both empirical and processed based modelling. The forest growth model component of *FullCAM* can be described as either a hybrid of process and empirical modelling, or an empirically constrained process model. In this system process models estimate the relative movements between pools and account for climatic variability while empirical data set calibration constraints. The empiric data that constrain the model reflect extensive field data (both existing and specifically collected). Independent data was used to verify the model application (Harms and Dalal 2002; Griffin et. al., 2002; Murphy et. al., 2002; Raison et. al., 2003).

Site and climate data are used in a simple process-based model (a simplified version of *3-PG* spatial) to develop continental estimates of productivity (Kesteven et. al., 2004). The *3-PG* variant used is a truncated version of the full *3-PG* model (Landsberg and Waring 1997; Sands and Landsberg 2002), retaining the essential features of Net Primary Productivity estimation, without species specific growth information or the carbon partitioning algorithms (Equation 1). This variant of the model provides a time series of the site productivity index (*P*) ranging from 1 (low) to 30 (high). The long term average productivity defines long-term potential biomass accumulation, while monthly productivity values provide a relative temporal productivity estimate at each point.

The essence of this model is the calculation of the amount of photosynthetically active radiation (*APAR*) absorbed by plant canopies. The factor converting *APAR* to biomass is reduced from the selected optimum value by modifiers dependent on soil fertility; atmospheric vapour pressure deficits, soil water content and temperature:

$$P = APAR * T * S * W * 0.01 * (1 - F) \qquad \text{Equation (1)}$$

Where: P denotes the productivity index.

T denotes a variable between 0 and 1 that reduces the potential P if the monthly temperature deviates substantially from a range of temperatures.

S denotes a level of fertility (high, medium and low). These levels are applied for each pixel, depending on soil type, before environmental modifiers were applied.

W denotes a variable between 0 and 1, which is calculated from the most limiting factor of Soil Water Content or vapour pressure deficit.

F denotes a ratio of number of frost days month^{-1} to the number of days in the month.

P is developed for each point over a continental grid using:

– monthly climate surfaces developed for the NCAS (Kesteven et. al., 2004),

– CSIRO's national soil moisture holding capacity and fertility mapping (McKenzie et. al., 2000a),

– the nine second (250 m) Digital Elevation Mapping Version 2.0 (AUSLIG 2001),

– Normalised Difference Vegetation Index (NDVI) data of the Environmental Resources Information Network (ERIN).

Long term average *P* values were then correlated to verified and spatially referenced observations of aboveground biomass in undisturbed forest stands at or near maturity. These biomass data were collated through an extensive search of published and unpublished data by CSIRO and ranged from arid shrublands (2 t ha^{-1}) to tall wet sclerophyll forests (900 t ha^{-1}) (Raison et. al., 2003). The relationship between mass and long term average productivity was then used to derive a map of potential site biomass at maturity (i.e., for long-term undisturbed stands).

Management Data

Land management practices in both agriculture and forestry in Australia have varied considerably over time depending on species, region, desired products and site conditions. However there were no consistent, nationally available compilations of this information and separate programs to compile the needed information were undertaken. While there was no overlap between the forest and agricultural management data programs, the methods used were similar. In both instances, a focus group was established comprising researchers and practitioners to give all management issues (e.g., forest and crop type, burning, harvesting, thinning) a jurisdictional (geographic) and temporal coverage. All available information was collated and supplemented with expert knowledge to give completeness where records were not available. The information gathered by these groups for use in the management databases is documented in Swift and Skjemstad (2002) and Squire and Raison (in press).

Databases were constructed around relevant geographic regions, further stratified spatially by relevant characteristics such as soil and forest type, then classified by a final non-spatial strata such as crop type or tree species. Management systems for each sub-region were then defined as bundles of practices that represented typical management regimes. Each regime was then apportioned to the finest spatial stratification, giving relative frequencies of implementation for available regimes that could vary over time. The resulting databases cover a large range of possible scenarios with over 5,000 regimes, each comprising 10 – 30 specific practices, being developed for plantation forests alone. The databases were developed within *FullCAM* to allow full integration with NCAS spatial data sources.

Coarse woody debris and litter

Coarse woody debris and forest floor litter is particularly difficult to estimate using measurement techniques because it is highly variable and dynamically related to forest productivity and disturbance history (particularly fire and harvest). Data was collected from available literature, but was sparse, particularly for forests without timber harvest. Supplementary data was collected during field sampling (Harms and Dalal 2002; Murphy et. al., 2002; Griffin et. al., 2002).

Estimates of coarse woody debris and litter are used to frame the initial model estimates to reflect typical species and management scenarios. *FullCAM* can then be run-in from the initial estimates with inputs to the debris and litter pools based on turnover from live pools (based on the forest growth model) and the imposition of a known disturbance history (from the land cover change data). This allows the conversion of an uncertain historic initial estimate to a site and species specific estimate.

Soils

The application of a spatial modelling approach for changes in soil carbon reduces the ongoing burden of measurement from that of sufficient measurements to estimate change over time across the country to that required for a strategic approach to model verification. However, even the application of a model based approach requires substantial amounts of descriptive and process data. The data requirements can be classed as:

> resource description (maps of soil type, carbon content, clay etc.);

> ancillary data (land-use, climate, residue inputs etc);
> model calibration data; and,
> model verification data.

Resource description data are the soil 'physical' parameters needed for input to the soil carbon model and include soil type, carbon content (pre-disturbance) and clay content. Maps of these parameters were developed through a synthesis of resource inventory data, predominantly available from state governments. Clay content was a consistent measure and relatively easily drawn into national synthesis. Soil type descriptions varied according to jurisdiction, but within the modelling framework these differences could be accommodated (Webbnet Land Resource Services Pty. Ltd. 2002). Considerable additional analytic work was required to achieve consistency in data on pre-disturbance soil carbon contents. This need was primarily derived from the differing analytic techniques used to assess carbon content in soil samples. To provide a common and consistent national map, archived samples of soil were reanalysed and correction factors to a *Leco* dry combustion standard were derived (Skjemstad et. al., 2000). Fractionation schemes were also derived for partitioning soil carbon into the pool structures used in the soil carbon model.

Ancillary data inputs to the soil carbon model include information on land use and management, climate, and crop yields (as they influence residue inputs when coupled with management practices). These data have been described in previous sections. The data required for model calibration is characterised by:

> quality and completeness of measurement;
> availability of time-series information; and,
> availability of measurements relevant to model parameters.

Testing the ability of the models to predict change in other locations, based on these calibrations was independently verified. This was done through an independent measurement program. The verification program needed to measure fewer parameters (e.g., total soil carbon change rather than change in fractions) and therefore could be applied to more sites. Calibration data was drawn from a series of both forestry and agricultural research sites. Such sites were sparse, but were ideally suited to the model calibration task having well recorded, comprehensive, and time-series consistent measurements of key model parameters.

Model verification used a mix of existing time-series data, and new paired-site comparisons to test model predictions of change. The model calibration and verification results for agriculture can be found in Skjemstad and Spouncer (2002) and for forestry in Paul et. al. (2002b) and Paul et. al. (2003b).

Wood Products

When an agricultural or forest system is harvested or thinned, carbon stored on-site in plant or debris material can be moved off-site as a range of products. The amount of time these products take to decay and return their carbon to the atmosphere depends on the species characteristics, type of product and the amount of movement between product pools. Forest products in particular can provide an important longer-term store of carbon off-site and hence need to be accounted for in a full mass balance model. Input data to estimate the flow of material into harvested wood products can be accessed via top-down national statistics (forest production and consumption reporting) or by modelled outputs from forest harvest activities (bottom-up).

The top-down model has been progressively developed (Jaakko Poyry Consulting 1999 and 2000) and has utilised a mix of input statistics from Australia's quarterly forest production and consumption statistics and industry estimates. Data for model calibration (e.g., processing losses, service life, and rates of recycling) have been variously drawn from available literature, industry estimates and expert opinion. For the bottom-up approach, *FullCAM* includes separate product pools for the forest (biofuel, pulp and paper, packing wood, furniture and poles, fibreboard, construction wood, and mill residue) and agricultural (biofuel, grains, bud and fruit products, cane products, leaf products, root products, hay, straw and silage products, and animal products) aspects of the model. Carbon in the on-site plant or debris pools can be moved to the relevant product pools at any harvest or thinning event. The amount of carbon moved to each product pool is determined by the quantity of carbon on the site, the intensity of the harvest and the desired product splits.

Each product has a different set of in-use decay and bioenergy use parameters. Forest products also have transfer to landfill rate and in-landfill decay parameters. Decay and transfer rates are modelled exponentially based on the percentage of material moved from the pool each year. Individual species can have a different set of product decomposition or transfer parameters, allowing different species with different product characteristics to be established over time (e.g., changing plantation species at the end of a rotation) while still tracking all products consistently. Further to the product decomposition modelling, *FullCAM* also incorporates *GORCAM* (Schlamadinger et. al., 1997) which allows modelling of the displacement of fossil fuel emissions due to use of bioenergy products and displacement due to the use of alternative products. This allows the relative merits of various types of forest and agricultural products to be assessed against other products that may be used as a substitute. The inclusion of GORCAM allows *FullCAM* to consider a life cycle approach in carbon accounting.

Model Calibration

Forest Growth

A novel approach has been taken to the estimation of forest growth, and is therefore treated here in more detail than other model components. A linear regression (Figure 1) found a significant correlation ($p < 0.01$, $r^2 = 0.68$) between long-term aboveground stand biomass (*M*) and long-term average *(P)* (Richards and Brack 2004a):

$$M = (6.011 * \sqrt{P} - 5.291)^2 \qquad \text{Equation (2)}$$

where P is the long-term average forest productivity index

M is the above ground biomass in t ha^{-1} dry matter.

For forests that have been disturbed (e.g., cleared, harvested or burnt) and are no longer near M (Equation 2), a simple mathematical model was developed to allow for the calculation of standing biomass, given years since disturbance (i.e., age) and the rate at which the maximum biomass is approached (Equation 3).

$$MA = M * e^{-k/A} \qquad \text{Equation (3)}$$

where MA is the predicted above ground tree biomass (t ha^{-1}) at age A (years)

M is the maximum long-term aboveground tree stand biomass

k is an estimated constant that determines the rate of approach towards M.

Given Equations 2 and 3, the long-term average annual increment between *A* and *A+ 1* years (*IA*) for a stand can be estimated from the long-term average productivity (*P*):

$$I_a = (6.011 * \sqrt{P} - 5.291)^2 * (e^{-k/A} - e^{-k/(A+1)}) \qquad \text{Equation (4)}$$

However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (PA) as a ratio with the average productivity (P):

$$I_a = I_a * P_a / P \qquad \text{Equation (5)}$$

Values of k for given species and regime types are available from an extensive spatial database that was derived from available empirical data. However, management interventions (forest treatments) can affect the value of M, k or the 'relative age' of the trees. These treatments can be modelled to advance (or retard) growth for a specified period (Type 1 event, e.g., allowing for five years growth in only four years) or increase growth over the entire rotation (Type 2 event, e.g., improve site productivity or change species) as per Snowdon (2002). The hybrid *FullCAM* forest growth model has been calibrated and adjusted for use in plantation systems based on these Type 1 and 2 responses.

Coarse Woody Debris and Litter

Carbon and nitrogen from the plant biomass pools is added and lost from the debris pools (deadwood, bark litter, leaf litter, dead coarse roots, dead fine roots) through turnover, mortality or disturbance events such as harvesting, thinning, fire, ploughing, grazing or herbicide application. Turnover occurs continually from each plant biomass pool (except stems) based on the current mass in the pool. The quantity of debris added from each plant biomass pool by disturbance events depends on the type and intensity of the event and the current plant mass.

Plant material moving to debris is divided into resistant and decomposable pools, each with different decomposition rates. Upon decomposition, a percentage of the stored carbon is released to the atmosphere, with the remainder entering the mulch pools, as described below. Decomposing litter moves to the mulch layer, which is in between the debris and soil. Mulch decomposition is modelled using the *GENDEC* (GENeral DEComposition Model) (Moorehead and Reynolds 1991).

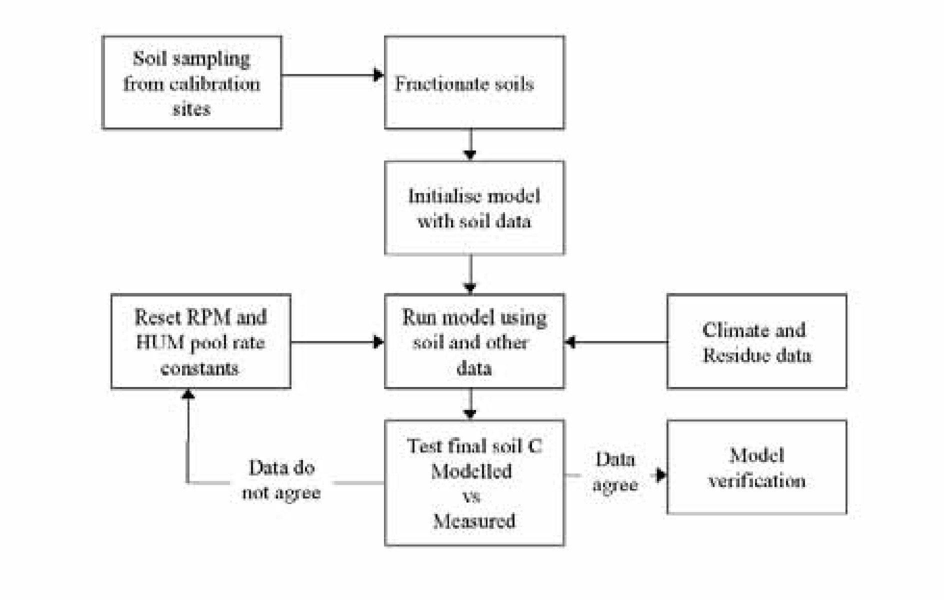
Decomposition rates are dependant on moisture, temperature and litter 'quality' based on the C:N ratio of the mulch pool. Material entering the mulch pool from decomposable debris enters the soluble plant mulch. Material entering from the resistant debris pools can enter either the less-resistant plant mulch or the more-resistant plant mulch pools.

Mulch is either decomposed or humified, moving carbon and nitrogen from the mulch pools to the soil pools. Decomposition occurs through consumption of mulch by soil microbes, thereby passing the carbon back to the atmosphere as emissions or storing it in the bodies of the microbes themselves. The microbes then either excrete the digested mulch or die, turning over their carbon and nitrogen to the soil pools. Humification is the process whereby mulch is moved to the soil pools through the action of more complex soil organisms such as earthworms or slaters.

Soil

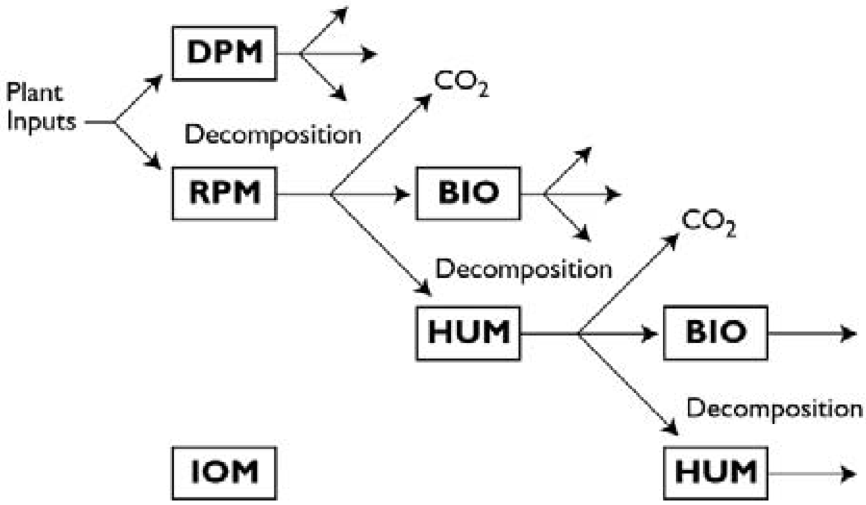
Calibration of the soil carbon model was completed around a structured procedure as shown in Figure 7.E1.

Figure 7.E1: Procedure for the calibration of the Roth-C soil component of FullCAM



The soil carbon turnover model used in *FullCAM* is an adaptation of the *Roth-C* soil carbon model (Jenkinson 1990). The structure of the model is represented in Figure 7.E2.

Figure 7.E.2: Structure of the Roth-C soil carbon model as implemented in FullCAM (modified from Jenkinson 1990)



After investigation of sites that met the requirements for model calibration, two agricultural and seven forestry sites were selected. One agricultural site is on a monsoonal subtropical environment with heavy clay soil and the other is in a temperate Mediterranean climate with a light textured soil. At each agricultural site, soil samples (0-30 cm) from the beginning and tend of the trial as well as some in between were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (hum) pools (Skjemstad and Spouncer 2002).

These pools, measured in the archival soil samples, were then used to initialize the model (RPM set to POC, IOM set to char-C, HUM set to TOC minus POC minus char-C) at the first time of sampling. Other pools were set to zero but were quickly generated by the model. It was found that at both sites that adjusting the Roth-C default resistant plant matter RPM pool decomposition rate modifier from 0.3 to 0.15 yr^{-1} rectified any divergence in the results. No other changes were necessary. Calibration of the forestry sites was completed subsequent to the agriculture calibration and tested model in seven locations:

> *Eucalyptus globulus* in the low rainfall region, south-west of Western Australia
> *E. globulus* in the high rainfall region, south-west of Western
> *Pinus radiata* in the Green Triangle South Australia and Victoria
> *E. grandis* in south-eastern Queensland and north-eastern New South Wales
> *P. radiata* in the south-eastern highlands. New South Wales
> *E. globulus* in south-eastern Gippsland, Victoria and
> *E. nitens* in the Tasmanian highlands.

The testing in the forestry sites confirmed the model calibrations for both forestry and agricultural sites.

Wood products

The NCAS has been constructed to determine national wood product stocks and changes using both top-down and bottom-up approaches. This has the advantage of being able to observe the degree of convergence between the two input estimates, the effect of divergence, and an ability to determine at any scale (stand to national), a wood product account.

Land cover change

Deforestation

A sequence of remotely sensed data (Landsat MSS imagery at 50m resolution for 1972, 1977, 1980, 1985, 1988, and Landsat TM at 25 m resolution for 1989, 1991, 1992, 1995, 1998, 2000, 2002, 2004, 2005) and spatially referenced databases (including soil, vegetation and climate maps, land use patterns and terrain variation) were used to develop indices to discriminate between forest and non-forest cover over Australia. The location and timing of deforestation and reforestation events is determined by comparing the forest extent maps from consecutive time slices. A detailed description of the mapping and its verification can be found in Furby (2002); Furby and Woodgate (2002); Caccetta et. al. (2003); Caccetta and Chia (2004); Lowell et. al. (2003); MBAC consulting (2003); and Lowell et. al. (2005). The resultant disturbance maps in combination with the biomass maps and growth model allow the full spatial and temporal modelling of deforestation and reforestation.

Incremental method development beyond that described in Caccetta et. al. (2003) includes the implementation of terrain illumination correction (Wu et. al., 2004), and the use of 'texture' based analysis to map sparse vegetation extent and change (Caccetta and Furby 2004). Mapping of tree crown cover density and the development and calibration of methods to map plantation types across Australia is ongoing, with both method refinement and field data being collected across Australia (MBAC Consulting *in prep.*).

Plantations

Plantations are identified and mapped into three classes, native forest (environmental type plantings), hardwood plantation and softwood plantation. Plantation forests are those that are identified as being due to deliberate human action, identified by type (e.g., introduction of non-endemic species), evidence of establishment practices (e.g., rip lines), planting patterns (e.g., rows, stand geometry) etc. The identification of conversion between forest and non-forest condition follows the same general approach described above.

Plantation classes are identified by discrimination against regionally specific collection of ground training data. The method uses an automated spectral discrimination.

Managed Native Forests

Identification of areas of managed native forest harvest and regrowth again uses the general mapping of forest and non-forest condition over time, with this specific activity identified by considering the temporal pattern of change, the spatial pattern of change, vegetation type, land tenure and context.

Fires

Fire 'masks' are also developed for each time epoch. This allows for the 'mapping' of fire scars overtime.

Model and Data Validation

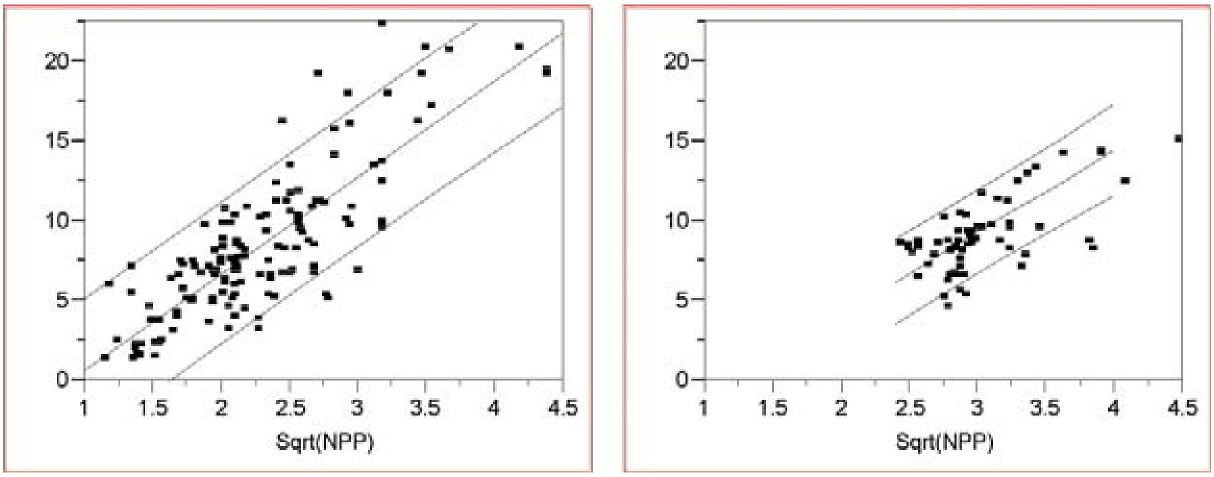
For the purposes of this section, a valid model is one where the model performance or outputs are satisfactory for its intended application. Implicitly, this may mean that the model form is reasonable (verified) and the numerical constants are appropriate (calibrated).

Forest Growth

Native Forests

The extensive search for all data on undisturbed forest sites to parameterise Equation 2 found relatively few points and consequently none these biomass data were reserved for validation. However, some recent and large scale inventories do report stand parameters that can be related to biomass and hence used for model validation. One such study estimated the volume on over 900 000 ha of 'remnant' native vegetation under private management in south eastern Queensland (MBAC Consulting 2003). Remnant vegetation was defined as areas where the predominant stratum is intact with at least 50% foliage projected cover and 70% of the height of the climax vegetation. For the purposes of this comparison, the remnant vegetation could be considered to be either undisturbed or relatively lightly disturbed and therefore approaching the long-term above ground biomass. An estimate of the biomass on sample plots was made using allometrics that relate aboveground biomass to stand basal area in native eucalypt forests (Snowdon et. al., 2000). A regression (Equation 6) between this estimated biomass and P was significant ($p<0.001$, $r^2 = 0.52$) with the residuals not demonstrating heterogeneity or non-normality (Figure 7.E3).

Figure 7.E3. Regression of long term productivity index (P) to aboveground biomass (M) (t ha-1) with 90% individual confidence lines. [ ] denotes standard error of the estimates.



a) Biomass data provided by CSIRO and used to parameterize equation 1 $M = 6.011 * (\sqrt{P} – 5.291)^2$ Equation (1) [0.346] [0.823]	b) Biomass estimated from Snowdon et. al. (2000) allometrics and MBAC Consultants (2003) inventory data $M\hat{} = 5.132 * (\sqrt{P} – 6.016)^2$ Equation (6) [0.667] [1.981]

Although the parameter estimates for Equation 6 are not significantly different to Equation 2 ($p>0.05$), the total aboveground biomass estimates using Equation 2 are significantly greater ($p>0.05$) than the estimates derived from the inventory.

<u>Plantations</u>

FullCAM outputs were compared to measurements from an intensively measured *Pinus radiata* plantation experiment - the Biology of Forest Growth (BFG). The BFG experiment was established in 1983 in the Australian Capital Territory (ACT) and has some 19 years of volume growth measurements combined with detailed site data, including aboveground biomass estimates for a period of 5 years. Data from this experiment has been used in the development and calibration of several physiological models (e.g., *BIOMASS* (McMurtrie et. al., 1992) and *CenW* (Kirschbaum 1999). The BFG site falls near the boundary between poor and average quality soil (Equation 1) with the broad value used in the national estate just in the later. However the soil quality at BFG is considered poor (Benson et. al., 1992). *FullCAM* allows easy adjustment of the effects of soil quality, by simply changing classes where the broad-scale estimate is not applicable at a fine plot scale. The biomass predictions from *FullCAM* (Figure E4) follow the general growth pattern, but the magnitude in the average soil prediction is consistently higher than the observed mass. This trend is also present in the volume predictions (Figure E5) with both the average and poor soil predictions showing good agreement with the growth pattern up to 25 years and with the poor quality soil run proving particularly accurate.

As the stand ages, the difference in volume between the simulated poor soil and the observed values began to increase. Volume growth in the control treatment at BFG continued at an average of 19 m^3 ha-1 yr^{-1} from age 10 to age 29, with only small fluctuations due to climatic conditions, while the modelled growth begins to slow by age 23. Despite this trend, there was only around a 10% difference between the actual and modelled values (average or poor) at age 29. Importantly, the increments over time periods are very similar, even though the absolute values can be quite different. The age structure of the national plantation estate will therefore minimise potential error over short time periods. As volume is back predicted by *FullCAM* from aboveground biomass, the differences in volume may simply be a function of the variable density function applied (Polglase et. al., 2004) or differences in allocation rather than actual differences in the aboveground biomass predictions.

Figure 7.E4. Aboveground biomass at BFG (control) compared to FullCAM estimates assuming poor and average soils.

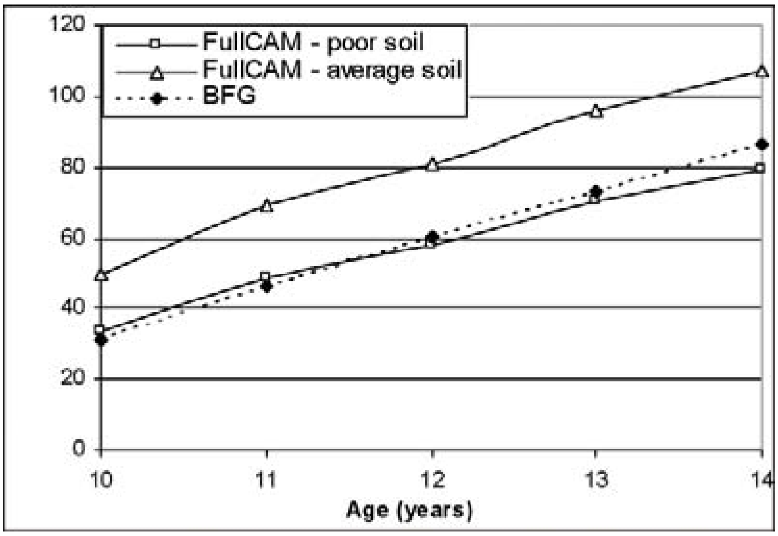
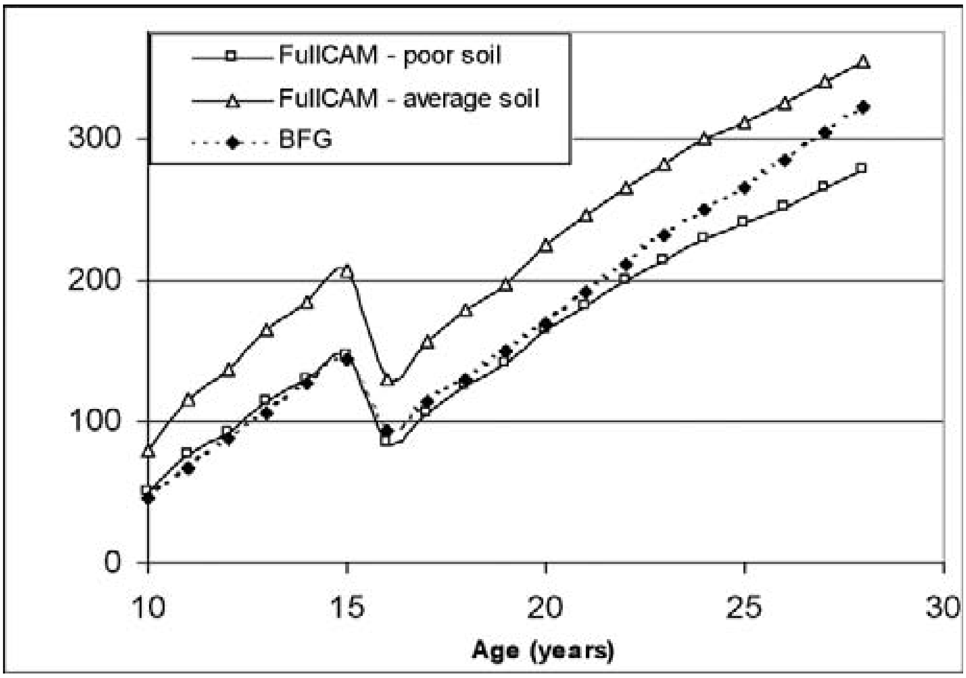


Figure 7.E5. Stem volume at the BFG experiment (control) compared to FullCAM estimates assuming poor and average soils.



Soils

Validation of the NCAS soil carbon model used a combination of comparison to results of time-series measurements at research sites (independent of those used for model calibration) and paired site sampling. The results of the validation activity are reported in Skjemstad and Spouncer (2002) and Paul et. al. (2003a). The validation results were generally good, with (fortuitously) best model performance in areas of most significant land use change. Overall, the model agreement with research site data was better than with the paired sites. Further investigations led to the conclusion that the paired sites were located in some soils where the model exhibits some weaknesses, but also that there was more imprecision in the paired sites due to soil variability and different site histories than expected.

Coarse Woody Debris and Litter

Given the complex and dynamic nature of this pool, it was concluded that verification could not rely on the measurement of inputs, transitions and losses due to disturbance. Instead, the mass balance cycling model approach was used to determine the quality of model calibration. Given inappropriate or poorly calibrated parameters of input, transfer and losses, the principal of mass balance meant that the model would, over a long period of time, predict inappropriate pool size (too large or too small in this or surrounding pools). Estimates of coarse woody debris were made from literature and field studies to frame the initial model estimates that reflect typical conditions.

Wood Products

The eventual constraining and convergence of top-down and bottom-up approaches to estimating harvested wood products will provide confidence in estimates of inputs of materials. Studies such as those by Ximenes and Gardner (2005) and Ximenes et. al. (2005) can also selectively validate various elements of the model parameterisation. In other areas of model parameterisation, significant further work will be required to reduce uncertainty in model estimates. These parameters include refined estimates of the service life of wood containing products, rates of recycling and re-entry to new products, and disposal by entry to landfill or incineration. Further work is being conducted on the rates of turnover, and forms of gas emitted during decomposition in landfill.

Land Cover Change

The validation of remotely sensed changes in forest cover is contained within an overall continuous improvement and validation program. The initial validation (Lowell et. al., 2003; Jones et. al., 2004; Lowell et. al., 2005) considered the initial time-series of change data from 1972-2000. This was done using air photograph comparisons. Results from this work then guided improvements made when the time-series was updated, with 2002 data, and the full time-series reanalysed to reflect the improvements. Similar updates were also undertaken for 2004 and 2005. Validation of analyses, for both changes in forest cover and changes in sparse woody vegetation used comparisons to very high resolution data which has significantly improved the quality of the validation. Previously the air photographs, even when using resolutions to 1:25,000 were inconclusive as a validation dataset.

An independent analysis of the "raw" accuracy of the classification of woody and non-woody points across the continent and over period 1972 – 2000 indicated that 2 – 6% of forest was incorrectly classified, while 4 – 15% of non-forest was incorrectly classified (Jones et. al., 2004). Errors in the estimated rates of change (afforestation/regrowth or deforestation) however, were lower than the above errors as a process of manual 'attribution' was used to confirm or reject changes in cover in the final dataset. Forms of error removed are those associated with green flushing in imagery, degradation, terrain illumination, irrigation, water bodies and fire scars.

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national program of site visits. The recently completed plantation mapping achieved an accuracy of 91% in terms of both species and spatial referencing for plantations identified as post 1990 plantations (MBAC Consulting, in prep.). Incorrect forest typing (for example, labelling hardwood as softwood and visa versa) contributed 5% of the error, with only 4% being incorrect by both location and type. These results provide considerable confidence in the methodology applied and allow, for the first time, a spatio-temporal analysis of Australia's plantation estate.

Deforestation is taken to occur when a removal of forest is deliberately done for the purpose of a change in land use. Regrowth is when, either deliberately or naturally, a forest regrows on an area previously deforested. Deforestation is spatially separated (and unique) from natural effects such as dieback and fire, and temporary removals of forest by harvest. This permanent or temporary nature of the change is determined through a visual checking of the time-series data.

The Nitrogen Model

The carbon cycling approaches used in the *FullCAM* model are similar to those implemented in the *Century* model (Parton et. al., 1987), which allowed *FullCAM* to be further developed to include nitrogen cycling, using the *Century* approach as a basis. Inclusion of nitrogen cycling serves two functions. The first is to constrain growth where there is insufficient nitrogen available to plants to support that growth. This is often particularly important in Australian conditions (Dalal et. al., 2002). The second is to estimate the amount of nitrogen volatilised, or lost to nitrification and denitrification. These estimates are of specific interest as losses of N_2O to the atmosphere are required for greenhouse gas emissions reporting. The model couples the nitrogen cycling with the boundary line approach (Conen et. al., 2000) and uses estimated nitrogen available, set temperatures and water filled pore space to determine N_2O emissions.

Calibrations of the nitrogen model component of *FullCAM* have been developed for one cropping and one plantation site. Sites with sufficient time-series data for calibration of both carbon and nitrogen are very scarce. Unfortunately, no site with a sufficiently long time-series description of carbon and nitrogen cycling has also measured actual emissions. To supplement the sparse emissions data available, a series of intact soil cores have been placed under various treatments in laboratory incubations. These incubations allow for identification of thresholds for denitrification, and of the quantum of emissions during denitrification. In concert with a series of in-situ field chambers, sufficient data should be available for model calibration and validation.

The model calibration has highlighted several issues that need to be considered. The first is that as the nitrogen cycling has faster turnover, and exhibits more volatile (episodic) behaviour than the carbon cycling, a daily time-series is required for model runs. Also, the model is very sensitive to plant uptakes, and in forest systems, storage in plant biomass.

Discussion

A key strength of the NCAS is its comprehensive treatment of both carbon and nitrogen cycles covering all terrestrial pools and processes so that:

- mass balances of carbon and nitrogen are achieved along with interactions between terrestrial and atmospheric stores; and,
- the interplay and effect on biological processes of carbon and nitrogen cycles (e.g., growth limited by nitrogen depletion; decomposition limited by substrate availability) are acknowledged.

The decision to implement the comprehensive and integrated form of NCAS was based on the development of a critical mass of resource information and significant core capabilities that have broad applications. The most significant of these are the fifteen Landsat MSS (1972-1988) and TM/ETM+ (1988-2004) coverages of Australia. The pixel resolution of the data is 50 m for MSS and 25 m for TM/ETM (Furby 2002). Another core product was interpolated monthly climate maps of Australia for rainfall, evaporation, minimum, maximum and average temperature and number of frost days per month. Slope and aspect-corrected 250 m resolution solar radiation measurements, direct and diffuse, were also developed (Landsberg and Kesteven 2001; Kesteven et. al., 2004). Together, these products provide a dynamic background to the modelling activities of the NCAS.

Compiling the necessary fundamental and derivative data also encouraged broad strategic relationships to evolve with other natural resource management interests in areas such as vegetation management, forest inventory, soil organic matter management, resource economics etc. The development of the NCAS has thus involved scientists from numerous different disciplinary backgrounds, bringing together their expert knowledge. Forest scientists, agricultural scientists, soil scientists, statisticians, remote sensing experts, climatologists, modellers, and specialist programmers were involved. These broader interests facilitate exchanges of data and knowledge that improve system efficiency and effectiveness.

Another important derivate of coordinated approaches is the capability to encourage systematic and continuous improvement and validation activities. The flexibility of the modelling approach allows parameters to be re-calibrated or new components to be relatively easily integrated, which again optimises the functional outputs derived from the dedication of public resources to this activity. The majority of the input data is related to climate at a fine temporal scale as this variability has a significant effect on many of the biological processes of growth and decay. Another substantial set of data is related to possible management activities and disturbance events and how these would impact on the basic processes.

The use of a hybrid process driven and empirical approach has enabled a robust generalized method for determining forest biomass stocks and rates of forest growth for Australia. Equation 1 provides for appreciation of the processes underpinning growth, while Equations 2 – 5 allow these process-based relationships to be grounded in empirical observations. Consequently the agreement between the patterns of observed biomass and *FullCAM* predictions (Figure 7.E3 – E5) was not unexpected. The regression approach has an advantage over a purely process-driven model which has been shown to generally over-predict site biomass since factors such as insect attack are not taken into account (Kurz et. al., 1998). The potential biomass estimate in *FullCAM* represents the biomass towards which growth will generally approach. It may be that the overprediction of biomass in Queensland's privately managed forests (Figure 7.E3) is a consequence of this process-model bias, but it may more likely be due to localised bias with the Snowdon et. al. (2000) allometrics or that the stands had been disturbed and were still returning to the long-term maximum state.

By taking mass balance approaches, and being comprehensive of all relevant land-based activities, the NCAS ensures that no gaps or overlaps occur in the estimates of greenhouse gas emissions. In the process of compiling necessary fundamental and derivative data, broad strategic relationships have evolved with other natural resource management interests in areas such as vegetation management, forest inventory, soil organic matter management, resource economics etc. These broader interests facilitate exchanges of data and knowledge that continuously improve the NCAS efficiency and effectiveness.

Although currently limited to use in carbon accounting, the *FullCAM* outputs have great potential for estimating other statistics of interest to the forest industry and other land managers. For example, any parameter that is related to above ground biomass (or other output produced by *FullCAM*) can be more precisely estimated by an inventory system using the point estimates output by *FullCAM* as auxiliary variables in a variable probably inventory. For example, Brack (2004), found that the presence of an auxiliary variable with an r^2 value similar to that found in Equation 6 could be used in an appropriate inventory design to improve the precision of the population estimates by a factor of two when compared to a systematic sampling system.

National Carbon Accounting Toolbox and DataViewer

As part of the NCAS program a public release version of *FullCAM* combined with electronic copies of the technical report series and Landsat imagery (the DataViewer) was made available. This provides a valuable resource to land managers while ensuring greater transparency for the NCAS. The DataViewer contains five of the fifteen national composite Landsat satellite sensor images (1972, 1980, 1989, 2000, 2004) obtained and registered by the NCAS, continental maps of long-term average rainfall, minimum, average and maximum temperatures, evaporation and number of frost days. Recent improvements in image compression technology allowed all of this data to fit onto a singe DVD. The associated program allows users to locate and zoom into any area of Australia and compare images to help determine changes in land use from 1972-2004. All of these images can be easily imported into more complex GIS systems.

Although a useful tool, the image compression used in the DataViewer does lead to some reduction in visual quality. The archive of Landsat data has been made publicly available through Geoscience Australia (www.ga.gov.au) for the cost of data transfer. This is a major improvement in the availability of land-use data for land managers in Australia. The National Carbon Accounting Toolbox (NCAT) contains a public release version of *FullCAM* and all of the NCAS Technical Reports which outline how and why the system was established, data used in the development of the system and the results of continental simulations. The public release version does not contain nitrogen cycle modelling capabilities or other model aspects currently under development or restricted to research use.

As part of the NCAT development, *FullCAM* was fitted with a Databuilder function. A single *FullCAM* plot file typically requires over 1,500 inputs, including monthly climate records and species and management information making it difficult and time consuming to develop a single model. The Databuilder function simplifies this process by downloading all the required data for a point from a webserver that contains all the climate, species and management data as used in NCAS continental simulations. Users simply select the type of system they wish to model (forest only, agriculture only or transitions between the two), enter a latitude and longitude (obtainable from the Dataviewer) and click a button to download the spatial data. The model then accesses the webserver and obtains the required climate and site information for the specific location from either 250m or 1km grids depending on the data type. Users then further decide what species and management actions they wish to model and further download the required parameters from the server. Hence users can quickly build a *FullCAM* plot using the best available data at the national level. These models can then be saved, shared with other users, and run at any time without a web connection. As the full model is provided, advanced users can also adjust any parameter in the model to better fit their exact circumstances.

ATTACHMENT E1:THE FULLCAM MODEL

Naming Conventions

Abbreviations used in names

Actv = Active soil carbon

Avg =Average B = Microbes (dead) (see P, Micr)

Bkdn =Breakdown C = Carbon Material whose every atom has six protons

C = Coarse (see Dcy, Root)

Cel = Cellulose (see Lig, Sol)

CM = Carbon mass of material Mass of carbon atoms in the material

Conp = Consumption (of fodder by animals,which emits methane)

Cons = Construction wood

Dcmp = Decomposition

De = Decomposable (see Re)

Debr = Debris

Dec = Decrease (due to)

Decomp = Decomposable

Dcy = Decay (sloughed off root), either CDcy (coarse decay)or FDcy (fine decay)

Dwd = Deadwood

Eff = Assimilation efficiency of microbes

Evap = Evaporation

F = Fine (see Dcy, Root)

Fibr =Fibreboard

Fodd = Fodder (inside animal stomachs)

Foli = Foliage Leaves and twigs of tree

Frac = Fraction of a specified part of a whole (a number from 0 to 1, inclusive)

Furn = Furniture

Grth =Growth (of trees or crops)

Humf = Humification Inc = Increase (due to)

Inrt = Inert soil carbon

Lig = Lignin (see Cel, Sol)

Lit =Litter, either LLit (leaf litter) or BLit (bark litter)

M = Mass (dry weight)

Micr = Microbes (live) (see B, P)

Mod = Modifier

N, Nitro =(Available) nitrogen

NCRatio = Ratio of nitrogen mass to carbon mass

NM = Nitrogen Mass

Nutr = Nutrition

P = Plant matter (dead) (see B, Micr)

Pack = Packing wood

Papr = Pulp and paper

PB = Plant matter and microbial matter

Rel = Relative

Resi = Residue (from wood product mill)

Root = Root, either CRoot (coarse root) or FRoot (fine root)

RotAge = Rotation age (years since trees were planted)

Sol = Soluble litter (see Cel, Lig)

Tbl =Table

Temp =Temperature

Turn =Turnover

Wall = Microbe cell wall

Abbreviated Quantities

ASW = Available soil water (in mm of rainfall or irrigation) (*3-PG* only)

BIO = Microbial biomass = Fast and slow decomposing biomass combined (BIO-F + BIO-S) (Roth-C only)

BIOF = BIO-F = Fast decomposing biomass (Roth-C only)

BIOS = BIO-S = Slow decomposing biomass (Roth-C only)

CO2 = Carbon dioxide

DPM = Decomposable plant material (Roth-C only)

GBF = Grain, buds, and fruit

GBFP = Grain, bud, and fruit products

GPP = Gross Primary Production = Overall production of tree or crop biomass in tonnes of carbon

HSS = Hay, straw, and silage

HUM = Humified organic matter (Roth-C only)

NPP = Net Primary Productivity = GPP - carbon lost in respiration

PAR = Photosynthetically Active Radiation (*3-PG* only)

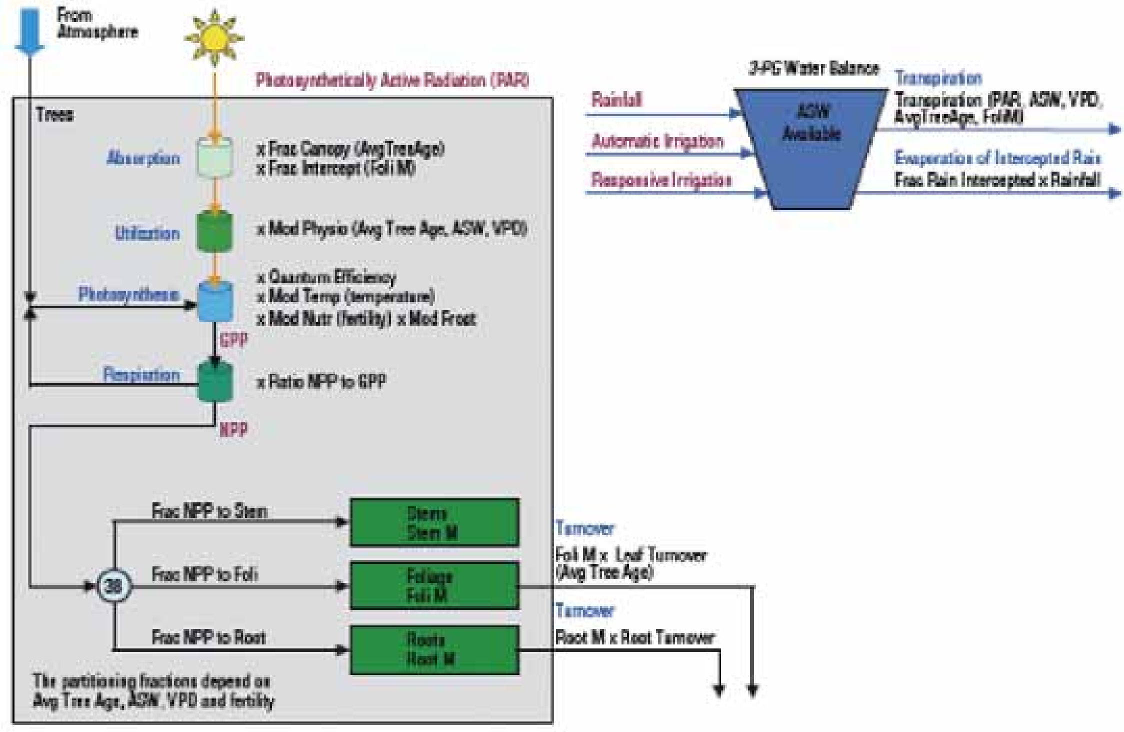
RPM = Resistant plant material (resistant to decomposition) (Roth-C only)

TSMD = Topsoil moisture deficit

VPD = Vapor Presure Deficit (in kPa) (*3-PG* only)

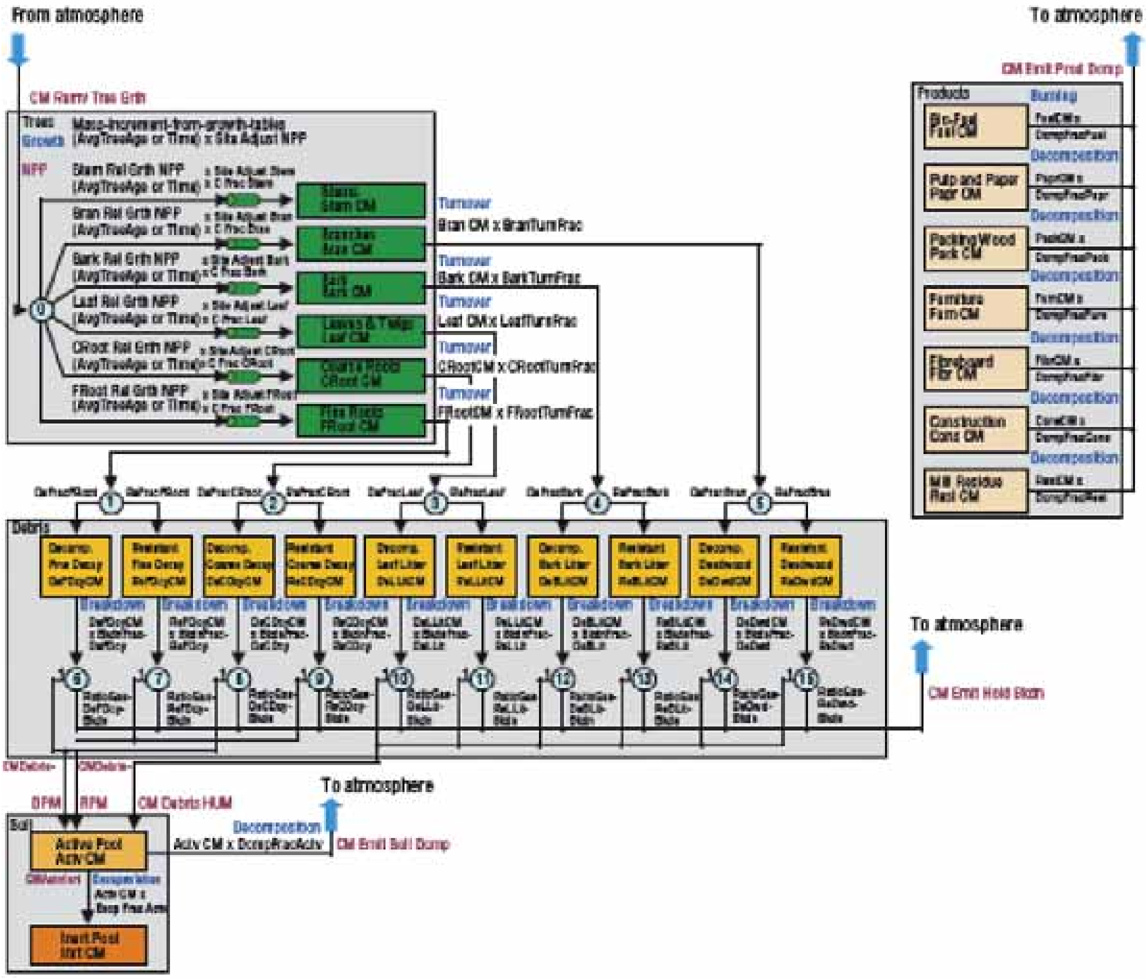
XXX = DPM, RPM, BIO-F or BIO-S (all active soil carbon categories except HUM)

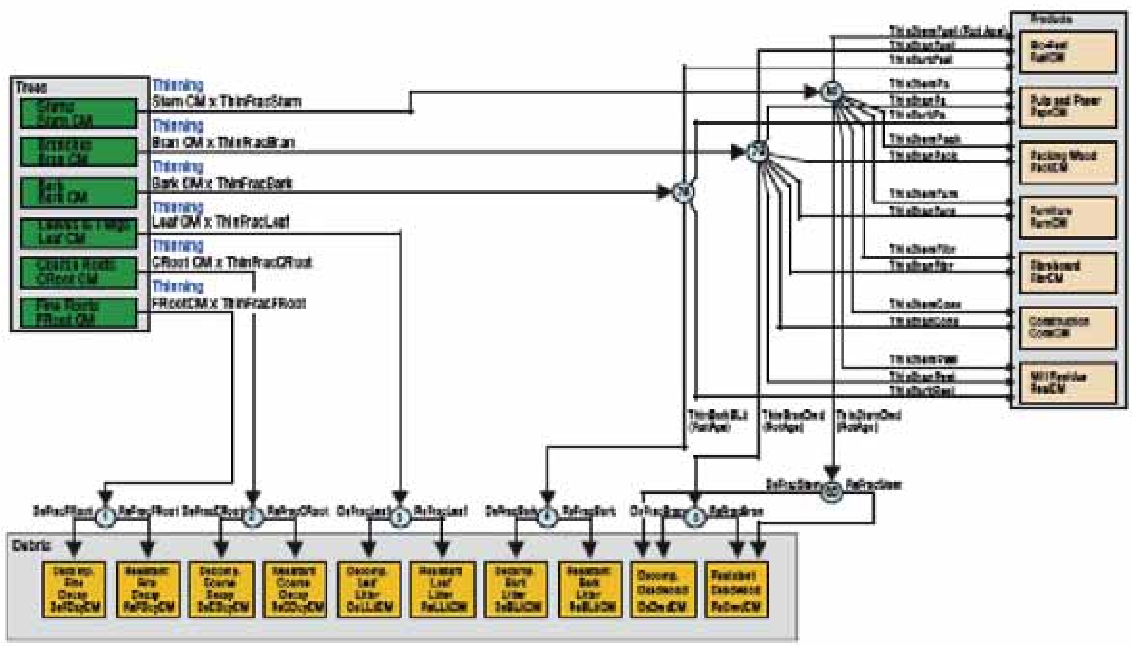
The *3-PG* Model



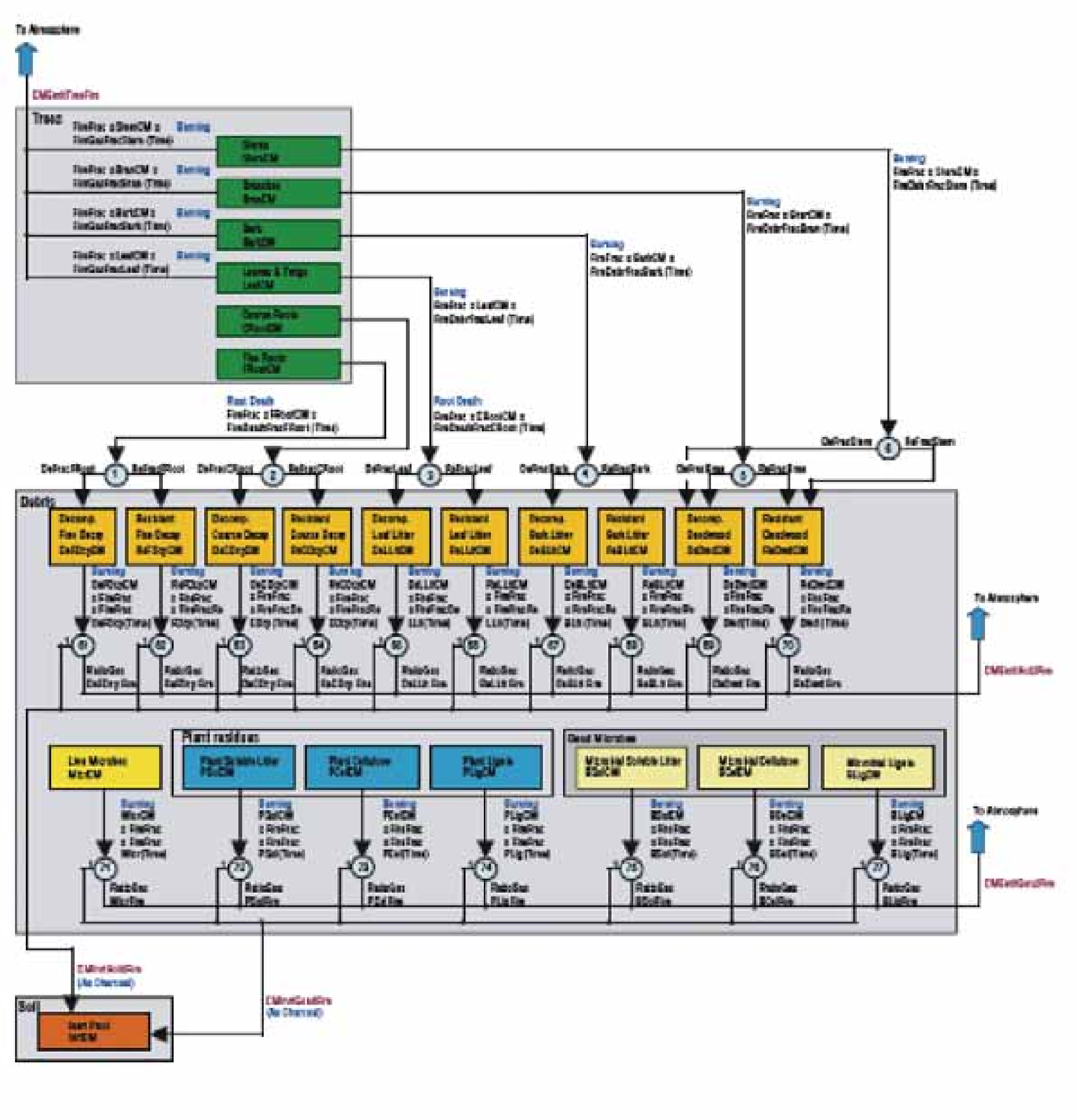
From Atmosphere
Photosynthetically Active Radiation (PAR)
Trees
Absorption
x Frac Canopy (AvgTreeAge)
x Frac Intercept (Foli M)
Utilization
x Mod Physio (Avg Tree Age, ASW, VPD)
Photosynthesis
x Quantum Efficiency
x Mod Temp (temperature)
x Mod Nutr (fertility) x Mod Frost
GPP
Respiration
x Ratio NPP to GPP
NPP
Frac NPP to Stem
Stems
Stem M
Frac NPP to Foli
Foliage
Foli M
Frac NPP to Root
Roots
Root M
38
The partitioning fractions depend on Avg Tree Age, ASW, VPD and fertility
Turnover
Foli M x Leaf Turnover (Avg Tree Age)
Turnover
Root M x Root Turnover
3-PG Water Balance
Rainfall
Automatic Irrigation
Responsive Irrigation
ASW Available
Transpiration
Transpiration (PAR, ASW, VPD, AvgTreeAge, FoliM)
Evaporation of Intercepted Rain
Frac Rain Intercepted x Rainfall

The *CAMFor* Model (a) Thinning

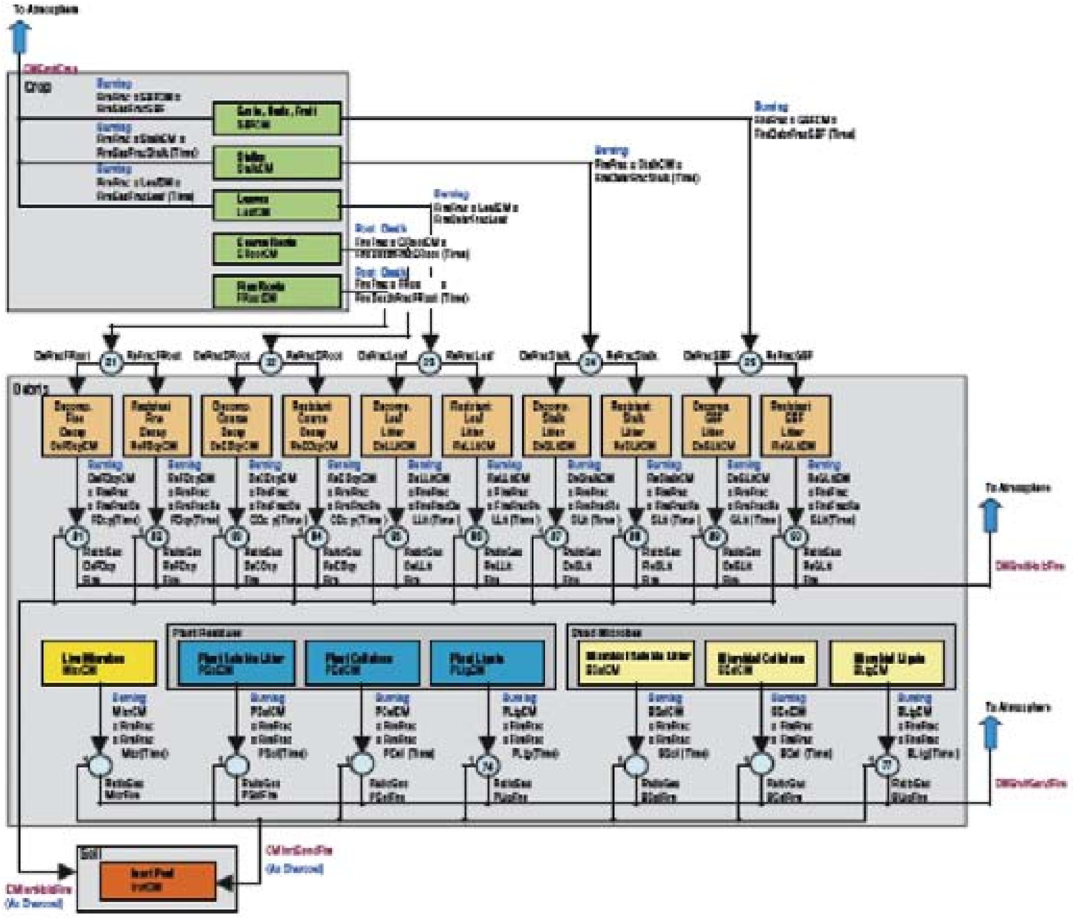




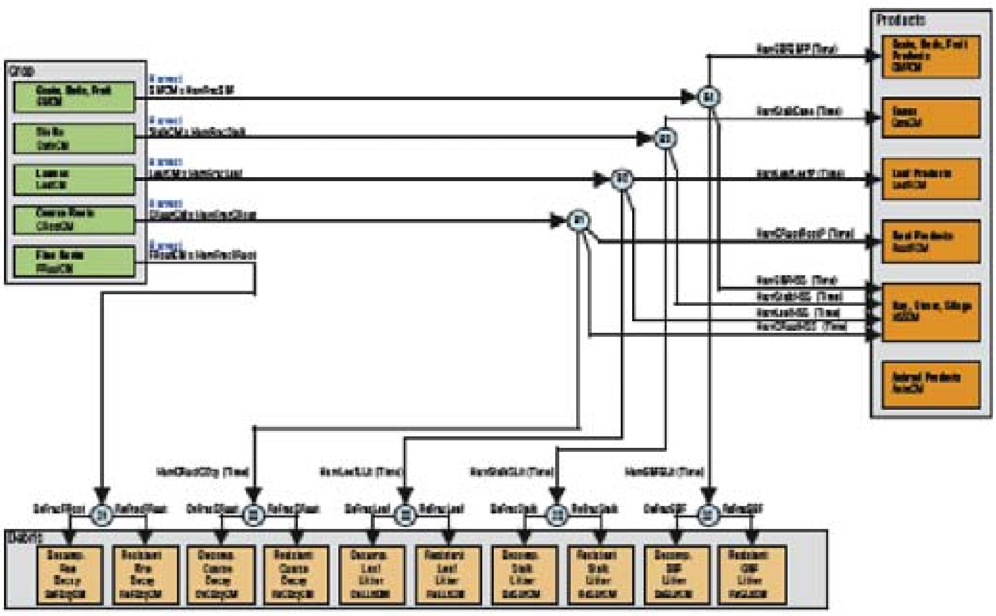
The *CAMFor* Model (b) Fire



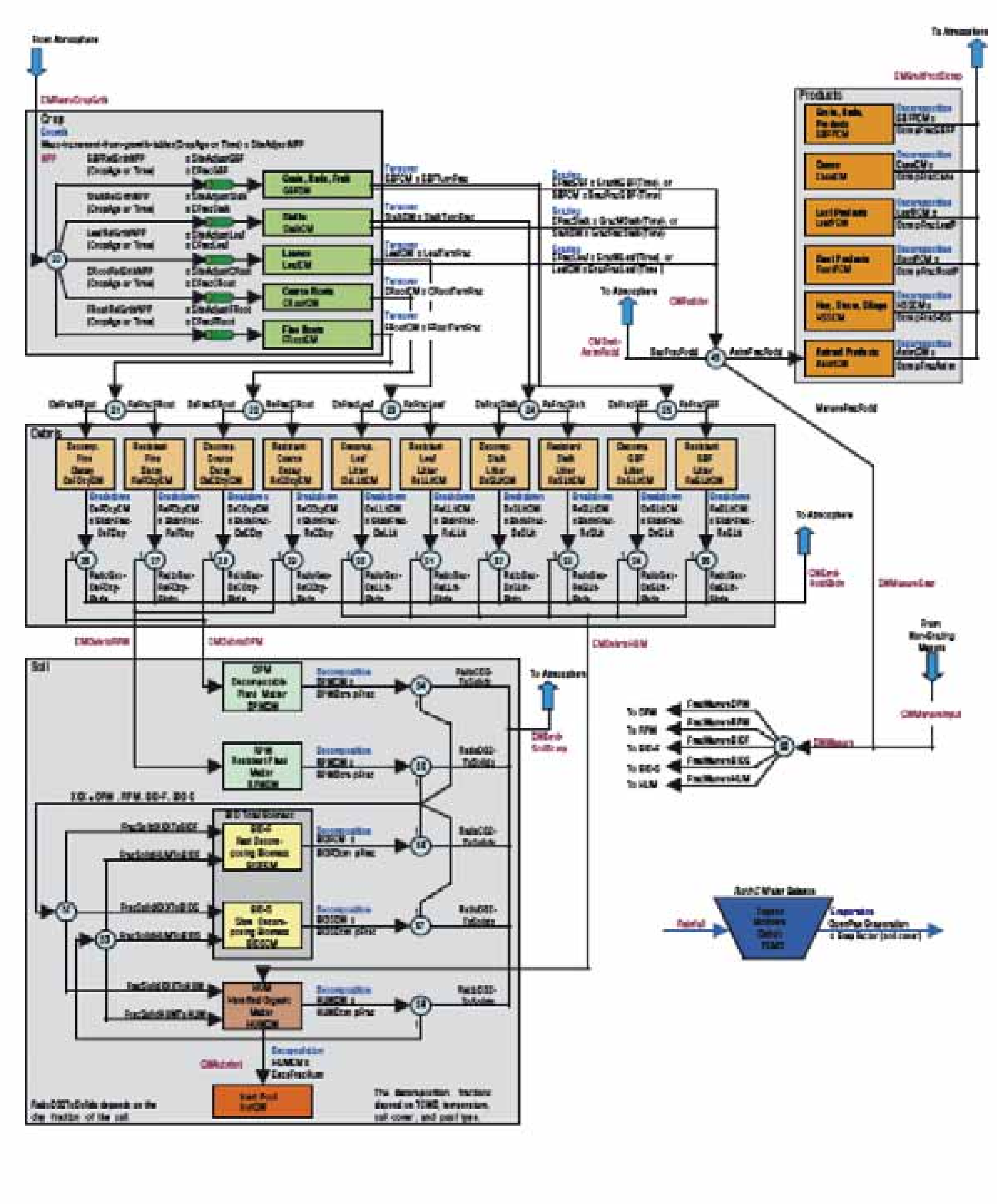
The *CAMAg* Model



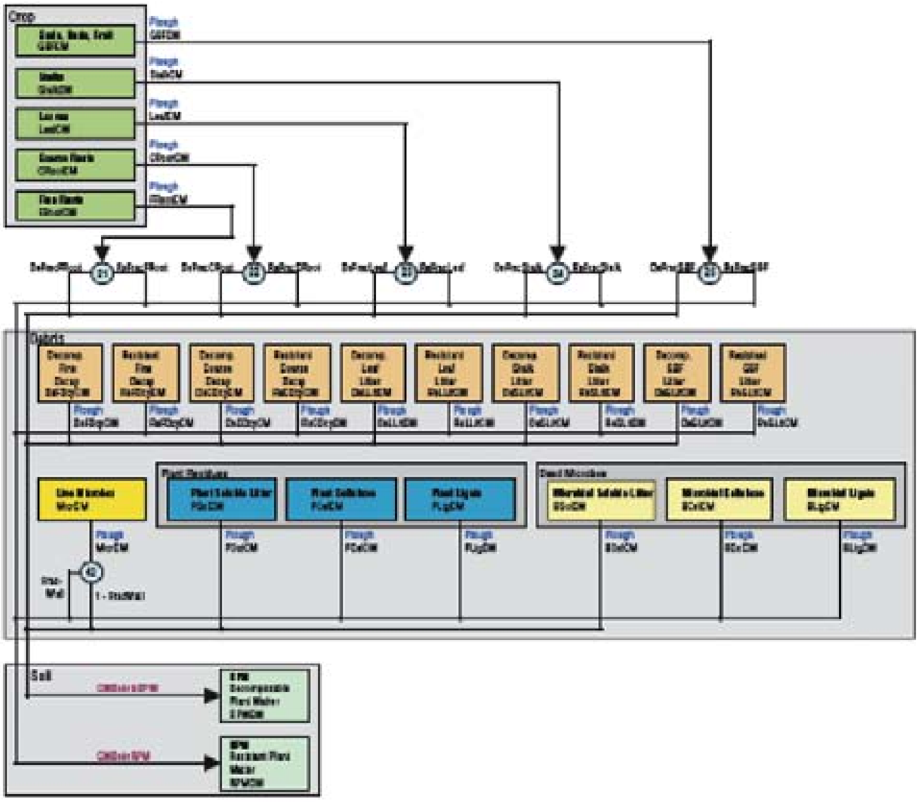
The *CAMAg* Model (a) Fire



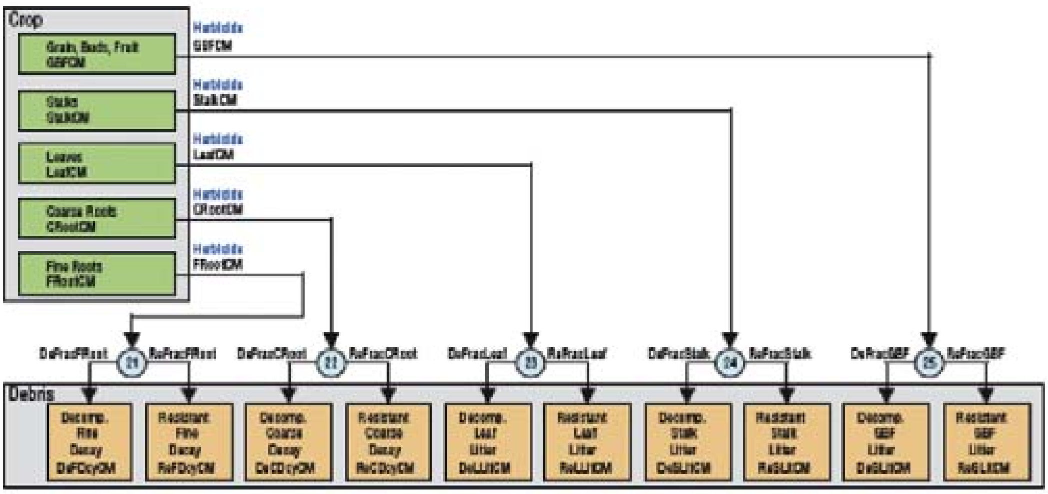
The *CAMAg* Model (b) Harvest



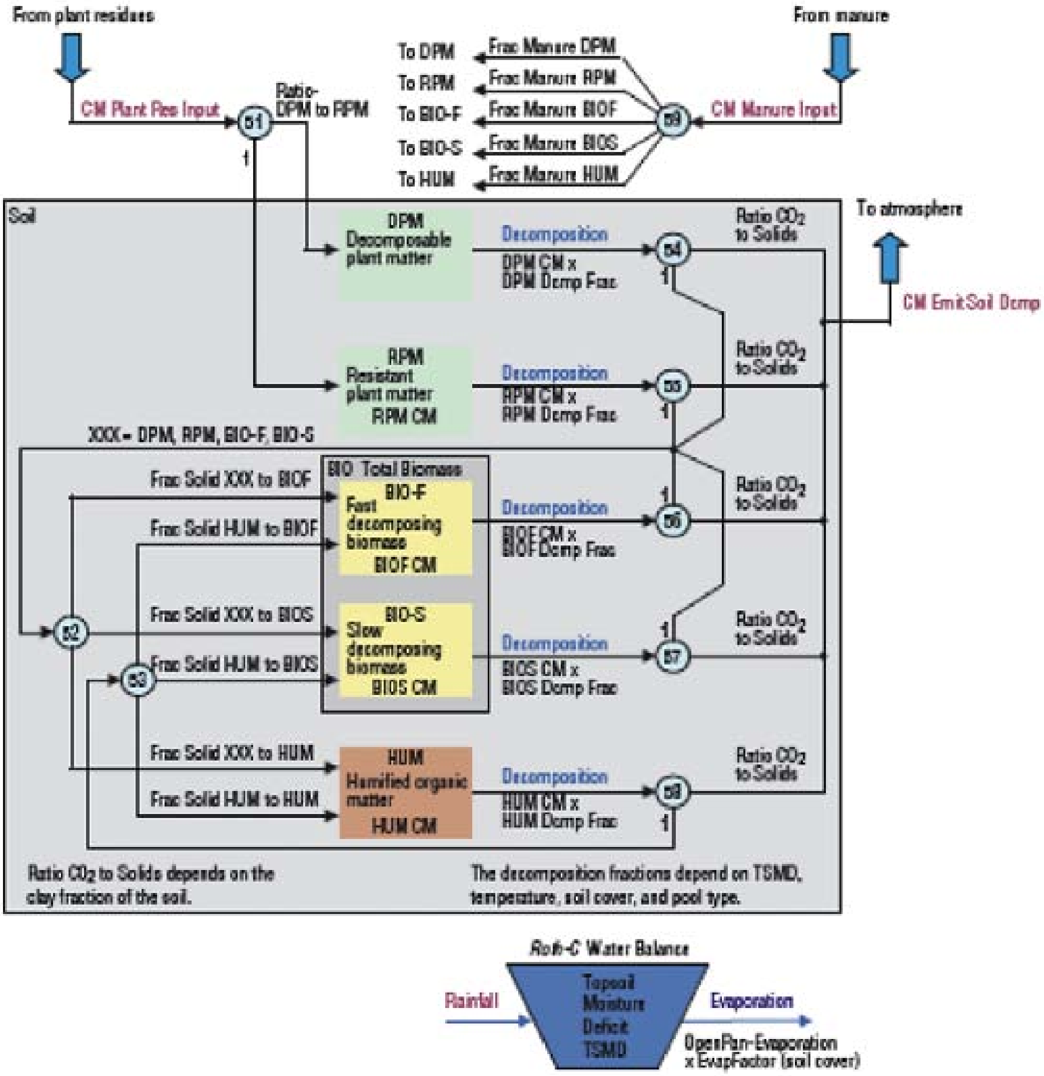
The *CAMAg* Model (d) Herbicide



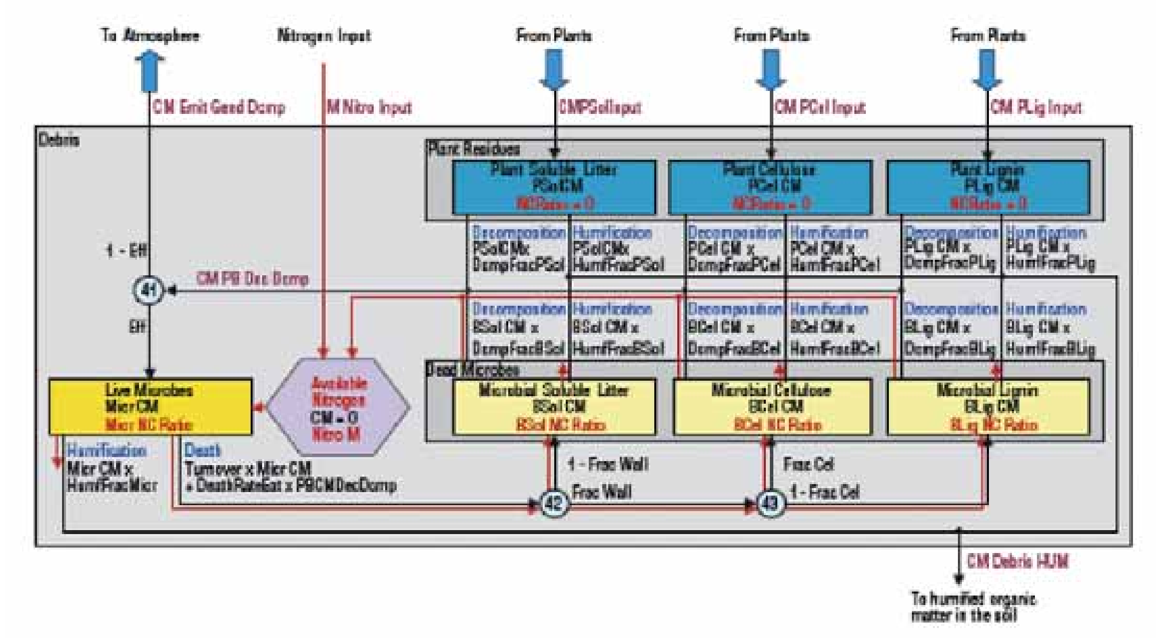
The *CAMAg* Model (c) Plough



The *GENDEC* Model



The *Roth-C* Model



8. WASTE

8.1 OVERVIEW

Total estimated *waste* emissions for 2004 were 17.1 Mt CO_2-e, or 3.3% of total net national emissions (Table 8.1). The majority of these emissions were from *solid waste disposal on land*, contributing 14.8 Mt or 86.2% of *waste* emissions. *Wastewater handling* contributed a further 2.3 Mt (13.7%) of *waste* emissions while *waste incineration* contributed 0.03 Mt (0.2%). *Waste* emissions are predominantly methane-generated from anaerobic decomposition of organic matter. Small amounts of carbon dioxide are generated through the *incineration of solvents and clinical waste* and nitrous oxide through the *decomposition of human wastes*.

Table 8.1 Waste CO_2-e emissions, 2004

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
6 WASTE	**28**	**16,555**	**566**	**17,149**
A. Solid waste disposal on land	NA	14,775	NE	14,775
B. Wastewater handling	NA	1,780	566	2,346
C. Waste incineration	28	NA	NE	28
D. Other waste	NA	NA	NA	NA

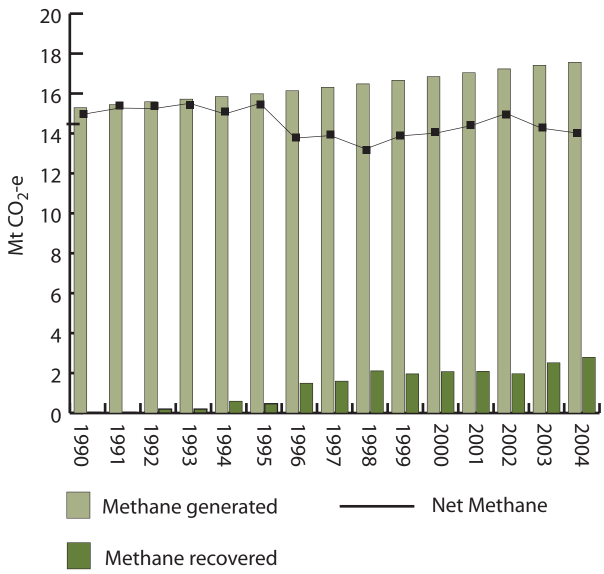
Trends

Waste emissions were 6.3% (1.2 Mt CO_2-e) lower in 2004 than they were in 1990 and 0.8% (0.1 Mt CO_2-e) lower than in 2003.

Emissions from municipal *solid waste disposal on land* decreased by 3.1% (0.5 Mt CO_2-e) over the period 1990 to 2004 (Figure 8.1), and was 0.8% (0.1 Mt CO_2-e) lower when compared with 2003. As waste degradation is a slow process, estimates of methane generation for 2004 reflect waste disposal over more than 50 years.

Rates of methane recovery from solid waste have improved substantially since 1990, increasing from a negligible amount to 2.8 Mt CO_2-e of methane in 2004.

Figure 8.1 Emissions from solid waste disposal on land, 1990–2004



Wastewater handling emissions increased by 22.8% (0.7 Mt CO_2-e) over the period 1990 to 2004, with an increase of 0.7% (0.02 Mt CO_2-e) since 2003. Estimates for *wastewater handling* emissions are largely based on estimates of industry production and population. Emissions of CO_2 from the incineration of solvents and clinical waste increased by 33.0% (0.01 Mt) between 1990 and 2004 and by a negligible amount (0.6%) since 2003.

8.2 OVERVIEW OF SOURCE CATEGORY DESCRIPTION AND METHODOLOGY – WASTE

Table 8.2 Summary of methods and emission factors used to estimate emissions from Waste

Greenhouse Gas Source And Sink Categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
6. Waste	**T2**	**CS**	**T2**	**M,CS**	**T1**	**D**
A. Solid Waste Disposal on Land	NA	NA	T2	M		
B. Wastewater Handling			T2	CS	T1	D
C. Waste Incineration	T2	CS	NE	NA	NE	NA
D. Other	NA	NA	NA	NA	NA	NA

T1= Tier 1, T2 = Tier 2, CS = country specific, M = model, D = default, NE = not estimated, NA = not applicable

8.2.1 SOLID WASTE DISPOSAL ON LAND (6.A)

Source Category Description

The anaerobic decomposition of organic matter in a landfill is a complex process that requires several groups of microorganisms to act in a synergistic manner under favourable conditions. Emissions emanate from waste deposited over a long period (in excess of 50 years in the Australian inventory). The final products of anaerobic decomposition are CH_4 and CO_2. Emissions of CO_2 generated from solid waste disposal are considered to be from biomass sources and therefore are not included in the waste sector of the inventory. Management of landfill sites is generally a municipal activity, with activity data collected by State Government agencies. CO_2 produced from the flaring of methane from waste is also considered as having been derived from biomass sources.

Methodology

The Australian methodology for calculating greenhouse gas emissions from solid waste is consistent with the IPCC Tier 2 First Order Decay (FOD) Model (IPCC 2006). The methodology deployed utilizes a dynamic, spatially-explicit model driven by landfill data provided by the relevant State/Territory Government agencies responsible for waste management. Although the structure of the methodology is constant across States, climate-specific parameters introduce variations in estimated emissions depending on location. The model tracks the stock of carbon estimated to be present in the landfill at any given time. Emissions are generated by the decay of that carbon stock, and reflect waste disposal activity over many decades. The methodology is fully integrated with the results of the Harvested Wood Products (HWP) model reported in chapter 7.

Landfill waste decays and emits methane, depending on its composition and the landfill conditions. Methane emissions in one year depend on the stock of organic material present in the landfill, which has been deposited over many preceding years. The IPCC guidelines recommend that the estimation of emissions from landfills is based on carbon stocks over 3-5 half lives. That is, for waste with a half life of 12 years, it is recommended that 36-60 years of waste data is used to derive emissions estimates.

Australian waste to landfill data

A time series for waste in each State has been constructed using recent data from the States, and other historic sources where available and consistent. Actual waste tonnes reported by the States comprise all or part of the most recent years' figures. Backcasting has been undertaken to derive a time series back to 1940, allowing for a carbon stock model covering 50 years.

Total waste to landfill data is disaggregated into three major waste streams:

> municipal solid waste;
> commercial and industrial waste; and,
> construction and demolition waste.

State/Territory data have been used to determine the stream percentages. Where disaggregated historical data cease, the streams have been held constant back to 1940. In Table 8.3 the stream percentages for each State and Territory as applied for the 2004 Inventory are outlined.

Table 8.3 State Waste stream percentages 2004

	NSW(1)	VIC(2)	QLD(3)	NT(3)	SA(4)	WA(5)	TAS(6)	ACT(7)
Municipal Solid Waste	30%	37%	37%	37%	36%	26%	57%	39%
Commercial and Industrial	44%	24%	9%	9%	19%	18%	33%	45%
Construction and Demolition	26%	39%	54%	54%	46%	56%	10%	16%

Sources: (1) NSW Environment Protection Authority; (2) EcoRecycle Victoria; (3) QLD Environment Protection Authority; (4) SA Environment Protection Authority; (5) WA Department of Environment; (6) Hobart City Council; (7) ACT Department of Urban Services; derived from NGGIC 2006g

Some states include clean fill in their waste to landfill estimates provided and this has an influence on the waste stream proportions, however, as this type of waste is largely inert, there is little effect on the final emissions estimate.

Each waste stream is further disaggregated into a mix of waste categories that contain significant fractions of biodegradable carbon. The categories considered are as follows:

- Food;
- Paper and Textiles;
- Garden and green;
- Wood; and,
- Other.

Data on paper and wood are taken from the Harvested Wood Products (HWP) Model reported in NGGIC 2006g. The model tracks carbon stored in wood and paper products entering the Australian economy: from the time of harvest through the production process and over its service-life in various products to the time of disposal. The wood harvest and production data underpinning this model date back to 1940.

Waste mix estimates are based on the quantities of wood and paper products sent to landfill as derived in the HWP Model and the weighted average of published data on waste mix for the non wood/paper product waste categories. Waste mix percentages change over time as the proportions of wood and paper entering the landfill vary.

Table 8.4 Waste mix percentage by stream for 2004

	Municipal Solid Waste	Commercial & Industrial	Construction & Demolition
Food	16 %	6%	0%
Paper and Textiles (a)	30 %	55%	3%
Garden and Green	15 %	3%	2%
Wood (a)	2%	13%	6%
Other	36 %	22%	88%

Sources: Nolan ITU 1995; EcoRecycle 2000,2005; SA Environment Protection Authority 2000; QLD Environment Protection Authority 2002; NSW Environment Protection Authority 2003; ACT Dept of Urban Services 2005;(a) derived from NGGIC 2006g.

The HWP model output of carbon in wood and paper products entering the landfill has been used to derive a complete time-series of waste to landfill between 1940 and 1990. From 1990 onwards, State and Territory data on total waste to landfill are used. The proportion of wood and paper in total waste is determined based on the HWP model output and residual waste is allocated to food, garden and other waste according to waste mix data collected periodically by State and Territory Authorities. Pre-1990 estimates of total waste to landfill are derived from actual wood and paper to landfill from the HWP model with the waste-mix proportions for other waste types held constant at 1990 levels.

Data on waste to landfill by waste mix category for Australia used in the calculations is reported in Table 8.5, while time-series of waste to landfill between 1990 and 2004 by state are shown in Figure 8.2.

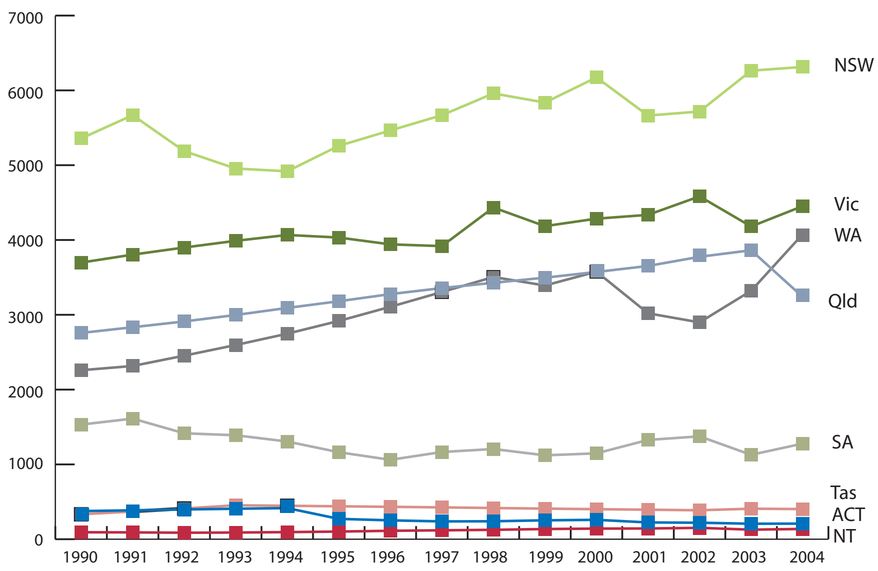
Table 8.5 Volumes of total waste and by type of waste: Australia, 1940–2004

Year	Total waste to landfill [a,b]	Food [b]	Paper [c]	Garden [b]	Wood [c]	Other [b]
	kt	kt	kt	kt	kt	kt
1940	9635	874	2364	796	609	4992
1950	10064	914	2465	832	607	5245
1960	15183	1402	3695	1272	686	8128
1970	17747	1622	4285	1475	811	9554
1980	17096	1525	4113	1393	945	9120
1990	16406	1438	4244	1285	1101	8338
1991	17083	1548	4208	1372	1117	8839
1992	16764	1460	4253	1316	1132	8603
1993	16878	1391	4353	1275	1149	8709
1994	17088	1386	4383	1274	1168	8878
1995	17367	1413	4433	1281	1187	8996
1996	17648	1438	4503	1289	1202	9158
1997	18196	1477	4570	1312	1217	9619
1998	19314	1581	4613	1401	1235	10469
1999	18829	1502	4673	1336	1250	10043
2000	19557	1613	4754	1424	1268	10475
2001	18761	1547	4836	1375	1286	9709
2002	19109	1515	4975	1392	1306	9920
2003	19499	1416	5054	1315	1329	10385
2004	20107	1404	5235	1329	1350	10790

Sources: a) State Government Agencies; b) AGO estimates derived from Nolan ITU 1995; EcoRecycle 2000,2005; SA Environment Protection Authority 2000; QLD Environment Protection Authority 2002; NSW Environment Protection Authority 2003; ACT Dept of Urban Services 2005; NGGIC 2006g. c) AGO estimates derived from NGGIC 2006g (see also Chapter 7).

The Australian methodology incorporates the IPCC Tier 2 FOD model presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The IPCC 2006 model provides the flexibility to apply individual decay profiles to each waste mix category. Each waste mix category decays according to an exponential curve which is a function of its individual half-life. Half lives are adjusted according to the prevailing climatic conditions at the landfill site. The FOD model is explained in detail in IPCC 2006 and the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2004 - Waste*.

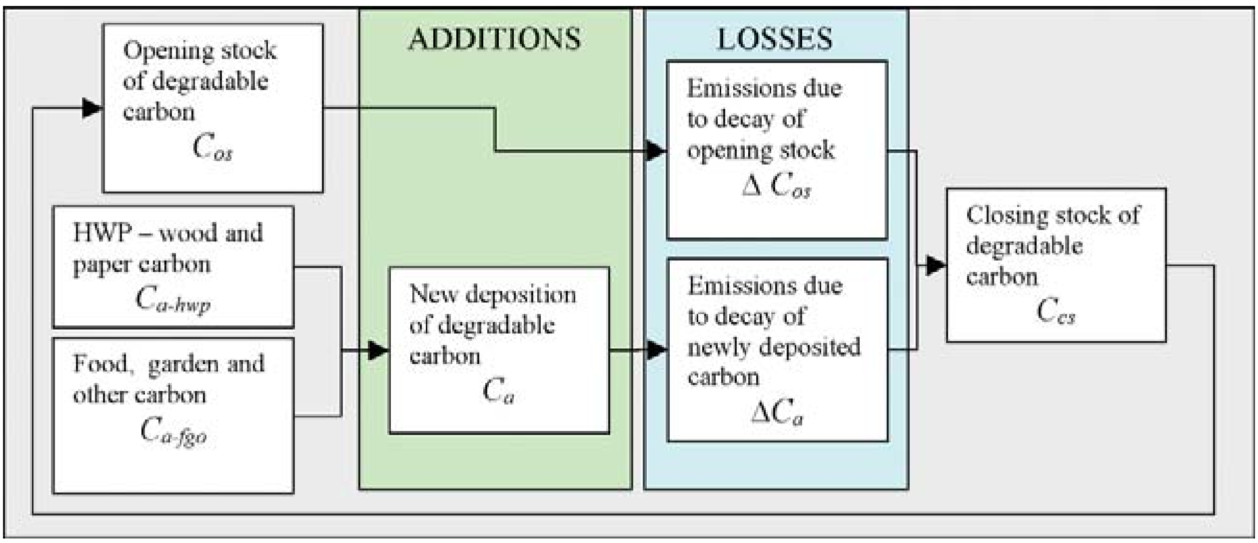
Figure 8.2 Solid waste to landfill by state



Sources:(1) NSW Environment Protection Authority; (2) EcoRecycle Victoria; (3) QLD Environment Protection Authority; (4) SA Environment Protection Authority; (5) WA Department of Environment; (6) Hobart City Council; (7) ACT Department of Urban Services

The IPCC 2006 FOD model takes account of the stock of carbon in a landfill by keeping track of additions of carbon through waste disposal and losses due to anaerobic decay. The concept of the carbon stock model approach is illustrated in Figure 8.3.

Figure 8.3 Carbon stock model flow chart



Carbon enters the landfill system via new deposition of waste C_a. Deposition is based on wood and paper carbon transferred from the HWP carbon pool $C_{a\text{-}hwp}$ and carbon in food, garden and other waste derived from data provided by State and Territory waste authorities $C_{a\text{-}fgo}$. A portion of the newly deposited carbon decays in the first year ΔC_a and the remainder contributes to the closing stock of carbon C_{cs}. Additionally, the opening stock of carbon decays over the year ΔC_{os} with the remainder going to the year's closing stock. The closing stock then becomes the next year's opening stock C_{os}. The total change in carbon stock is estimated simultaneously with estimated emissions of methane.

$C_{cs} = C_{os} - \Delta C_{os}$ (emissions lost from opening stock) + $C_a - \Delta C_a$ (emissions lost from new deposition)

Values for the degradable organic carbon (DOC) content for each waste mix category used in the model are listed in Table 8.6. Unless otherwise stated, the source for these parameters is IPCC (2006). Country specific studies on the carbon content of wood products have been taken into consideration in the choice of DOC value for wood.

Table 8.6 Key Model Parameters: DOC values used in the First Order Decay Model

Waste Type	DOC
Food[(a)]	0.15
Paper and Textiles[(a)]	0.40
Garden and Green[(a)]	0.17
Wood[(b)]	0.50
Other	-

Source: [(a)] IPCC 2006; [(b)] Jaakko Pöyry Consulting 1999

The half lives for each waste mix category have been determined based on default half lives reported in IPCC 2006 and on prevailing climatic conditions at the landfill sites of the principal cities in each State and Territory. In each State, average annual temperature and annual rainfall data for the principal landfill sites were taken from data published by the Australian the Bureau of Meteorology. The assumptions of climatic conditions for each State/Territory and the corresponding half lives and resulting k values for each waste mix category are outlined in Table 8.7.

Table 8.7 Key Model Parameters: Half-lives by waste mix category and State

State / Territory	Climate description	Waste mix category	Half life (years)	k value
NSW	Wet Temperate	Food	4	0.17
		Paper and Textiles	12	0.06
		Garden and Green	7	0.10
		Wood	23	0.03
VIC, WA, SA, TAS, ACT	Dry Temperate	Food	12	0.06
		Paper and Textiles	17	0.04
		Garden and Green	14	0.05
		Wood	35	0.02
QLD, NT	Moist and Wet Tropical	Food	2	0.35
		Paper and Textiles	10	0.07
		Garden and Green	4	0.17
		Wood	20	0.03

Source: IPCC 2006

WASTE

Recent research on the decay of wood products in Australian landfills demonstrated that under conditions experienced at certain landfill sites wood products may decay much more slowly that previously thought (Gardner et al 2004). This broad conclusion has been reflected in IPCC 2006 and is implemented through the long default half lives adopted for wood and paper products in the model.

Permanent storage of carbon in landfills

Certain proportions of organic carbon found in wood and paper products are not available to anaerobic decay leading to a permanent storage of carbon in a landfill. This permanent store of carbon from wood and paper products is also tracked in the first order decay model.

Carbon stocks at the end of each year, additions and losses and methane emissions between 1990 and 2004 are shown in Table 8.8. The carbon stocks at 1990 are based on the accumulation of carbon in the landfill since 1940.

Table 8.8 Carbon stocks, losses and accumulation 1990 to 2004

Year	Carbon additions to the pool (C kt)	Carbon loss (through emissions) (C kt)	Closing stock of carbon (C kt)	Methane generated (CH_4 Gg)
1990	1,341	1,092	69,406	728
1991	1,353	1,103	70,777	735
1992	1,355	1,113	72,152	742
1993	1,371	1,123	73,558	748
1994	1,381	1,132	74,975	755
1995	1,398	1,142	76,415	761
1996	1,419	1,153	77,882	769
1997	1,441	1,165	79,376	776
1998	1,469	1,177	80,899	785
1999	1,473	1,190	82,430	793
2000	1,510	1,203	84,004	802
2001	1,522	1,217	85,597	811
2002	1,554	1,231	87,242	821
2003	1,561	1,244	88,902	829
2004	1,603	1,255	90,635	836

Source: Australian Greenhouse Office.

Methane recovery

Net emissions are derived after accounting for methane recovery undertaken at the landfill site. Methane recovery for flaring and power is estimated for Australia from a survey of the main landfill power and flaring operators. Methane recovered (R(t)) is subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill. It is assumed that all solid waste disposal on land in Australia is disposed to anaerobic or managed landfills (not open dumps or unmanaged sites), hence a methane correction factor of 1 applies.

Non-Methane Volatile Organic Compounds (NMVOC)

Small quantities of NMVOC are contained in landfill gas emitted from landfills in Australia. Some of these NMVOC are generated by the decomposition process and others are residuals from the particular types of waste dumped in the landfill.

The CSIRO Division of Coal and Energy Technology in Sydney (Duffy, Nelson & Williams 1995) investigated NMVOC emissions from four landfills in the Sydney region. They found significant concentrations, up to 10 parts per million by volume (ppmv), for approximately 60 different compounds. Researchers in the UK (Baldwin & Scott 1991) have found between 2,200 and 4,500 milligrams per cubic metre (mg/m^3) of NMVOC present in landfill gas.

In Australian landfills, liquid waste is rarely disposed of with solid waste whereas co-disposal is common practice in the UK. On this basis the lower range of 2,000 mg/m^3 found by the UK researchers is used for NMVOC emissions from Australian landfills unless other site-specific information is available.

It is assumed that NMVOC emissions from landfills comprise 0.2% of total landfill gas emissions; the average methane fraction of landfill gas as generated before release to the atmosphere is 0.6. (This quantity is a weighted mean for all previous years of waste data used to calculate any inventory year's data) and the proportion of methane emitted after oxidation is 0.83.

8.2.2 WASTEWATER HANDLING (6.B)

Source Category Description

The anaerobic decomposition of organic matter in wastewater results in emissions of CH_4. In Australia wastewater is usually treated at municipal wastewater treatment plants, which receive wastewater from:

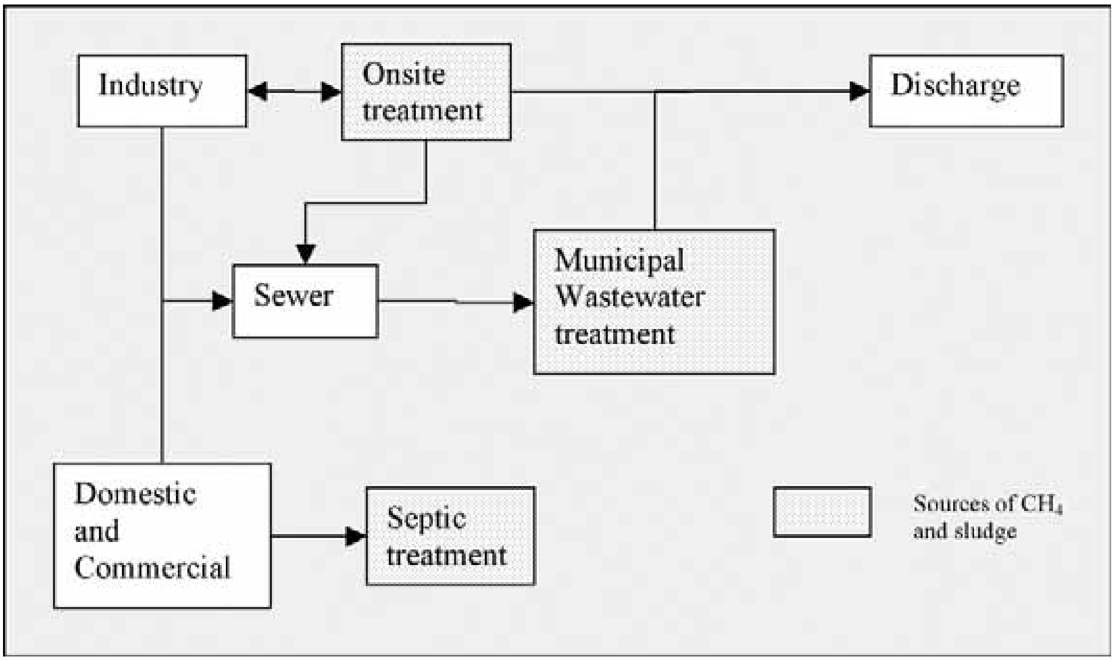
> domestic premises,
> commercial establishments, and
> industrial processing plants.

Municipal wastewater treatment plants in Australia treat a major portion of the domestic sewage and commercial wastewater, and a significant part of industrial wastewater. The main greenhouse gas emitted from wastewater treatment is CH_4. Wastewater treatment also produces N_2O and NMVOC. Carbon dioxide emissions are excluded from this sector except where they are derived from non-biomass sources of carbon. A schematic diagram of the pathways for wastewater in Australia is shown in Figure 8.4.

Emissions are estimated from the sum of the following four sources:

> municipal wastewater treatment plants,
> industrial wastewater,
> on-site domestic and commercial wastewater treatment, and
> disposal of sludge generated from the above.

Figure 8.4 Pathways for Wastewater



As shown in the figure, industry treats its wastewater onsite either for direct disposal or for discharge to the sewer. In sewered areas the domestic and commercial sectors discharge directly to the sewer, and in unsewered areas some form of on-site treatment such as septic tanks is used. From the sewer, the wastewater flows to the municipal wastewater treatment plant (MWTP) where it is treated and later discharged.

Methane gas is the principal by-product of anaerobic decomposition of organic matter in wastewater. Large quantities of methane are not usually found in wastewater due to the fact that even small amounts of oxygen are toxic to the anaerobic bacteria that produce the methane. In wastewater treatment plants, however, there are a number of processes that foster the growth of these organisms by providing anaerobic conditions.

As methane is generated by the decomposition of organic matter, the principal factor which determines the methane generation potential of wastewater is the amount of organic material in the wastewater stream. This is most commonly measured (in the case of municipal wastewater) by the Biochemical Oxygen Demand (BOD) of the wastewater. BOD is a measure of the amount of oxygen consumed by the microorganisms that feed on the organic matter over a period of time. For industrial wastewater, Chemical Oxygen Demand (COD) is used. COD is a measure of the total material available for chemical oxidation (both biodegradable and non-biodegradable) (IPCC 2006).

Sources of anaerobic conditions include:

> sewerage systems – methane generated within the pipeline is released when it enters the inlet of the treatment plant,
> primary sedimentation tanks, and
> sludge thickening tanks.

Industrial Wastewater (6.B.1)

Industrial wastewater emissions are estimated using IPCC default methods, COD and wastewater generation rates, supplemented with Australian data where available. Emission trends are driven by changes in production levels of key industries.

Methods for dealing with industrial wastewater in Australia are varied. Some is treated entirely on-site, while a large amount is treated entirely off-site at municipal wastewater treatment plants. Increasingly industrial wastewater is partially treated on-site before being recycled or discharged to the sewer and treated at municipal wastewater treatment plants. This is due to trade waste discharge licence compliance requirements for a certain quality of wastewater to be achieved prior to sewer discharge.

Most of the industrially produced COD in wastewater comes from the manufacturing industry. According to the IPCC, sectors like food and beverage manufacturing produce significant amounts of COD, some of which is anaerobically treated. Some concentrated industrial wastewater is removed from factories in tankers operated by specialised waste disposal services. This wastewater is usually transported to a special treatment facility.

Methodology

The methodology to determine the amount of CH_4 generated from industrial wastewater is given in IPCC 2000 and focuses on 9 industrial sectors which are considered to generate the most significant quantities of wastewater:

- > Dairy production
- > Pulp and paper production
- > Meat and poultry processing
- > Organic chemicals production
- > Sugar production
- > Beer production
- > Wine production
- > Fruit processing
- > Vegetable processing

The level of methane emissions is driven largely by estimates of chemical oxygen demand (COD) in the wastewater anaerobically treated flowing from each of the nine major wastewater industries. The estimates of COD in wastewater anaerobically treated are generated using country specific data. The variables required to estimate COD are reported in Table 8.9.

Table 8.9 Key parameters for industrial wastewater emissions, 2004

Commodity	Wastewater generation rate (m^3/t)	COD generation rate (kg COD/m^3)	Fraction COD anaerobically treated
Dairy	5.8	0.8	0.4
Pulp and Paper	27.2 [(b)]	0.3	0.0
Meat and Poultry	13.7	6.1	0.5
Organic Chemicals	67.0 [(a)]	3.0 [(a)]	0.1 [(a)]
Sugar	0.4 [(a)]	2.5	0.3
Beer	6.8	7.5	0.6
Wine	23.0 [(a)]	1.5 [(a)]	0.0
Fruit	20.0	0.2	1.0
Vegetables	20.0	0.2	1.0

Source: O'Brien 2006a unless otherwise stated. (a) NGGIC 1995 (b) A3P 2006

Methane emissions are calculated from the level of COD in the wastewater treated anaerobically using an emission factor 0.25 kg CH_4/kg BOD (IPCC 2000). Fractions of methane recovered by industry are sourced from empirical data presented in NGGIC 1995 and O'Brien 2006a. The fractions of methane recovery by commodity are presented in Table 8.10.

Table 8.10 Methane recovered as a percentage of industrial wastewater treatment 2004

Commodity	Fraction of Methane Recovered/flared (%)
Dairy [(b)]	6%
Pulp and Paper [(b)]	0%
Meat and Poultry [(b)]	6%
Organic Chemicals [(b)]	6%
Sugar [(b)]	6%
Beer [(a)]	100%
Wine [(b)]	6%
Fruit [(b)]	6%
Vegetables [(b)]	6%

Source: (a) O'Brien 2006a (b) NGGIC 1995

Methane Emissions from Disposal of Sludge Generated by Industrial Wastewater Treatment

A proportion of the COD generated in the industrial wastewater ultimately treated as sludge (a constant value of 0.15 is assumed to be treated as sludge (NGGIC 1995)). Sludge is treated via two main methods, land-spread and landfill. Sludge that is disposed to landfill is accounted for in the solid waste sub-sector. It is estimated that 60% of industrial sludge is treated via the land-spread method.

Domestic and Commercial Wastewater (6.B.2)

Methodology

<u>Methane Emissions from Wastewater Treatment at Municipal Wastewater Treatment Plants (MWTPs)</u>

The IPCC 2000 default method is used for the estimation of methane emissions from this Domestic and Commercial Wastewater treatment.

The key variable in the estimation of methane from domestic and commercial wastewater is the biochemical oxygen demand (BOD) from wastewater anaerobically treated. Quantities of BOD treated by Australia's major wastewater treatment plants are based on per-capita BOD generation values for each State/Territory. Sewered populations are based on data reported in WSAA 2005.

Methane emissions from wastewater are calculated from the level of BOD in the wastewater (excluding sludge). The country-specific methane emission factor, 0.65 kg CH_4/ kg BOD, is based on the IPCC 2000 default emission factor of 0.25 kg CH_4/kg COD and research conducted by Water Services Association of Australia (WSAA) which has shown COD/BOD ratios of approximately 2.6:1.

Methane Emissions from Disposal of Sludge Generated by Municipal Wastewater Treatment Plants

All wastewater treatment plants produce sludge that needs to be disposed in some way. Sludge generated in Australia is often disposed in sludge lagoons, sludge drying beds or anaerobic digesters. Disposal of this sludge can produce methane if it is allowed to decompose anaerobically. The amount of methane generated is variable depending on the type of treatment process generating the sludge and the method of sludge disposal.

A constant value of 0.54 is used to determine the quantity of domestic and commercial BOD load ultimately treated as sludge (NGGIC 1995). This quantity of BOD relevant to sludge treatment is subtracted from total BOD before emissions are calculated from wastewater treatment. Of this BOD load in sludge, a constant value of 0.29 is considered to be anaerobically treated (NGGIC 1995). Methane emissions from sludge decomposition are estimated as 12 per cent of the BOD load in sludge anaerobically treated (NGGIC 1995).

Methane Emissions from On-Site Domestic and Commercial Wastewater Treatment

The total unsewered population on a State by State basis is calculated according to the Australian Bureau of Statistics and WSAA data and the assumption that each person in unsewered areas in Australia produces 22.5 kg BOD per year (NGGIC 1995). The amount of BOD that settles out as solids and undergoes anaerobic decomposition is assumed to be 15%, which is the IPCC default fraction for total urban wastewater (IPCC Vol. 3 1997).

Nitrous Oxide

The methodology used to estimate N_2O emissions from human sewage is the IPCC default methodology (IPCC 1997 Vol. 3).

Default values were used to derive the estimate of N_2O. Per capita protein consumption of 99.4g/day (36.28kg/year) was sourced from the Australian Institute of Health and Welfare (de Looper and Bhatia 1998).

Non-Methane Volatile Organic Compounds (NMVOC)

There has been little research into the release of NMVOC from wastewater treatment plants. BOD values obtained and used for calculations of methane emissions are used for the calculation of NMVOC from domestic and commercial wastewater and for industrial wastewater. A default value of 0.3 kg NMVOC/tonne BOD for municipal wastewater treatment plants is used.

8.2.3 INCINERATION (6.C)

Emissions are estimated from the incineration of solvents and clinical waste. Blue Scope Steel (formerly BHP) incinerates a quantity of solvent generated through various metal product coating and finishing processes. In this instance, incineration is used as a method to minimize emissions of solvents and VOCs to the atmosphere and leads to emissions of CO_2. Emissions from this source have been based on data estimated by the AGO for the last three years.

Carbon dioxide emissions from incineration of solvents are estimated by converting the volume of solvent incinerated to the weight of solvent, deriving the energy content of the mass of solvent, and using a carbon dioxide emission factor per petajoule of solvent.

In addition to the incineration of solvents, a quantity of clinical waste is incinerated in four major facilities located in QLD, NSW, SA and WA. Data on clinical waste incineration have been obtained from O'Brien 2006b.

The quantity of carbon dioxide emitted as a result of the incineration of clinical waste is based upon the quantity of clinical waste incinerated, the carbon content of the waste and the proportion of that carbon which is of fossil origin.

8.2.4 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.

8.2.5 SOURCE SPECIFIC QA/QC

The waste sector source categories are covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Data provided by waste agencies are compared with known published data sources.

8.2.6 RECALCULATIONS SINCE THE 2004 INVENTORY

Recalculations for the 2004 inventory were performed following:

a) a revision to solid waste activity data;

b) a revision to the on-site industrial wastewater treatment model parameters; and,

c) the inclusion of emissions from the incineration of clinical waste.

The above recalculations resulted in a 0.9 Mt decrease in 1990 and a 1.9 decrease in emissions in 2004 in the waste sector.

8.2.7 SOURCE SPECIFIC PLANNED IMPROVEMENTS

Further data on domestic wastewater treatment is expected to become available. These data will be used to further refine the assumptions behind the municipal wastewater treatment methodology and better reflect measures implemented by utilities to reduce greenhouse emissions.

9. OTHER (UNFCCC SECTOR 7)

Australia does not report any emissions under the UNFCCC category 7, ‘Other’.

10. RECALCULATIONS AND IMPROVEMENTS

National greenhouse gas inventories have been produced for a comparatively short time, especially when compared with other major national statistics, such as gross domestic product. Emissions processes are pervasive and complex and, consequently, emissions estimation techniques and data sources for the Australian inventory are still evolving, particularly in some sectors. Internationally, this is also the case for the inventories of other countries. In addition, the IPCC guidelines on national inventory preparation themselves have recently been revised.

The development of improved estimation techniques is a resource intensive exercise and the IPCC encourages the allocation of development resources into priority areas. In Australia, a number of recalculations have been undertaken for the 2004 Revised inventory and these are summarised in section 10.1-10.3 below. The development effort behind these recalculations has been undertaken in line with the Inventory Improvement Plan for the Australian inventory. This plan is aimed at reducing existing emission estimate uncertainties as much as possible, with development focused on key source categories, sources with high uncertainties and where implementation of new methods is feasible (for example, as a result of new data becoming available). The Australian improvement plan also seeks to respond to international expert reviews and revisions to international guidelines on inventory preparation. Some of the principal elements of the research programme that is underway to inform future inventories are set out in section 10.4.

10.1–10.3 RECALCULATIONS IN THE 1990-2004 TIME SERIES

Estimates of emissions presented in past inventory reports have been recalculated for a number of reasons including end-of-series averaging effects (for the *agriculture* sector), revisions of data, the inclusion of additional sources of data or from refinements in the estimation methodology. To ensure the accuracy of the estimates, and to maintain consistency of the series through time, recalculations of past emission estimates are undertaken for all previous years.

Within the 1990–2004 time series there have been a number of sectors where recalculations have been undertaken. Details of the reasons for these recalculations have been given in the sectoral chapters. The principal sectors where recalculations were undertaken for the National Inventory Report 2004 Revised are set out in Table 10.1.

Table 10.1 Principal recalculations for the 2004 Revised inventory

	Category	Principal Reason
1.A	Energy	Revised fuel consumption data for all years
1.A.3b	Passenger car and light commercial vehicles	Revised methodology for non-CO_2 emissions to incorporate Tier 3 method based on capital stocks and driver behaviour for passenger car and light commercial vehicles by principal fuel and State.
1.B	Fugitives–coal mining	Improved coverage of mine-specific data
1.B	Fugitives–decommissioned mines	Refinement to methodology to allow for flooding of decommissioned mines
2.A	Cement production	Refined methodology to allow for presence of magnesium carbonate
2.B	Chemicals	Refined activity data and emission factors for titanium dioxide, nitric acid and ammonia
2.F	Halocarbons	Refined methodology to incorporate country-specific data on the capital stock of stationary air conditioners
4.A-F	Agriculture	Recalculations due to 3 year averaging of reported emissions
4.A	Agriculture	Refined methodology for tropical beef cattle
4.D	Agricultural soils	Inclusion of new source. Emissions from soil disturbance reported under 4.D.4 'Other'. Revised data for histosols.
5.A	Forest lands	Revised activity data
5.G	Other	Revised activity data
6.B	Wastewater treatment: Industrial	Revised activity data
6.C	Waste incineration	Revised activity data

The number of recalculations is high for this inventory due to the availability of new and better data and methodologies after a period of relative stability for the inventory. The refinements reflect the introduction of greater methodology complexity, and therefore accuracy, completeness, comparability and time-series consistency of Australia's inventory. In general, the refinements have introduced enhanced characterisations of the capital stocks at point of emission, differences in emissions processes at the regional level and dynamic linkages between current emissions and past activities. In some cases, this inventory has introduced elements taken from the new *2006 IPCC Guidelines for the Preparation of National Inventories* and, in some instances, changes have been introduced to respond to comments from the UNFCCC expert review teams.

The net effect of the recalculations at the aggregate emission trends and to some extent levels, however, is relatively minor. The estimated recalculations from the *National Inventory Report 2004 Revised* are set out in Table 10.2.

Table 10.2 Principal estimated recalculations for the 2004 Revised inventory

Year	Net Mt CO_2-e Emissions		Difference	
	Previously Published[(a)]	Latest estimates	Mt CO_2-e	% of Previous value
1990	506.9	499.9	-7.0	-1.4
1991	485.5	478.4	-7.1	-1.5
1992	473.8	465.5	-8.3	-1.7
1993	464.3	454.6	-9.7	-2.1
1994	468.1	457.1	-10.9	-2.3
1995	470.4	459.0	-11.4	-2.4
1996	473.3	462.2	-11.1	-2.3
1997	480.1	470.5	-9.6	-2.0
1998	504.1	493.4	-10.7	-2.1
1999	507.5	497.4	-10.1	-2.0
2000	520.8	510.4	-10.4	-2.0
2001	530.4	518.8	-11.6	-2.2
2002	537.1	527.2	-9.9	-1.8
2003	514.6	507.5	-7.1	-1.4
2004	533.5	525.7	-7.8	-1.5

(a) AGO (2006) - National Inventory Report 2004

The overall effect of the recalculations for the *National Inventory Report 2004 Revised* was to decrease the estimate of Australia's greenhouse emissions for 1990 by 7.0Mt (1.4%), and to decrease the 2004 estimate by 7.8 Mt (1.5%).

The estimated recalculations at a sectoral level indicate slightly larger changes than at the aggregate level. The largest changes were recorded in *Land Use, Land Use Change and Forestry*, principally reflecting the effects of changes to estimates in the Forest Lands Remaining Forests category. For the non - LULUCF sectors taken as a whole, the recalculations have had only small impacts.

Table 10.3 Principal estimated recalculations for the 2004 Revised inventory by sector

Sector	1990 Mt	2002 Mt	2003 Mt	2004 Mt
1.A Fuel Combustion	0.4	-0.9	0.9	1.8
1.A.1 Energy Industries	-0.0	-1.1	-1.4	-2.0
1.A.2 Manufacturing and Construction	0.1	-0.1	-0.1	0.5
1.A.3 Transport	0.2	0.1	2.2	3.2
1.A.4 Other sectors	0.1	0.1	0.1	0.1
1.A.5 Other	0.0	0.0	0.0	0.0
1.B Fugitives	-0.9	-1.2	0.2	-0.6
2 Industrial Processes	0.0	0.9	0.9	0.8
3 Solvents	IE	IE	IE	IE
4 Agriculture	-3.4	-4.0	-3.8	-3.3
5 Land Use, Land Use Change and Forestry	-2.2	-2.8	-3.4	-4.5
6 Waste	-0.9	-1.8	-1.9	-1.9
Total	-7.0	-9.9	-7.1	-7.8
Total (excluding LULUCF)	-4.8	-7.1	-3.7	-3.3

10.4 PLANNED IMPROVEMENTS

Future refinements will be informed by the ongoing technical review of sectoral methodologies and data sources undertaken by the Australian Greenhouse Office as part of Australia's efforts to comply with inventory good practice. Priorities for the inventory development process have been informed by analysis of key sources and key trends; by analysis of the level of uncertainty surrounding existing emission estimates; and the comments received from previous international reviews of Australia's inventory.

Table 10.4 clearly shows the links between the inventory development programme and both the key source analysis presented in Annex 1 and the uncertainty analysis presented in Annex 7. A key area for development is in the land use, land use change and forestry sector, where the full details are set out in the *National Carbon Accounting System, Development Plan 2004-2008,* published by the Australian Greenhouse Office in January 2005 (AGO 2005b).

Table 10.4 Summary of Planned Improvements to the Australian Inventory

Category	Key source?	Sectoral uncertainty estimate	Description
Energy			
1A3 Non-CO_2 from Road Transport	Yes	44%	Review of non-CO_2 emission factors
1.B.1 Fugitive emissions – mining (CH_4)	Yes	21%	Review of emissions data from mining
All	Yes	-	Streamlined data collection processes
Industrial processes			
Review of minor new sources	No	-	Exploration of new data sources
All	Yes	-	Streamlined data collection processes
Agriculture			
4.A Enteric fermentation - cattle (CH_4)	Yes	6%	Field research into emission factors
4.E Burning of savannas (CH_4)	Yes	120%	Field research into fire dynamics and fuel loads
4.E Burning of savannas (N_2O)	Yes	131%	Field research into fire dynamics and fuel loads
4.D Agricultural soils (N_2O)	Yes	102%	Review of methodologies for fertiliser application and conservation practices
LULUCF			
5. Forestry (CO_2, N_2O)	Yes	40%	Full incorporation of plantations into the NCAS Incorporation of N cycle capability
Waste			
6.B Wastewater handling (CH_4)	Yes	50%	Incorporation of new activity data

Sources: Annex 1, Annex 7. AGO 2005b.

RECALCULATIONS AND IMPROVEMENTS

ANNEX 1: KEY SOURCE ANALYSIS

A *key source 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 sources for the UNFCCC inventory using the Tier 1 level and trend assessments as recommended in the IPCC *Good Practice* report. 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)*, *land converted to grassland* and *road transportation* as the most significant of the key source categories—on a level basis. On a trends basis, the most important categories include *public electricity (solid fuel)*, *land converted to grasslands and croplands*, and *enteric fermentation (sheep)*. The full results are reported in Tables A.1 to A.3.

Further key category analysis was conducted excluding the Land Use, Land Use Change and Forestry sectors, as is required by the IPCC Good Practice Guidance. Under this analysis, the three most important categories on a level basis include *public electricity (solid fuel)*, *enteric fermentation (cattle)* and *road transportation* . On a trends basis, the most important categories are estimated to be *public electricity (solid fuel)*, *enteric fermentation (sheep and cattle)* and *solid waste disposal*. The results of this latter analysis are presented in Tables A.4 to A.6.

The Australian analysis has been undertaken using a relatively high degree of disaggregation of sources, which permits a greater degree of understanding of Australia's key categories. Past analyses by the UNFCCC secretariat of Australian data, using higher levels of aggregation common in the analyses undertaken by other countries, have not produced any important distinctions.

Table A.1: Key source categories for Australia's inventory-level assessment

A IPCC Source Category		B Gas	C Base Year Estimate	D Current Year Estimate	E Level Assessment	F Cumulative Total
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2	117909	177490	0.27	0.27
1.A.3.b.	Road Transportation - Liquid Fuels	CO_2	53153	68403	0.10	0.37
5.C	Land Converted to Grassland	CO_2	111377	56156	0.09	0.46
4.A.1	Enteric Fermentation - Cattle	CH_4	42646	47497	0.07	0.53
5.B	Forest land Remaining Forest land	CO_2	42761	31184	0.05	0.58
5.A	Land Converted to Forest Land	CO_2	1989	21460	0.03	0.61
6.A	Solid Waste Disposal on Land	CH_4	15250	14775	0.02	0.64
4.A.3	Enteric Fermentation - Sheep	CH_4	24563	14353	0.02	0.66
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2	8239	13752	0.02	0.68
1.B.1.a.i.	Fugitive Emissions - Underground Coal Mines	CH_4	12012	10767	0.02	0.70
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2	4593	8755	0.01	0.71
2.C.1	Iron and Steel Production - Coke	CO_2	10174	8432	0.01	0.72
4.E	Prescribed Burning of Savannas	CH_4	4643	7728	0.01	0.73
1.A.1.b	Petroleum Refining - Liquid Fuels	CO_2	5160	7044	0.01	0.74
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4	3280	7027	0.01	0.75
1.A.4.b	Other Sectors - Residential - Gaseous Fuels	CO_2	4613	6713	0.01	0.76
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2	4140	6369	0.01	0.77
1.A.4.c	Other Sectors - Agriculture, Forestry and Fisheries - Liquid Fuels	CO_2	3371	6052	0.01	0.78
5.G	Harvested Wood Products	CO_2	4419	5313	0.01	0.79
5.B	Land Converted to Cropland	CO_2	13164	5191	0.01	0.80
1.A.2.b	Non-Ferrous Metals - Solid Fuels	CO_2	4684	5174	0.01	0.81
2.G.	Other: Confidential emissions reported as CO_2e	CO_2	1885	5062	0.01	0.82

A IPCC Source Category		B Gas	C Base Year Estimate	D Current Year Estimate	E Level Assessment	F Cumulative Total
1.A.3.a	Civil Aviation - Liquid Fuels	CO_2	2893	4811	0.01	0.82
4.D.2	Agricultural Soils - Nitrogen excretion on pasture, range and paddock	N_2O	4968	4230	0.01	0.83
1.A.2.f	Other - Mining - Liquid Fuels	CO_2	1741	3884	0.01	0.84
4.D.3.1	Agricultural Soils - Atmospheric Deposition	N_2O	3291	3747	0.01	0.84
2.A.1	Cement Production	CO_2	3463	3555	0.01	0.85
5.C	Forest Land Remaining Forest Land	CH_4	1530	3490	0.01	0.85
4.E	Prescribed burning of savannas	N_2O	1966	3290	0.01	0.86
1.B.2.c.	Oil and Natural Gas - Venting	CO_2	1966	3161	0.00	0.86
4.D.1	Fertilisers	N_2O	1558	3159	0.00	0.87
2.C.3	Aluminium Production	CO_2	2017	3022	0.00	0.87
4.D.3	Nitrogen leaching and runoff	N_2O	2575	2968	0.00	0.88
1.A.2.f	Other - Gaseous Fuels	CO_2	2951	2793	0.00	0.88
1.A.2.c	Chemicals - Liquid Fuels	CO_2	3249	2792	0.00	0.88
1.A.2.b	Non-Ferrous Metals - Liquid Fuels	CO_2	3026	2696	0.00	0.89
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2	958	2675	0.00	0.89
1.A.2.c	Chemicals - Gaseous Fuels	CO_2	1745	2686	0.00	0.90
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0	2344	0.00	0.90
1.A.2.f	Other - Mining - Solid Fuels	CO_2	2179	2340	0.00	0.90
1.A.4.a	Other Sectors- Commercial- Gaseous Fuels	CO_2	1810	2299	0.00	0.91
1.B.1.c	Fugitives - Coal - Decommissioned Mines	CH_4	363	2185	0.00	0.91
1.B.2.c	Fugitives - Oil and Natural Gas - flaring	CO_2	3601	2126	0.00	0.91
1.B.2.b.iv	Fugitives - Gas - Distribution	CH_4	4092	1974	0.00	0.92
1.A.3.c	Railways - Liquid Fuels	CO_2	1727	1796	0.00	0.92
1.A.4.a	Other Sectors- Commercial - Liquid Fuels	CO_2	1231	1795	0.00	0.92
1.A.2.a	Iron and Steel - Solid fuels	CO_2	1191	1740	0.00	0.92
1.A.2.f	Other Sectors - Construction - Liquid Fuels	CO_2	2809	1694	0.00	0.92
2.C.1	Iron	CO_2	0	1634	0.00	0.92
1.A.2.e	Food Processing, Beverages and Tobacco - Gaseous Fuels	CO_2	1246	1580	0.00	0.93
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2	2309	1523	0.00	0.93
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2	2860	1478	0.00	0.93
1.A.3.b.	Road Transportation - Liquid Fuels	N_2O	561	1469	0.00	0.94
1.A.2.f	Other Sectors - Mining - Gaseous fuels	CO_2	46	1361	0.00	0.94
1.A.2.a	Iron and Steel - Gaseous fuels	CO_2	1383	1327	0.00	0.94
5.C	Land Converted to Grassland	CH_4	2652	1327	0.00	0.94
1.B.2.c.	Oil and Natural Gas - Venting	CH_4	1734	1278	0.00	0.95
4.B	Manure Management - swine	CH_4	1050	1256	0.00	0.95
2.C.3	Aluminium production	CF_4	3326	1255	0.00	0.95
1.A.4.b	Residential - liquid fuels	CO_2	1315	1165	0.00	0.95
1.A.1.b	Petroleum Refining - Gaseous fuels	CO_2	576	1161	0.00	0.95

Table A.2: Key source categories for Australia's inventory—trend assessment

A IPCC Source Categories		B Gas	C 1990 Emissions	D 2004 Emissions	E Trend Assessment	F % Contribution to Trend	G Cumulative Total of Column F
5.C	Land converted to Grassland	CO_2	111378	56156	0.11	0.22	0.22
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2	117909	177490	0.10	0.19	0.41
5.A	Land Converted to Forest Land	CO_2	1989	21460	0.03	0.07	0.47
5.A	Forest Land converted to Cropland	CO_2	13164	5191	0.03	0.07	0.54
5.B	Forest Land Remaining Forest Land	CO_2	42761	31184	0.02	0.05	0.59
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	53153	68403	0.02	0.04	0.64
4.A.3	Enteric Fermentation - Sheep	CH_4	24563	14353	0.02	0.04	0.68
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2	8239	13752	0.01	0.02	0.69
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2	4593	8755	0.01	0.01	0.71
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4	3280	7027	0.01	0.01	0.72
2.G.	Other: Confidential emissions reported as CO_2e	CO_2	1885	5062	0.01	0.01	0.74
4.E	Prescribed Burning of Savannas	CH_4	4643	7728	0.01	0.01	0.75
4.A.1	Enteric Fermentation - Cattle	CH_4	42646	47497	0.00	0.01	0.76
1.A.4.c	Other Sectors - Agriculture, Forestry and Fisheries - Liquid Fuels	CO_2	3371	6052	0.00	0.01	0.76
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0	2344	0.00	0.01	0.77
1.B.2.b	Fugitives - Natural Gas Distribution	CH_4	4092	1974	0.00	0.01	0.78
2.C.1	Iron and Steel Production - Coke	CO_2	10174	8432	0.00	0.01	0.79
2.C.3	Aluminium Production	CF_4	3938	1494	0.00	0.01	0.80
1.A.2.f	Other - Mining - liquid fuels	CO_2	1741	3884	0.00	0.01	0.80
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2	4140	6369	0.00	0.01	0.81
5.A	Forest Land Remaining Forest Land	CH_4	1530	3490	0.00	0.01	0.82
1.B.1.c	Fugitives - Coal - Undeground mines	CH_4	12012	10767	0.00	0.01	0.82
1.A.4	Other Sectors - Residential - Gaseous Fuels	CO_2	4612	6713	0.00	0.01	0.83
1.B.1.c	Fugitives - Other - Decommissioned mines	CH_4	363	2185	0.00	0.01	0.84
1.A.3.a	Civil Aviation - Liquid fuels	CO_2	2893	4811	0.00	0.01	0.84
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2	2309	1523	0.00	0.01	0.85
1.B.2.c.	Oil and Natural Gas - Flaring	CO_2	3601	2126	0.00	0.01	0.86
2.C.1	Iron - Gaseous fuels	CO_2	0	1634	0.00	0.01	0.86
1.A.1.b	Petroleum Refining - Liquid Fuels	CO_2	5160	7044	0.00	0.01	0.87
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2	2860	1478	0.00	0.01	0.87
4.D.1	Fertilisers	N_2O	1558	3159	0.00	0.01	0.88
5.C	Forest Land converted to Grassland	CH_4	2652	1327	0.00	0.01	0.88
1.A.2.f	Other Sectors - Mining - Gaseous Fuels	CO_2	46	1360	0.00	0.00	0.89
6.A	Solid Waste Disposal on Land	CH_4	15249	14775	0.00	0.00	0.89
1.A.2.f	Other Sectors - Construction - Liquid Fuels	CO_2	2809	1693	0.00	0.00	0.90
4.E	Prescribed burning of savannas	N_2O	1965	3290	0.00	0.00	0.90
2.E	Production of HFCs	HFC-23	1126	0	0.00	0.00	0.90

A	IPCC Source Categories	B Gas	C 1990 Emissions	D 2004 Emissions	E Trend Assessment	F % Contribution to Trend	G Cumulative Total of Column F
1.B.2.c.	Oil and Natural Gas - Venting	CO_2	1966	3160	0.00	0.00	0.91
4.D.2	Agricultural Soils - Animal production	N_2O	4967	4230	0.00	0.00	0.91
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2	2309	1522	0.00	0.00	0.92
2.C.3	Aluminium Production	CO_2	2017	3021	0.00	0.00	0.91
6.B.1	Industrial Wastewater	CH_4	1783	985	0.00	0.00	0.92
1.A.3.b.i.	Road Transportation - liquid fuels	N_2O	560	1468	0.00	0.00	0.92
1.A.3.d.ii	Navigation (domestic) - liquid fuels	CO_2	1368	568	0.00	0.00	0.93
1.A.4	Other Sectors - Residential - Biomass	CH_4	1711	995	0.00	0.00	0.93
1.A.2.c	Chemicals - Gaseous Fuels	CO_2	1744	2637	0.00	0.00	0.93
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-143a	0	769	0.00	0.00	0.94
4.B	Manure management - solid storage and dry lot	N_2O	201	925	0.00	0.00	0.94
5.D	Harvested Wood Products	CO_2	4419	5313	0.00	0.00	0.94
1.A.2.c	Chemicals - Liquid Fuels	CO_2	3248	2792	0.00	0.00	0.95
1.A.2.d	Pulp and paper - Solid Fuels	CO_2	333	970	0.00	0.00	0.95
1.A.1.b	Petroleum refining - Gaseous Fuels	CO_2	576	1161	0.00	0.00	0.95
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-125	0	552	0.00	0.00	0.95
1.B.2.c.	Oil and Natural Gas - Venting	CH_4	1733	1278	0.00	0.00	0.95
5.A	Forest Land Remaining Forest Land	N_2O	417	952	0.00	0.00	0.95

Table A.3: Key source categories for Australia's inventory—summary

A IPCC Source Categories		B Direct Greenhouse Gas	C Key Source Category Flag	D If Column C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2		Level, Trend
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2		Level, Trend
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2		Level, Trend
1.A.1.b	Petroleum Refining - Liquid Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2		Level, Trend
1.A.2.a	Iron and Steel - Solid Fuels	CO_2		Level, Trend
1.A.2.a	Iron and Steel - Gaseous Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Liquid Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Solid Fuels	CO_2		Level
1.A.2.c	Chemicals - Gaseous Fuels	CO_2		Level, Trend
1.A.2.c	Chemicals - Liquid Fuels	CO_2		Level, Trend
1.A.2.c	Chemicals - Solid Fuels	CO_2		Trend
1.A.2.d	Pulp and Paper - Gaseous Fuels	CO_2		Trend
1.A.2.e	Food Processing, Beverages and Tobacco - Gaseous Fuels	CO_2		Level
1.A.2.f	Other - Gaseous Fuels	CO_2		Level, Trend
1.A.2.f	Other - Liquid Fuels	CO_2		Level, Trend
1.A.2.f	Other - Solid Fuels	CO_2		Level
1.A.3.a	Civil Aviation - Liquid Fuels	CO_2		Level, Trend
1.A.3.b	Road Transportation - Liquid Fuels	CO_2		Level, Trend
1.A.3.b	Road Transportation - Liquid Fuels	N_2O		Level, Trend
1.A.3.c	Railways	CO_2		Level
1.A.3.d.ii	Navigation (domestic)	CO_2		Trend
1.A.4	Other Sectors - Biomass	CH_4		Level, Trend
1.A.4	Other Sectors - Gaseous Fuels	CO_2		Level, Trend
1.A.4	Other Sectors - Liquid Fuels	CO_2		Level, Trend
1.B.1.a.i.	Fugitive Emissions - Underground Coal Mines	CH_4		Level, Trend
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4		Level, Trend
1.B.1.c.	Fugitive Emissions - Other	CH_4		Level, Trend
1.B.2.b.	Oil and Natural Gas - Natural Gas	CH_4		Level, Trend
1.B.2.c.	Oil and Natural Gas - Flaring	CO_2		Level, Trend
1.B.2.c.	Oil and Natural Gas - Venting	CO_2		Level, Trend
1.B.2.c.	Oil and Natural Gas - Venting	CH_4		Level, Trend
2.A.1	Cement	CO_2		Level
2.C.1	Iron and Steel Production	CO_2		Level, Trend
2.C.1	Iron	CO_2		Level, Trend
2.C.3	Aluminium Production	CO_2		Level, Trend
2.C.3	Aluminium Production	CF_4		Level, Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFCs		Level, Trend
2.G.	Other: Confidential emissions reported as CO_2e	CO_2		Level, Trend
4.A.1	Enteric Fermentation - Cattle	CH_4		Level, Trend
4.A.3	Enteric Fermentation - Sheep	CH_4		Level, Trend
4.B	Manure Management	CH_4		Level, Trend
4.D	Agricultural Soils	N_2O		Level, Trend

A IPCC Source Categories		B Direct Greenhouse Gas	C Key Source Category Flag	D If Column C is Yes, Criteria for Identification
4.E	Prescribed Burning of Savannas	CH_4		Level, Trend
4.E	Prescribed Burning of Savannas	N_2O		Level, Trend
5.A	Forest Land converted to Cropland	CO_2		Level, Trend
5.B	Forest Land - Remaining Forest Land	CO_2		Level, Trend
5.B	Forest Land - Remaining Forest Land	CH_4		Level, Trend
5.C	Forest Land converted to Grassland	CO_2		Level, Trend
5.C	Forest Land converted to Grassland	CH_4		Level, Trend
5.D	Other	CO_2		Level, Trend
6.A	Solid Waste Disposal on Land	CH_4		Level, Trend
6.B	Waste-water Handling	CH_4		Trend

Table A.4: Key source categories for Australia's inventory-level assessment excluding LULUCF

A IPCC Source Category		B Gas	C Base Year Estimate	D Current Year Estimate	E Level Assessment	F Cumulative Total
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2	117909	177490	0.34	0.34
1.A.3.b.	Road Transportation - Liquid Fuels	CO_2	53153	68403	0.13	0.46
4.A.1	Enteric Fermentation - Cattle	CH_4	42646	47497	0.09	0.55
6.A	Solid Waste Disposal on Land	CH_4	15250	14775	0.03	0.58
4.A.3	Enteric Fermentation - Sheep	CH_4	24563	14353	0.03	0.61
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2	8239	13752	0.03	0.63
1.B.1.a.i.	Fugitive Emissions - Underground Coal Mines	CH_4	12012	10767	0.02	0.66
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2	4593	8755	0.02	0.67
2.C.1	Iron and Steel Production - Coke	CO_2	10174	8432	0.02	0.69
4.E	Prescribed Burning of Savannas	CH_4	4643	7728	0.01	0.70
1.A.1.b	Petroleum Refining - Liquid Fuels	CO_2	5160	7044	0.01	0.72
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4	3280	7027	0.01	0.73
1.A.4.b	Other Sectors - Residential - Gaseous Fuels	CO_2	4613	6713	0.01	0.74
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2	4140	6369	0.01	0.75
1.A.4.c	Other Sectors - Agriculture, Forestry and Fisheries - Liquid Fuels	CO_2	3371	6052	0.01	0.76
1.A.2.b	Non-Ferrous Metals - Solid Fuels	CO_2	4684	5174	0.01	0.77
2.G.	Other: Confidential emissions reported as CO_2e	CO_2	1885	5062	0.01	0.78
1.A.3.a	Civil Aviation - Liquid Fuels	CO_2	2893	4811	0.01	0.79
4.D.2	Agricultural Soils - Nitrogen excretion on pasture, range and paddock	N_2O	4968	4230	0.01	0.80
1.A.2.f	Other - Mining - Liquid Fuels	CO_2	1741	3884	0.01	0.81
4.D.3.1	Agricultural Soils - Atmospheric Deposition	N_2O	3291	3747	0.01	0.82
2.A.1	Cement Production	CO_2	3463	3555	0.01	0.82
4.E	Prescribed burning of savannas	N_2O	1966	3290	0.01	0.83
1.B.2.c.	Oil and Natural Gas - Venting	CO_2	1966	3161	0.01	0.83
4.D.1	Agricultural Soils - Fertilisers	N_2O	1558	3159	0.01	0.84
2.C.3	Aluminium Production	CO_2	2017	3022	0.01	0.85
4.D.3	Agricultural Soils - Nitrogen leaching and runoff	N_2O	2575	2968	0.01	0.85
1.A.2.f	Other - Gaseous Fuels	CO_2	2951	2793	0.01	0.86
1.A.2.c	Chemicals - Liquid Fuels	CO_2	3249	2792	0.01	0.86
1.A.2.b	Non-Ferrous Metals - Liquid Fuels	CO_2	3026	2696	0.01	0.87
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2	958	2675	0.01	0.87

A IPCC Source Category		B Gas	C Base Year Estimate	D Current Year Estimate	E Level Assessment	F Cumulative Total
1.A.2.c	Chemicals - Gaseous Fuels	CO_2	1745	2686	0.00	0.88
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0	2344	0.00	0.89
1.A.2.f	Other - Mining - Solid Fuels	CO_2	2179	2340	0.00	0.89
1.A.4.a	Other Sectors- Commercial- Gaseous Fuels	CO_2	1810	2299	0.00	0.89
1.B.2.c	Fugitives - Oil and Natural Gas - flaring	CO_2	3601	2126	0.00	0.90
1.B.1.c	Fugitives - Coal - Decommissioned Mines	CH_4	363	2185	0.00	0.90
1.B.2.b.iv	Fugitives - Gas - Distribution	CH_4	4092	1974	0.00	0.90
1.A.3.c	Railways - Liquid Fuels	CO_2	1727	1796	0.00	0.91
1.A.4.a	Other Sectors- Commercial - Liquid Fuels	CO_2	1231	1795	0.00	0.91
1.A.2.a	Iron and Steel - Solid fuels	CO_2	1191	1740	0.00	0.91
1.A.2.f	Other Sectors - Construction - Liquid Fuels	CO_2	2809	1694	0.00	0.92
2.C.1	Iron	CO_2	0	1634	0.00	0.92
1.A.2.e	Food Processing, Beverages and Tobacco - Gaseous Fuels	CO_2	1246	1580	0.00	0.92
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2	2309	1523	0.00	0.92
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2	2860	1478	0.00	0.93
1.A.3.b.	Road Transportation - Liquid Fuels	N_2O	561	1469	0.00	0.93
1.A.2.f	Other Sectors - Mining - Gaseous fuels	CO_2	46	1361	0.00	0.93
1.A.2.a	Iron and Steel - Gaseous fuels	CO_2	1383	1327	0.00	0.94
1.B.2.c.	Oil and Natural Gas - Venting	CH_4	1734	1278	0.00	0.94
4.B	Manure Management - swine	CH_4	1050	1256	0.00	0.94
2.C.3	Aluminium production	CF_4	3326	1255	0.00	0.94
1.A.4.b	Residential - Liquid fuels	CO_2	1315	1165	0.00	0.94
1.A.1.b	Petroleum Refining - Gaseous fuels	CO_2	576	1161	0.00	0.95
2.A.2	Lime production	CO_2	704	1101	0.00	0.95
1.A.3.d	Navigation - Liquid fuels	CO_2	940	1081	0.00	0.95
1.A.4.b	Other sectors - Residential - Biomass	CH_4	1711	996	0.00	0.95
6.B.1	Waste-Water Handling - Industrial Wastewater	CH_4	1783	986	0.00	0.95

Table A.5: Key source categories for Australia's inventory—trend assessment excluding LULUCF

A IPCC Source Categories		B Gas	C 1990 Emissions	D 2004 Emissions	E Trend Assessment	F % Contribution to Trend	G Cumulative Total of Column F
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2	117909	177490	0.04	0.21	0.21
4.A.3	Enteric Fermentation - Sheep	CH_4	24563	14353	0.02	0.12	0.32
4.A.1	Enteric Fermentation - Cattle	CH_4	42646	47497	0.01	0.04	0.36
6.A	Solid Waste Disposal on Land	CH_4	15249	14775	0.01	0.03	0.40
2.C.1	Iron and Steel Production - Coke	CO_2	10174	8432	0.01	0.03	0.43
1.B.1.a.i.	Fugitive Emissions - Underground Coal Mines	CH_4	12012	10767	0.01	0.02	0.46
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2	8239	13752	0.01	0.02	0.48
1.B.2.b	Fugitives - Natural Gas Distribution	CH_4	4092	1974	0.00	0.02	0.50
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2	4593	8755	0.00	0.02	0.52
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4	3280	7027	0.00	0.02	0.54
2.C.3	Aluminium Production	CF_4	3938	1494	0.00	0.02	0.56
2.G.	Other: Confidential emissions reported as CO_2e	CO_2	1885	5062	0.00	0.02	0.58
1.B.2.c.	Oil and Natural Gas - Flaring	CO_2	3601	2126	0.00	0.02	0.60
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0	2344	0.00	0.02	0.62
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2	2860	1478	0.00	0.01	0.63
4.D.2	Agricultural Soils - Animal production	N_2O	4967	4230	0.00	0.01	0.65
4.E	Prescribed Burning of Savannas	CH_4	4643	7728	0.00	0.01	0.66
1.A.2.f	Other Sectors - Construction - Liquid Fuels	CO_2	2809	1693	0.00	0.01	0.68
1.A.4.c	Other Sectors - Agriculture, Forestry and Fisheries - Liquid Fuels	CO_2	3371	6052	0.00	0.01	0.66
1.B.1.c	Fugitives - Other - Decommissioned mines	CH_4	363	2185	0.00	0.01	0.70
1.A.2.f	Other - Mining - liquid fuels	CO_2	1741	3884	0.00	0.01	0.71
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	53153	68403	0.02	0.01	0.72
2.C.1	Iron - Gaseous fuels	CO_2	0	1634	0.00	0.01	0.73
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2	2309	1523	0.00	0.01	0.74
2.E	Production of HFCs	HFC-23	1126	0	0.00	0.01	0.75
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2	2309	1522	0.00	0.01	0.76
1.A.2.f	Other Sectors - Mining - Gaseous Fuels	CO_2	46	1360	0.00	0.01	0.77
1.A.2.c	Chemicals - Liquid Fuels	CO_2	3248	2792	0.00	0.01	0.78
6.B.1	Industrial Wastewater	CH_4	1783	985	0.00	0.01	0.79
4.D.1	Agricultural Soils - Fertilisers	N_2O	1558	3159	0.00	0.01	0.80
1.A.3.a	Civil Aviation - Liquid fuels	CO_2	2893	4811	0.00		0.80
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2	4140	6369	0.00	0.01	0.81
1.A.4	Other Sectors - Residential - Biomass	CO_2	1711	995	0.00	0.01	0.82
1.A.3.d.ii	Navigation (domestic) - liquid fuels	CO_2	1368	568	0.00	0.00	0.83
1.A.2.b	Non-Ferrous metals - Liquid fuels	CO_2	3025	2696	0.00	0.00	0.84
1.A.4	Other Sectors - Residential - Gaseous Fuels	CO_2	4612	6713	0.00	0.00	0.84

ANNEX 1

A IPCC Source Categories		B Gas	C 1990 Emissions	D 2004 Emissions	E Trend Assessment	F % Contribution to Trend	G Cumulative Total of Column F
1.A.2.f	Other - Mining - Gaseous	CO_2	2950	2793	0.00	0.00	0.85
1.B.2.c.	Oil and Natural Gas - Venting	CH_4	1733	1278	0.00	0.00	0.86
4.E	Prescribed burning of savannas	N_2O	1965	3290	0.00	0.00	0.86
2.A.1	Cement production	CO_2	3462	3554	0.00	0.00	0.87
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-143a	0	769	0.00	0.00	0.88
1.A.3.b.	Road Transportation - Liquid Fuels	N_2O	560	1468	0.00	0.00	0.89
1.A.2.c	Chemicals - Solid Fuels	CO_2	1194	751	0.00	0.00	0.90
1.B.2.c.	Oil and Natural Gas - Venting	CO_2	1966	3161	0.00	0.00	0.91
1.A.2.e	Food Processing, Beverages and Tobacco - Solid Fuels	CO_2	1190	795	0.00	0.00	0.90
1.A.2.b	Non-Ferrous Metals - Solid Fuels	CO_2	4694	5184	0.00	0.00	0.90
4.B	Manure Management solid storage and dry lot	N_2O	201	925	0.00	0.00	0.91
1.B.2.c.	Oil and Natural Gas - Flaring	CH_4	944	565	0.00	0.00	0.91
1.A.2.f	Other - Gaseous Fuels	CO_2	1046	711	0.00	0.00	0.91
1.A.1.b	Petroleum Refining - Liquid fuels	CO_2	5160	7044	0.00	0.00	0.92
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-125	0	552	0.00	0.00	0.92
1.A.2.d	Pulp and Paper - Solid Fuels	CO_2	333	970	0.00	0.00	0.92
2.C.3	Aluminium production	C_2F_6	611	230	0.00	0.00	0.92
4.D.4	Agricultural Soils - Other - Soil Disturbance	N_2O	673	341	0.00	0.00	0.92
2.C.3	Aluminium Production	CO_2	2017	3021	0.00	0.00	0.93
1.A.4.b	Other Sectors - Residential - Liquid fuels	CO_2	1315	1161	0.00	0.00	0.93
1.A.2.c	Chemicals - Gaseous Fuels	CO_2	1744	2637	0.00	0.00	0.93
1.A.1.b	Petroleum Refining - Gaseous fuels	CO_2	576	1161	0.00	0.00	0.94
1.A.2.a	Iron and Steel - Gaseous Fuels	CO_2	1383	1327	0.00	0.00	0.94
1.A.2.f	Other - Mining - Solid Fuels	CO_2	2179	2340	0.00	0.00	0.95
4.C	Rice	CH_4	490	236	0.00	0.00	0.95
4.D	Agricultural Soils - Atmospheric deposition	N_2O	3290	3748	0.00	0.00	0.95

Table A.6: Key source categories for Australia's inventory—summary excluding LULUCF

A IPCC Source Categories		B Gas	C Key Source Category Flag	D If Colum C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production - Gaseous Fuels	CO_2		Level, Trend
1.A.1.a	Public Electricity and Heat Production - Liquid Fuels	CO_2		Trend
1.A.1.a	Public Electricity and Heat Production - Solid Fuels	CO_2		Level, Trend
1.A.1.b	Petroleum Refining - Liquid Fuels	CO_2		Level, Trend
1.A.1.b	Petroleum Refining - Gaseous Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Gaseous Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Liquid Fuels	CO_2		Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries - Solid Fuels	CO_2		Level, Trend
1.A.2.a	Iron and Steel - Solid Fuels	CO_2		Level
1.A.2.a	Iron and Steel - Gaseous Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Gaseous Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Liquid Fuels	CO_2		Level, Trend
1.A.2.b	Non-Ferrous Metals - Solid Fuels	CO_2		Level, Trend
1.A.2.c	Chemicals - Gaseous Fuels	CO_2		Level, Trend
1.A.2.c	Chemicals - Liquid Fuels	CO_2		Level, Trend
1.A.2.c	Chemicals - Solid Fuels	CO_2		Trend
1.A.2.d	Pulp and Paper - Solid Fuels	CO_2		Trend
1.A.2.e	Food Processing, Beverages and Tobacco - Gaseous Fuels	CO_2		Level
1.A.2.e	Food Processing, Beverages and Tobacco - Solid Fuels	CO_2		Trend
1.A.2.f	Other - Gaseous Fuels	CO_2		Level, Trend
1.A.2.f	Other - Liquid Fuels	CO_2		Level, Trend
1.A.2.f	Other - Solid Fuels	CO_2		Level, Trend
1.A.3.a	Civil Aviation - Liquid Fuels	CO_2		Level, Trend
1.A.3.b.	Road Transportation	CO_2		Level, Trend
1.A.3.b.	Road Transportation	N_2O		Level, Trend
1.A.3.c	Railways	CO_2		Level
1.A.3.d.ii	Navigation (domestic)	CO_2		Level, Trend
1.A.4	Other Sectors - Biomass	CH_4		Level, Trend
1.A.4	Other Sectors - Gaseous Fuels	CO_2		Level, Trend
1.A.4	Other Sectors - Liquid Fuels	CO_2		Level, Trend
1.B.1.a.i.	Fugitive Emissions - Underground Coal Mines	CH_4		Level, Trend
1.B.1.a.ii.	Fugitive Emissions - Surface Coal Mining	CH_4		Level, Trend
1.B.1.c.	Fugitive Emissions - Other	CH_4		Level, Trend
1.B.2.b.	Oil and Natural Gas - Natural Gas	CH_4		Level, Trend
1.B.2.c.	Oil and Natural Gas - Flaring	CO_2		Level, Trend
1.B.2.c.	Oil and Natural Gas - Flaring	CH_4		Level, Trend
1.B.2.c.	Oil and Natural Gas - Venting	CO_2		Level, Trend
1.B.2.c.	Oil and Natural Gas - Venting	CH_4		Trend
2.A.1	Cement	CO_2		Level, Trend
2.A.2	Lime	CO_2		Level

A IPCC Source Categories		B Gas	C Key Source Category Flag	D If Colum C is Yes, Criteria for Identification
2.C.1	Iron and Steel Production	CO_2		Level, Trend
2.C.1	Iron	CH_4		Level, Trend
2.C.3	Aluminium Production	CO_2		Level, Trend
2.C.3	Aluminium Production	CF_4		Level, Trend
2.C.3	Aluminium Production	C_2F_6		Level, Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFCs		Level, Trend
2.G.	Other: Confidential emissions reported as CO_2-e	CO_2		Level, Trend
4.A.1	Enteric Fermentation - Cattle	CH_4		Level, Trend
4.A.3	Enteric Fermentation - Sheep	CH_4		Level, Trend
4.B	Manure Management	CH_4		Level, Trend
4.C	Rice	CH_4		Trend
4.D	Agricultural Soils	N_2O		Level, Trend
4.E	Prescribed Burning of Savannas	CH_4		Level, Trend
4.E	Prescribed Burning of Savannas	N_2O		Level, Trend
6.A	Solid Waste Disposal on Land	CH_4		Level, Trend
6.B	Waste-Water Handling	CH_4		Trend

ANNEX 2: METHODOLOGY AND DATA FOR ESTIMATING CARBON DIOXIDE EMISSIONS FROM FOSSIL FUEL COMBUSTION

The full Australian methodology and data descriptions for the estimation of this inventory are documented in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005*, which is available on the Australian Greenhouse Office website at www.greenhouse.gov.au/inventory. The essential material in these documents has been reproduced in chapter 3.

ANNEX 3: OTHER DETAILED METHODOLOGICAL DESCRIPTIONS

The full Australian methodology for the estimation of this inventory is documented in *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005*, which is available on the Australian Greenhouse Office website at www.greenhouse.gov.au/inventory.

ANNEX 4: CARBON DIOXIDE REFERENCE APPROACH FOR THE ENERGY SECTOR

Estimation of CO_2 Using the IPCC Reference Approach

The reference approach estimate CO_2 emissions from *fuel combustion activities* (covering both *stationary energy* and *transport*). It is calculated using a top-down approach based on national energy statistics for production, imports, exports and stock change. The Australian national energy statistics are produced by ABARE and shown below in Table A6a. The energy consumption data and methodology within the reference approach differ to some degree from that used for the bottom-up, sectoral approach. However, the reference approach can be considered as a further means of quality control supporting the National (sectoral) emissions total. For this inventory, Australia has submitted a complete time series of estimates using the reference approach, from 1990 to 2004.

Comparison of Australian Methodology with IPCC Reference Approach

Total CO_2 emissions estimated using Australia's National approach methodology are 351.9 Mt. Total CO_2 emissions estimated using the reference approach are 351.2 Mt. This is an overall 0.2% difference between the two methods. The main reasons underlying the difference are:

1) An artefact caused by deficiencies in the design of Tables 1.A(b) and 1.A(d). The CRF does not allow for the subtraction of the energy content of the fuels whose carbon is sequestered. It only allows for the subtraction of the sequestered carbon and carbon emitted elsewhere, i.e. in other sectors. Therefore, the energy consumption reported using this method for the Reference Approach includes energy which is netted out of the national approach. The energy consumption for the Reference Approach and the National Approach will therefore never balance using the CRF tables in their current format. This explains why the extent of non-reconciliation is different for energy and for CO_2.

2) The discrepancy for liquid fuels is caused by the unreliability of the Reference Approach figure, which in turn derives from the crude oil density values used to convert reported indigenous production and imports in volumetric units into energy units, as required by the CRF.

3) The defect described under point (1) also leads to slight discrepancies in both emission factors and oxidation factors between the two approaches for a number of individual fuel types.

The Reference Approach analysis was not updated for the *National Inventory Report 2004 Revised*. It will be updated for Australia's next submission.

Table A.6a: Australian Energy Statistics balance (PJ)

A energy supply and disposal in Australia, 2003-04 - energy units

Item	Black coal	Brown coal	Coke	Coal by-products	Briquettes	Wood	Bagasse	Crude oil and ORF	LPG	Refined products	Biofuels	Natural gas	Town gas	Hydro-electricity	Electricity	Solar	Uranium	Total
Supply																		
Primary indigenous	7 614.7	683.6				97.2	101.1	1 099.0	122.9		10.6	1 492.0		56.7		2.6	4 544.0	15 824.5
plus all Imports								939.9	20.2	360.5								1 320.6
less all Exports	6 208.1	0.0	0.0		0.0			618.7	75.0	173.2		430.5					4 276.5	11 782.0
less Stock changes and discrepancies	- 167.2	- 0.7	22.4	- 11.3	- 4.2	0.0	0.0	- 76.3	- 9.2	- 80.8	0.0	0.0	0.3	0.0	0.0	0.0	267.5	- 59.5
Total domestic availability	1 573.7	684.3	- 22.4	11.3	4.2	97.2	101.1	1 496.6	77.3	268.1	10.6	1 061.4	- 0.3	56.7	0.0	2.6		5 422.5
Less																		
Coke ovens	132.2		- 102.6	- 19.2						1.0					0.1			11.4
Briquetting		8.4			- 3.7										0.4			5.0
Petroleum refining								1 501.8	- 27.5	-1 474.4		22.7			6.5			29.2
Gas manufacturing									1.1			2.9	- 1.4					2.7
Public Elec. generation	1 298.5	675.9		5.2	2.8	3.8	0.9	0.0	0.1	21.1	8.4	266.0		56.7	- 851.2			1 488.4
Other conversion			71.9	- 16.3				- 6.1		6.1			- 4.1		- 22.7			28.9
Fuel use in conversion									1.8	74.6		32.9	0.0		126.2			235.5
Final domestic availability	143.0	0.0	8.3	41.6	5.1	93.3	100.2	0.9	101.9	1 639.6	2.2	737.0	5.1	0.0	740.6	2.6		3 621.3
End use																		
Agriculture									1.3	86.6		0.1			6.7			94.7
Mining	7.2		0.3	1.3				0.9	1.0	100.8		149.6			66.3			327.3
Iron and steel	24.3		0.5	31.0					0.4	1.5		57.9			22.9			138.5
Chemical	2.3		0.9	8.3	1.6				11.8	57.9		101.2	3.9		14.7			200.4
Other industry	103.8	0.0	6.6	1.0	0.7	26.5	100.2	0.0	5.9	70.8	1.7	250.2			250.7			818.0
Construction									0.2	24.3		2.6			0.3			27.4
Road transport									65.8	976.5	0.5	1.2						1 044.1
Rail transport									0.0	26.0		0.0			7.7			33.6
Air transport										162.6								162.6
Water transport	4.0									49.6		0.1						53.7
Commercial	1.3				2.7	0.4			4.2	17.1		43.8	0.3		166.6	0.2		236.6
Residential	0.1				0.1	66.4			11.2	3.1		130.3	0.8		204.8	2.5		419.3
Lubricants, greases bitumen & solvents										62.9								62.9
Total final energy consumption	143.0	0.0	8.3	41.6	5.1	93.3	100.2	0.9	101.9	1 639.6	2.2	737.0	5.1	0.0	740.6	2.6		3 621.3

Source: ABARE, 2006a, Table A

ANNEX 5: ASSESSMENT OF COMPLETENESS

The UNFCCC Guidelines require inventory compilers to assess inventories for the level of completeness of national inventories. The sources of greenhouse gas emissions are many and diverse and, in general, are not directly observable without considerable cost. Many emission sources are minor and resource intensive to estimate. Consequently, all national inventories have minor omissions which, for transparency, need to be identified. This section addresses the completeness of key activity datasets, such as the consumption of fossil fuels, and the completeness of the coverage of emissions and removals sources for the Australian inventory.

Completeness of Activity Data

The emission estimates were reviewed for internal consistency and completeness through the application of mass balance approaches to ensure the reconciliation of carbon supplies and carbon uses within the economy for fossil fuels, carbonates and biomass entering the economy. Details have been provided in the respective sectoral chapters.

Omitted Emission Sources

The UNFCCC reporting guidelines provide standard reporting templates that are designed to accommodate the circumstances of as many countries as possible. The reporting templates are not always closely aligned with Australia's circumstances. Consequently, in Australia's reporting tables there are a number of categories where the term "not occurring" has been reported for certain cells because of an absence of a certain economic activity. An example is *adipic acid* production, which does not occur in Australia. In some cases, Australia has chosen to report emissions for a particular category as "included elsewhere" where existing data collections or methodologies do not allow for the splitting of the sources of emissions. An example is the reporting of all emissions from the use of fossil fuels for *ammonia production* under the Industrial Processes sector, rather than being split between the Industrial Process and Energy sectors, because the data do not support an accurate splitting of emissions between the two.

Nonetheless, there are a small number of emission sources which are believed to be minor and which are reported as 'not estimated' either because of a lack of data or because the emission processes are not well enough understood to permit the development of reliable methodologies. In some instances, default methodologies are not specified by the IPCC due to limited understanding internationally of these processes.

With each new inventory, a number of emission sources and removals have been added to the national inventory, resources permitting, as the remaining outstanding sources are generally minor while at the same time resource-intensive to estimate.

For this inventory, the following new emission sources were added:

> Nitrous oxide emissions from soil disturbance.

The new emission sources add less than 1% to the inventory in 1990. Other sources have been identified but have not yet been included within the inventory, as is explained below.

CH_4 and N_2O from lubricants (1A5)

A portion (40%) of lubricant consumption is assumed to be combusted in this inventory. There should be some non-CO_2 emissions as a result, although no emission factors were readily available for this report for the estimates to be produced. Such emissions would, in any case, be minor.

CO_2 from Burning of Coal Deposits and Waste Piles (1B1)

The spontaneous combustion of waste piles is a known source of CO_2 emissions. Research undertaken on the measurement of this emission source has not yet been able to develop any reliable approach to the estimation of this emission source. Similarly, neither the 1996 IPCC Guidelines nor the 2006 IPCC Guidelines include a default methodology that could be applied in the absence of information on this source.

Fugitive Emissions From Bore Holes

The use of bore water from the Great Artesian Basin and other sources has been an important source of irrigation for Australia's agricultural industries. Carbon dioxide is often released in small quantities from the bore holes during pumping. Government programmes for capping the bores to improve the efficiency of water use may have led to reductions in this source of emissions in recent years. More research is being conducted into this source of emissions to develop adequate datasets and methodologies.

CO_2 From Metal Production (2.C.5)

Coke is used as a reducing agent in the production of some metals for certain types of production technologies. CO_2 emissions from this source have been reported in the industrial process and energy sectors of this inventory. Emissions may also arise if the metallic ores being processed contain carbonates. In Australia, metallic ores are predominantly sulphide ores, rather than carbonate ores, and so emissions from this source, if any, are thought to be minor.

CO_2 From Food and Drink Production (2.D.2)

The Australian Greenhouse Office is currently exploring the availability of data to support estimates from this minor emissions source.

Miscellaneous SF_6 uses (2.F)

In the Australian inventory SF_6 emissions are reported from the use of this gas in the electricity industry. SF_6 may also be used in a number of other applications, such as in the production sport shoes, tyres and tennis balls, but no data is available to support estimates for any of these uses.

PFC Consumption in Refrigeration and Fire Extinguishers (2.F)

Some countries report minor emissions of PFCs from the use of refrigerators and fire extinguishers. The Australian Greenhouse Office is currently exploring the existence or otherwise of these sources in Australia.

Liming of agricultural soils (5)

Australia has not reported emissions from CO_2 from liming of agricultural soils, reflecting the lack of adequate data for the time series required. However, it is known that any actual emissions from this source are likely to be small, given knowledge of the maximum potential supplies available for this, and a range of other, purposes.

ANNEX 6: ADDITIONAL INFORMATION: GLOSSARY

Activity	A process that generates greenhouse gas emissions or uptake. In some sectors it refers to the level of production or manufacture for a given process or category.
Automotive Diesel Oil (ADO)	A middle distillate petroleum product used as a fuel in high-speed diesel engines. It is mostly consumed in the road and rail transport sectors and agriculture, mining and construction sectors.
Anaerobic	A process relying on bacteria that can live without oxygen
Anthropogenic	Resulting from human activities. In the inventory, *anthropogenic emissions* are distinguished from *natural emissions*.
Bagasse	The fibrous residue of the sugar cane milling process which is used as a fuel in sugar mills
Briquettes	A composition fuel manufactured from brown coal, which is crushed, dried and moulded under high pressure without the addition of binders.
Clinker	An intermediate product from which cement is made
Coke	The solid product obtained from the carbonisation of suitable types of coal at high temperature. It is low in moisture and volatile matter and is mainly used in the iron and steel industry as an energy source and chemical agent. Semi-coke or coke obtained by carbonisation at low temperatures is included in this category.
Dolomite	A naturally occurring mineral ($CaCO_3$.mg CO_3) which can be used to produce lime, iron and steel
Emission Factor activity	The quantity of greenhouse gases emitted per unit of some specified
Emission Intensity	The total emissions divided by the total energy content of the fuels or the total energy used in a sector. The overall emissions intensity of coal used in australia, for example, is determined by the quantity and emission factors for each of the many types and grades of coal used.
Enteric Fermentation	The process in animals by which gases, including methane, are produced as a by-product of microbial fermentation associated with digestion of feed
Feedlot	A confined yard area with watering and feeding facilities where livestock (mainly beef cattle) are completely handfed for the purpose of production. It does not include the feeding or penning of cattle for weaning, dipping or similar husbandry purposes or for drought or other emergency feeding, or at a slaughtering place or in recognised saleyards.
Feedstocks	Products derived from crude oil and destined for further processing in the refining industry, other than blending. Products include those imported for refinery intake and those returned from the petrochemical industry to the refining industry, such as naphtha.
Flaring	The process of combusting unwanted or excess gases at a crude oil or gas production site, a gas processing plant or an oil refinery
Forest	Parties are required to select single minimum values for land area, tree crown cover and tree height. The NCAS when assessing australia's land use change emissions uses a criteria of 20% tree crown cover, 2 metre minimum tree height, and a minimum of 0.2 hectares in land area for inclusion. These minimum criteria are within the ranges outlined in the marrakech accords.

Fuel Oil	Covers all residual (heavy) fuel oils including those obtained by blending
Fugitive Emissions	Generally deliberate but not fully controlled emissions that typically result from leaks, including those from pump seals, pipe flanges and valve stems. Fugitive emissions also include methane emitted from coal mine seams. During petroleum storage tank filling, venting loss of vapour is a fugitive emission.
Global Warming Potential (GWP)	Represents the relative warming effect of a unit mass of a gas compared with the same mass of CO_2 over a specific period. Multiplying the actual amount of gas emitted by the gwp gives the co_2-equivalent emissions.
Greenhouse Gases	Gases that contribute to global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). In addition, the photochemically important gases—NMVOCs, oxides of nitrogen (NO_x) and carbon monoxide (CO)—are also considered. NMVOC, NO_x and CO are not direct greenhouse gases. However, they contribute indirectly to the greenhouse effect by influencing the rate at which ozone and other greenhouse gases are produced and destroyed in the atmosphere.
Hydrofluorocarbons (HFCs)	Used as substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)
Industrial Diesel Fuel (IDF)	A petroleum product primarily consumed in the rail and water transport sectors.
Intergovernmental Panel on Climate Change (IPCC)	The international body responsible for assessing the state of knowledge about climate change. The IPCC increases international awareness of climate change science and provides guidance to the international community on issues related to climate change response.
Key Category	The IPCC *Good Practice* report (IPCC 2000) 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. The tier 1 key category analysis identifies categories that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms. Tier 2 analysis identified categories that contribute to 90% of total uncertainty in the inventory.
Kyoto Protocol	The Kyoto Protocol to the convention on climate change was developed through the unfccc negotiating process. The protocol was negotiated in Kyoto, Japan, in 1997. It sets binding greenhouse gas emissions targets for unfccc developed country parties that ratify the agreement.
Liquefied Petroleum Gas (LPG)	A light hydrocarbon fraction of the paraffin series. It occurs naturally, associated with crude oil and natural gas in many oil and gas deposits, and is also produced in the course of petroleum refinery processes. LPG consists of propane (C_3H_8) and butane (C_4H_{10}), or a mixture of the two. In Australia, LPG as marketed contains more propane than butane.
Lubricants	Hydrocarbons that are rich in paraffin and not used as fuels. They are obtained by vacuum distillation of oil residues.
Military Transport	Includes all activity by military land vehicles, aircraft and ships

National Carbon Accounting System	An integrated suite of models that estimate emissions from biomass, litter and soil carbon in a geographic information system framework with the support of resource inventories, field studies and remote sensing to assess land cover change
Natural Gas	Consists primarily of methane (around 9%, with traces of other gaseous hydrocarbons, as well as nitrogen and carbon dioxide) occurring naturally in underground deposits. As a transport fuel it is generally used in compressed or liquefied form.
Navigation	All civilian (non-military) marine transport of passengers and freight. Domestic marine transport consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements. International shipping using marine bunker fuel purchased in australia is reported but not included in the national inventory emissions total.
NMVOC	Non-methane volatile organic compounds such as alkanes, alkenes and alkynes, aromatic compounds and carbonyls that are gases at standard temperature and pressure (i.e. Boiling points below 200°C) and normally 10 or less carbon atoms per molecule; excludes chlorofluorocarbons (CFCs)
PFC	Perfluorocarbons, chemical compounds containing carbon and fluorine atoms only (e.g. CF_4 and C_2F_6)
Prescribed Burning	The intentional burning of forests to reduce the amount of combustible material present and thereby reduce the risk of wildfires. In Australia this is known as 'fuel reduction burning'.
Process Emission	The gas released as a result of chemical or physical transformation of materials from one form to another
Reference approach	A 'top–down' tier 1 IPCC methodology for estimating CO_2 emissions from fuel combustion activities (1.a).
Savanna	A grassland ecosystem with associated woody shrub and/or tree overstorey, the latter with projective foliage cover comprising less than 30% of the area. The IPCC category of 'savanna' is extended to include all non-agricultural grassland ecosystem types that experience burning in Australia.
Sink	Any process or activity that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere. It includes chemical transformations in the atmosphere and uptake of the gases from the atmosphere by the underlying land and ocean surfaces.
Solid Waste	Waste from various activities; includes *municipal solid waste* (waste from domestic premises and council activities largely associated with servicing residential areas; such as street sweepings, street tree lopping, parks and gardens and litter bins), *commercial and industrial waste*, and *building and demolition waste*
Solvent	An organic liquid used for cleaning or to dissolve materials
Source	Any process or activity that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere

Tier	The IPCC methods for estimating emissions and removals are divided into 'tiers' encompassing different levels of activity and technology detail. Tier 1 methods are generally very simple (activity multiplied by default emissions factor) and require less data and expertise than the most complicated tier 3 methods. Tier 2 and 3 methods generally require more detailed country-specific information on things such as technology type or livestock characteristics. The concept of tiers is also used to describe different levels of key source analysis, uncertainty analysis, and quality assurance and quality control activities.
Town Gas	Includes all manufactured gases that are typically reticulated to consumers, including synthetic natural gas, reformed natural gas, tempered LPG, and tempered natural gas
Uncertainty	Uncertainty is a parameter associated with the result of measurement that characterises the dispersion of values that could be reasonably attributed to the measured quantity (e.g. The sample variance or coefficient of variation). In general inventory terms, uncertainty refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency etc.
United Nations Framework Convention on Climate Change (UNFCCC)	Entered into force in 1994. Parties to the convention have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.
Venting	The process of releasing gas into the atmosphere without combustion. This may be done either at the production site or at the refinery or stripping plants. It is done to dispose of non-commercial gas or to relieve system pressure.

ANNEX 7: UNCERTAINTY ANALYSIS

Uncertainty is inherent within any kind of estimation—be it an estimate of the national greenhouse gas emissions, or the national gross domestic product. 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 over the complexities of the modelling of key relationships between observed variables and emissions.

The purpose of estimating the uncertainty attached to emissions estimates is principally to provide information on where inventory resources should be allocated to maximise the future improvements to inventory quality.

Assessing uncertainty is, itself, a difficult exercise, especially in the absence of quantitative data. Australia has conducted an uncertainty analysis for the individual sectors in line with the IPCC *Good Practice* guidelines. Monte Carlo and Latin Hypercube approaches were used to estimate emission uncertainty in some sectors, which is equivalent to the IPCC Tier 2 methodology.

The estimates have been mainly prepared by the judgement of the sectoral expert consultants. However, the estimates of uncertainty for the Australian inventory have been reviewed in 2005 by independent experts under protocols developed by the Australian CSIRO Atmospheric Research Division. The CSIRO report confirmed, with one or two exceptions, the quantitative judgements made in relation to uncertainty of inventory estimates and provide a strong basis for confidence in the assessments reported in this chapter.

The uncertainties for individual sectors are reported in more detail below. The estimated uncertainties tend to be low for carbon dioxide from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates from these sources are typically as low as ± 4–5%. Uncertainty surrounding estimates of emissions are higher for agriculture, land use change and forestry, reflecting inherently high uncertainty due to the very nature of the processes involved (e.g. biological processes). A medium band of uncertainty applies to estimates from fugitive emissions, most industrial processes and non-CO_2 gases in the energy sector. The ranges presented are broadly consistent with the typical uncertainty ranges expected for each sector, as identified in the IPCC *Good Practice Report*. This table has not been updated since the publication of the National Inventory Report 2004.

Table A.7: General Reporting Table for Uncertainty (IPCC Good Practice Guidance Reporting Table 6.1)

A IPCC Source category	B Gas	C Base year emissions 1990 Gg CO_2 e	D Year t emissions 2004 Gg CO_2e	E Activity data Uzncert'y %	F Emission factor uncert'y %	G Combined uncert'y %	H Uncert'y in total inventory %	I Type A Sensit'y %	J Type B Sensit'y %	K Uncert'y in trend of EF %	L Uncert'y in activity data %	M Uncert'y in total emissions %	Q footnote ref no.
1.A. Coal	CO_2	132550	193895	2	5	5.39	1.957	0.107	0.383	0.535	1.1	1.2	1,2
	CH_4	28	39	2	5	5.39	0.000	0.000	0.000	0.000	0.0	0.0	1
	N_2O	439	656	2	20	20.10	0.025	0.000	0.001	0.008	0.0	0.0	1
1.A. Liquid	CO_2	89489	109761	2	3	3.61	0.742	0.031	0.217	0.092	0.6	0.6	1
	CH_4	497	656	2	40	40.05	0.049	0.000	0.001	0.010	0.0	0.0	1
	N_2O	705	1454	2	60	60.03	0.164	0.001	0.003	0.084	0.0	0.1	1
1.A Gaseous	CO_2	32992	50342	2	3	3.61	0.340	0.031	0.099	0.092	0.3	0.3	1
	CH_4	28	166	2	5	5.39	0.002	0.000	0.000	0.001	0.0	0.0	1
	N20	20	32	2	20	20.10	0.001	0.000	0.000	0.000	0.0	0.0	1
1.B.1 Fugitives coal mining	CH_4	17076	21253	5	20	20.62	0.821	0.006	0.042	0.129	0.3	0.3	1,3
1.B.2 Fugitives oil	CO_2	385	245	5	5	7.07	0.003	0.000	0.000	-0.002	0.0	0.0	1,4
1.B.2 Fugitives Natural gas	CO_2	10	6	10	3	10.44	0.000	0.000	0.000	0.000	0.0	0.0	1,4
1.B.2 Fugitives venting & flaring	CO_2	5568	5287	5	5	7.07	0.070	-0.001	0.010	-0.006	0.1	0.1	1,4
1.B.2 Fugitives oil	CH_4	65	183	5	5	7.07	0.002	0.000	0.000	0.001	0.0	0.0	1,4
1.B.2 Fugitives Natural gas	CH_4	4215	2209	10	3	10.44	0.043	-0.004	0.004	-0.013	0.1	0.1	1,4
1.B.2 Fugitives venting & flaring	CH_4	2678	1843	5	5	7.07	0.024	-0.002	0.004	-0.010	0.0	0.0	1,4
2.A.1 Cement	CO_2	3361	3450	2.5	2.5	3.54	0.023	0.000	0.007	0.000	0.0	0.0	5
2.A.2 Lime	CO_2	685	1075	2.5	2.5	3.54	0.007	0.001	0.002	0.002	0.0	0.0	5
2.A.3 Limestone Consumption	CO_2	955	938	4	2.5	4.72	0.008	0.000	0.002	0.000	0.0	0.0	5
2.B.5 Rutile	CO_2	504	946	2.5	2.5	3.54	0.006	0.001	0.002	0.002	0.0	0.0	5
2.B.5 Polymers	CH_4	9	9	5	5	7.07	0.000	0.000	0.000	0.000	0.0	0.0	5
2.C 1 Steel	CO_2	10174	10067	2.5	5	5.59	0.105	-0.001	0.020	-0.006	0.1	0.1	5
2.C.1 Steel	CH_4	59	61	2.5	5	5.59	0.001	0.000	0.000	0.000	0.0	0.0	5
2.C.3 Aluminium	CO_2	2017	3024	2.5	2.5	3.54	0.020	0.002	0.006	0.004	0.0	0.0	5
2.C.3 Aluminium	PFCs	3938	1494	27	0	27.00	0.076	-0.005	0.003	0.000	0.1	0.1	5
2.F HFCs	HFCs	1126	3341	27	0	27.00	0.169	0.004	0.007	0.000	0.3	0.3	5
2.F SF_6	SF_6	521	521	27	0	27.00	0.026	0.000	0.001	0.000	0.0	0.0	5
2.G Other	CO_2e	1882	4861	5	5	7.07	0.064	0.006	0.010	0.028	0.1	0.1	5
4.A Enteric fermentation	CH_4	67507	61740	0	5.5	5.50	0.637	-0.018	0.122	0.000	0.0	0.0	6
4.B Manure management	CH_4	1541	1949	0	10.5	10.50	0.038	0.001	0.004	0.000	0.0	0.0	6
4.B Manure management	N20	531	1300	0	10.3	10.30	0.025	0.001	0.003	0.015	0.0	0.0	6
4.C Rice Cultivation	CH_4	490	237	5	10	11.18	0.005	-0.001	0.000	-0.006	0.0	0.0	7
4.D Agricultural Soils	N20	14124	16558	0	52	52.00	1.614	0.003	0.033	0.174	0.0	0.2	7
4.E Burning of Savannas	CH_4	4643	7733	50	15	52.20	0.757	0.006	0.015	0.084	1.1	1.1	7
4.E Burning of Savannas	N20	1966	3293	50	15	52.20	0.322	0.002	0.006	0.036	0.5	0.5	7
4.F Agricultural Residues	CH_4	193	223	5	20	20.62	0.009	0.000	0.000	0.001	0.0	0.0	7
4.F Agricultural Residues	N_2O	99	102	5	20	20.62	0.004	0.000	0.000	0.000	0.0	0.0	7

A IPCC Source category	B Gas	C Base year emissions 1990 Gg CO_2 e	D Year t emissions 2004 Gg CO_2e	E Activity data Uzncert'y %	F Emission factor uncert'y %	G Combined uncert'y %	H Uncert'y in total inventory %	I Type A Sensit'y %	J Type B Sensit'y %	K Uncert'y in trend of EF %	L Uncert'y in activity data %	M Uncert'y in total emissions %	Q footnote ref no.
5.A Forest land remaining forest	CO_2	-46988	-54074	0	30	30.00	-3.041	-0.009	-0.107	-0.274	0.0	0.3	8
land	CH_4	1531	3977	0	77	77.00	0.574	0.005	0.008	0.359	0.0	0.4	8
	N_2O	418	1085	0	93	93.00	0.189	0.001	0.002	0.118	0.0	0.1	8
5.B Conversion to Grasslands	CO_2	111378	56156	0	10	10.00	1.053	-0.120	0.111	-1.202	0.0	1.2	8
	CH_4	2653	1327	0	20	20.00	0.050	-0.003	0.003	-0.058	0.0	0.1	8
	N_2O	725	363	0	20	20.00	0.014	-0.001	0.001	-0.016	0.0	0.0	8
5.B Conversion to Croplands	CO_2	13164	-5191	0	10	10.00	-0.097	-0.038	-0.010	-0.376	0.0	0.4	8
	CH_4	732	487	0	20	20.00	0.018	-0.001	0.001	-0.011	0.0	0.0	8
	N_2O	200	133	0	20	20.00	0.005	0.000	0.000	-0.003	0.0	0.0	8
6.A Solid Waste	CH_4	15387	14968	0	3.25	3.25	0.091	-0.002	0.030	-0.008	0.0	0.0	5
6.B Wastewater handling	CH_4	3350	3541	0	50	50.00	0.332	0.000	0.007	0.002	0.0	0.0	5
6.B Wastewater handling	N_2O	479	566	0	50	50.00	0.053	0.000	0.001	0.006	0.0	0.0	5
6.C Waste incineration	CO_2	11	17	0	50	50.00	0.002	0.000	0.000	0.001	0.0	0.0	5
Total Emissions		506886	533494										
Total Uncertainties							3.9					1.9	

1 Energy Strategies; 2. George Wilkenfeld & Associates; 3. Dr David Williams, CSIRO; 4 Australian Petroleum Production & Exploration Association; 5 Burnbank Consulting; 6 Dr Mark Howden, CSIRO; 7. Dr Carl Meyer, CSIRO; 8. Dr Gary Richards, Australian Greenhouse Office.

The estimates of uncertainty surrounding the emissions estimates for individual sectors may be combined to present an estimate of the overall uncertainty for the inventory as a whole. Following the recommendations of the IPCC Good Practice Guidance, the emission estimates across the energy sector have been aggregated because of the hidden dependencies that exist between sectoral activity levels as a result of the constraint of overall consumption and since aggregate fuel consumption is more accurately known than the consumption in individual sectors. The results of the application of the IPCC Tier 1 approach to estimating the uncertainty of the inventory as a whole, which identifies separately estimates of uncertainty for both activity and emission factors where available, and which does not account for correlations between variables (unlike some of the sectoral analyses), are presented in Table A.7.

As indicated in the *IPCC Good Practice Guidance* the Tier 1 approach is valid as long as a number of restrictive assumptions are met. An alternative, more flexible approach, which relies on Monte Carlo analysis and a more detailed specification of the sources of uncertainty, is currently under consideration for development by the Australian Greenhouse Office for use in future national inventory reports. This analysis would be equivalent to the IPCC Tier 2 approach and would take into consideration a number of refinements proposed by the CSIRO independent review.

The Tier 1 results presented in Table A.7 show the estimated uncertainty surrounding the aggregate inventory estimate for 2004 to be ± 4 %. The reported estimated uncertainty for the trend in emissions is ± 2 %. This estimate has been calculated on the assumption that the total uncertainty for parts of agriculture, land use, land use change and forestry, and the waste sectors are uncorrelated through time. The overall estimate of uncertainty in the trend is sensitive to this assumption. If the alternative assumption was applied, that of full correlation in the total uncertainty of these sectors over time, the uncertainty in the trend estimate is estimated at ± 6 %. Further analysis will be conducted into this issue for future inventories.

Energy

Stationary Energy

Uncertainty analyses were conducted for emissions from three sectors: 1.A.1.a. *Electricity*, 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* (Table A.8). The overall uncertainty in estimated emissions from *electricity generation* was ±5%. The highest uncertainty was for N_2O emissions, with an associated uncertainty of up to ±16%. However, as emissions of N_2O (and CH_4) account for only a small fraction, 0.4%, of the subsector's total emissions, there is a negligible impact on overall uncertainty for this sector.

Table A.8: Quantified uncertainty values for key stationary energy subcategories[(a)]

Greenhouse gas source and sink category	Uncertainty (%)			
	CO_2	CH_4	N_2O	Total CO_2-e
1. ENERGY				
A Fuel combustion activities				
1.A.1.a. Electricity	±5	±9	±15	±5
Black coal	±6	±9	±15	±6
Brown coal	±4	±9	±15	±4
Petroleum	±4	±9	±7	±4
Natural gas	±4	±9	±16	±4
Biomass	NA	±9	±4	±4
Biogas	NA	±9	±16	±4
1.A.1.b. Petroleum refining	**±4**	**±9**	**±12**	**±4**
Petroleum	±4	±9	±12	±4
Gas	±4	±9	±12	±4
1.A.1.c Manufacture of solid fuels and other energy industries	**±4**	**±9**	**±12**	**±4**
Coal	±4	±9	±12	±4
Petroleum	±4	±9	±12	±4
Gas	±4	±9	±12	±4

(a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube (a type of Monte Carlo) analysis

Overall uncertainty associated with emissions estimates from both 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* sectors was ±4%. Again, the uncertainty associated with emissions of N_2O and CH_4 has negligible impact on overall uncertainty. An uncertainty analysis on minor, mobile source categories of the *stationary energy* sector gave uncertainty values ranging from ±16.4% to ±24.5% for CO_2, from ±25.4% to ±63.9% for CH_4, and ±44.7% to ±64.2% for N_2O.

Table A.9: Quantified uncertainty values for mobile source categories[(a)]

Greenhouse gas source and sink category	Uncertainty (%)		
	CO_2	CH_4	N_2O
1.A.4. Other sectors			
b. Residential			
Lawn mowers	±24.5	±45.2	±46.3
1.A.5. Other			
b. Mobile	**±16.4**	**±25.4**	**±44.7**
Military transport—land	±18.5	±32.9	±54.6
Military transport—water	±24.4	±63.9	±62.7
Military transport—aviation	±24.0	±47.2	±64.2

(a) Uncertainty reported at 95% confidence limits estimated using Monte Carlo analysis.

Transport

Monte Carlo analyses were conducted for all subsectors and fuel types. The uncertainty distributions for emission factors and activity data were developed on the basis of expert judgment.

The total estimated uncertainties in the *transport* subsector were ±4% for CO_2, ±24% for CH_4, and ±42% for N_2O. Uncertainties in the emissions from individual source categories ranged from ±1% to ±24% for CO_2, ±23% to ±59% for CH_4, and ±32% to ±63% for N_2O. The largest source of uncertainty is in the emission factors.

The estimates also reflect the relatively higher uncertainty attached to the emission estimates for particular vehicle types, which are drawn from ABS data and its survey of motor vehicle use, than for the sector as a whole. This outcome reflects the dependency between activity variables; and because overall transport fuel consumption is more accurately known than the individual segments.

Table A.10: Emissions and quantified uncertainty values for key transport subcategories[(a)]

Greenhouse gas source and sink category	Uncertainty (%)		
	CO_2	CH_4	N_2O
1.A.3. Transport	**±4**	**±24**	**±42**
	±4	±23	±41
a. Civil aviation	**±9**	**±52**	**±52**
b. Road transport	**±4**	**±25**	**±42**
i. Passenger cars	±6	±31	±44
ii. Light trucks	±7	±38	±41
iii. Medium trucks	±9	±41	±60
iv. Heavy trucks	±10	±44	±61
v. Buses	±8	±36	±53
vi. Motorcycles	±10	±43	±61
c. Railways	**±5**	**±39**	**±39**
d. Navigation	**±8**	**±59**	**±32**
e. Other transportation	**±24**	**±46**	**±63**
International bunkers			
Aviation	±10	±58	±59
Marine	±4	±47	±52

(a) Uncertainty reported at 95% confidence limits.

Fugitives

The overall uncertainty for *fugitive* emissions was estimated to be ±11% (Table A.11). The estimated uncertainty for *solid fuels* CH_4 was ±19%. Uncertainties in oil and natural gas emissions were estimated to be ±4% for CO_2, ±5% for CH_4 and ±4% for N_2O.

Table A.11: Quantified uncertainty values for key fugitive emissions subcategories[(a)]

Greenhouse gas source and sink category				Uncertainty (%)			
				CO_2	CH_4	N_2O	CO_2-e
1. ENERGY							
B. Fugitive emissions				**±4**	**±14**	**±4**	**±11**
	1.B.1. Solid fuels			**NE**	**±19**	**NE**	**±19**
		1B1ai Underground mines		NE	±21	NE	±21
			Underground activities	NE	±21	NE	±21
		Post mining		NE	±17	NE	±17
		1.B.1.a.i.i. Surface mining		NE	±17	NE	±17
	1.B.2. Oil and natural gas			**±4**	**±5**	**±4**	**±4**
		1.B.2.a. Oil		±8	±5	±8	±7
		1.B.2.b. Natural gas		±9	±9	NA	±9
		1.B.2.c. Venting and flaring		±4	±4	±4	±4

(a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube analysis.

Industrial Processes

An analysis of uncertainty was conducted using the methods recommended in the *Revised 1996 IPCC Guidelines* and random sampling techniques described in the IPCC *Good Practice* report (Latin Hypercube simulations). Uncertainty estimates of the components of each emission estimate (activity levels and emission factors) are based on expert judgement.

As the IPCC Tier 1 approach is not suitable for assessing uncertainty where approximately normal distribution assumptions cannot be sustained, an analysis was undertaken using Latin Hypercube techniques. These techniques can take into account asymmetric probability distributions associated with emission factors. For example, as the average emission factor for PFCs tends to the minimum limit that is understood to be technically feasible, the probability of the emission factor being lower than estimated is less than the probability of it being higher than estimated.

The Latin Hypercube analysis gave an uncertainty of ±5% (Table A.12). The uncertainty in the *industrial processes* subsectors ranged from ±4% to ±20%.

Table A.12: Quantified uncertainty values for key industrial processes subsectors using different techniques[(a)]

Source	Uncertainties and distribution		Emission factors - uncertainties and distributions								
	Production/ use	Distribu-tion	CO_2	Distribution	CH_4	Distribution	N_2O	Distribution	CF_4	Distribution	C_2F_6
Cement clinker	±5.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
Cement kiln dust	±7.01	Normal	±5.01	Normal	NA	NA	NA	NA	NA	NA	NA
Cement total organic carbon	NA	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Commercial lime	±5.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
In-house lime	±4.01	Normal	±5.01	Normal	NA	NA	NA	NA	NA	NA	NA
Limestone use	±8.01	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Dolomite use	±8.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
Soda ash production	±5.00	Normal	NA	Stoichiometry	NA	NA	NA	NA	NA	NA	NA
Soda ash use	±5.00	Normal	NA	Stoichiometry	NA	NA	NA	NA	NA	NA	NA
Magnesia	±5.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Ammonia	±7.02	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Nitric acid	±10.00	Normal	NA	NA	NA	NA	±9.99	Normal	NA	NA	NA
Nitrous oxide	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA	NA	NA
Synthetic rutile	±5.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Titanium dioxide	±20.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Iron and steel	±5.01	Normal	±2.05	Triangular	±3.82	Triangular	±16.33	Triangular	NA	NA	NA
Hot briquetted iron	±5.00	Normal	±4.08	Triangular	±4.34	Triangular	±9.07	Triangular	NA	NA	NA
Aluminium	±5.01	Normal	±5.00	Normal	NA	NA	NA	NA	±16.22	Triangular	Function of CF_4
Total emissions	26019.09										
Aggregate uncertainty	±2.88										

(a) Uncertainty reported at 95% confidence limits assuming approximately normal distributions. Source: Burnbank Consulting.

Agriculture

Livestock

An uncertainty analysis was undertaken for the *livestock* subsectors, addressing both CH_4 and N_2O emissions. Uncertainty distributions were developed for the inputs and the relationships used in the inventory. Where possible, uncertainties were based on quantitative analysis of probability distributions. Nevertheless, many of the distributions remain based on expert judgement. For many biological variables there are limits to the likely minimum and maximum values, and these constrain the distributions. For example, feed intakes have maximum values that are defined by the physiology of the livestock and the characteristics of the feed. Minimum values of feed intake relate to productivity and survival below which the industry wouldn't attempt to operate.

The estimated uncertainty in *enteric fermentation* emissions ranged from –5.1% to +5.9% (Table A.13) while the uncertainty in the *manure management* emissions was in the order of 10%. For total CO_2-e emissions from *livestock* the uncertainty was estimated to be –5.3% to +6.1%. The uncertainty in the reported cattle numbers was the most significant contributor to the overall uncertainty.

Recent measurements of methane emissions from sheep on high-quality pastures and cattle on grain diets in Australia show that the inventory procedure produces accurate estimates of methane emission rates. However, further work is needed to reduce uncertainties relating to feed intakes, methane emissions from sheep on low-quality pasture, methane emissions from beef cattle, and emissions from manure under a range of conditions.

Table A.13: Relative uncertainty in emission estimates for the livestock subsector[(a)]

Greenhouse gas source and sink categories	Uncertainty (%)	
	CH_4	N_2O
A. Enteric fermentation	–5.1 to +5.9	
B. Manure management	–9.8 to +11.1	–10.1 to +10.6

(a) Uncertainty reported at 95% confidence limits estimated using Monte Carlo analysis.

Other Agriculture

Estimates of uncertainties in the emissions for the *other agriculture* subsectors were determined using a Latin Hypercube analysis (Table A.14). Ideally, the probability distributions of the input variables would be determined by statistical analysis of real data. However, in the current analysis, suitable data sets were not available and the probability distributions were defined using expert judgement. The uncertainty in emission factors and associated parameters were determined from surveys of the published international literature, with emphasis on local Australian measurements. All variables are considered to be independent except fuel load and burning efficiency, which were positively correlated. The activity data with the greatest uncertainties are the areas of savanna fires. These are collated from a large and dispersed number of state government organisations with a wide range of data quality protocols.

There is large relative uncertainty in the emission estimates from all subcategories, including approximately –45 to +55% for methane in the *field burning of residues* subsector and –32% to +52% for nitrous oxide from *agricultural soils*. By way of comparison, estimates presented in the IPCC *Good Practice* guidelines indicate uncertainties of up to +55% and +500% for these sectors respectively as being likely to be typical. Significantly, in all subsectors, most of this uncertainty was derived from the uncertainties in emission factors and associated parameters. Uncertainty in the activity data was a relatively minor contributor to overall uncertainty. Partly this is a result of using three-year averages of annual activity data. The effect of averaging is to significantly reduce the sensitivity of the emissions estimates to uncertainty in the value for any individual year. In most cases, the uncertainty ranges are distributed asymmetrically around the estimates because, while emission factors usually have well constrained minima, their maxima are generally unconstrained.

Table A.14: Relative uncertainty in emission estimates for other agriculture subsectors[(a)]

Greenhouse gas source and sink categories	Uncertainty (%)	
	CH_4	N_2O
4. AGRICULTURE		
C. Rice cultivation	**–19 to 22**	
1. Irrigated	–19 to 22	
D. Agricultural soils		**–32 to 52**
1. Direct soil emissions		–30 to 42
2. Animal production		–49 to 120
3. Indirect		–61 to 107
E. Prescribed burning of savannas	**–52 to 112**	**–55 to 115**
F. Field Burning of agricultural residues	**–45 to 55**	**–43 to 50**
1. Cereals	–49 to 60	–47 to 59
2. Pulse	–59 to 85	–59 to 92
3. Tuber and root	NO	NO
4. Sugar cane	–45 to 60	–48 to 63
5. Other	–57 to 96	–57 to 99

(a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube.

Land Use, Land Use Change and Forestry

Australia's National Carbon Accounting System (NCAS) uses Tier 3 methods (ecosystem model) of emissions estimation and an Approach 3 (full spatial enumeration) method of representing land (IPCC 2003). Unlike the Tier 1 and Tier 2 methods, Tier 3 uses complex modelling to estimate emissions in a way that fully represents both annual and spatial variability. Tier 3 and Approach 3 methods were chosen because the causes of most emissions in Australia (forest conversion) are from rare events (a small fraction of the forest estate). Tier 3 methods allow more complex forms of sensitivity and uncertainty analysis, and in concert with verification activities give an ability to identify any potential bias.

The verification processes focus on the detailed checking of land areas and modelled emissions estimates. That is, the testing of the NCAS results is typically against actual measures that have a 'certain' outcome. The benefits of verification by direct measurement are, first, the detailed data derived can be used to determine the model and land area estimation performances in general (e.g., by region, soil type, vegetation type) and in detail, for example, by carbon pool (e.g., litter, fast turnover soil organic matter). Second, having actual measures allows for continuous improvement whereby the verification data can subsequently be used to enhance calibration, which is then tested again in subsequent verification. This ensures a growing base of data for model calibration while also ensuring that calibration and verification data remain independent.

Extensive independent verification programs of the land cover change and plantation mapping via remote sensing techniques have been continuously applied throughout the time-series updates. The methods applied to verification of the land cover change results are published in the NCAS Technical Reports (Lowell et. al., 2003 and Jones et. al., 2004) and in peer review literature (Lowell et. al., 2005). This program initially relied on verification against historic air photographs, and more recently, by using very high resolution satellite data (1m). The verification of the plantations mapping (MBAC Consulting *in prep.*) was based on on-site field inspection. This alternative approach was used because it was able to provide a definite date of planting (from signage or company records) and could accurately provide parameters such as species, stocking rate, condition etc. that could not be derived with certainty from remote techniques. This program was based on several hundred sites throughout Australia, selected to be representative of geographic regions, plantation types and plantation ages.

The direct measurement of forest biomass is rare, and as destructive sampling is required, no time-series growth data based on whole mass measurement is available. However, through the use of allometric equations from measurable forest stand parameters of basal area, height etc. it is possible to model total stand biomass. As these measures are widely used in forest inventory, there is a wealth of industry data available as both single point in time and time-series (permanent plot) measurements against which growth and biomass estimates have been verified. In addition, research site data comparisons and select whole-stand mass measurements have been applied. The benefits of comparisons with research data has been that additional to commonly available stand biomass estimates are data on site conditions and management. Because of the cost and logistical difficulty in actually measuring total stand biomass, the approach taken was to destructively sample and weigh forest plots of a single species across a productivity gradient (Ximines et. al., 2005). This approach could then test both the biomass predictions and replication of the gradient in forest productivity and carrying capacity by model estimates.

Much like the verification activities for forest biomass, a tiered approach was applied to the verification of modelled soil carbon change estimates. Most geographically widespread and representative data were taken from paired site samples, before and after land use change. The change in total soil organic carbon was compared to modelled estimates. Soil fractionations were also completed to test the model performance in predicting turnover in various soil carbon pools. Wherever possible, models were also compared to research site data (Skjemstad and Spouncer 2002). This again had the benefit of multiple pool, time-series measurements for comparison, along with the recorded impacts of detailed site condition and management.

The methods of uncertainty analysis described by the IPCC Good Practice Guidance 2003 are typically designed for Tier 1 and Tier 2 emissions factor based approaches. More complex methods for dealing with potential error propagation and inter-correlation of parameter uncertainties needs to be applied to the process model forms of inventory used in Tier 3. However, the fundamental approach of using *Monte Carlo* forms of analysis for both sensitivity and uncertainty analysis remains relevant and are applied.

The sensitivity and uncertainty analysis of the NCAS are used to determine:

> that the best estimate (most likely outcome) is not subject to bias;

> the parameter sensitivity, in order to understand the drivers of uncertainty and guide improvement programs and verification priorities; and,

> to determine the probability distribution of possible outcomes.

The sensitivity and uncertainty analyses undertaken are described in detail in each of the methods Appendices 7.B, 7.C and 7.D. To enable these analyses a *Monte Carlo* analysis capability has been integrated into the modelling framework and is routinely applied.

Uncertainty analyses using *Monte Carlo* techniques are also supplemented by the determination of accuracies of spatial data through verification programs. Verification can also be used to identify if there is any potential bias in the spatial inputs to the emissions modelling.

Table A.14: Estimation of uncertainties in components of the land use change and forestry subsectors (UNFCCC accounting)

Subsector	Uncertainty Level
Forest land remaining forest (CO_2, CH_4, N_2O)	±30, -45 +77,-53 +93
Grassland conversion (CO_2, CH_4, N_2O)	±10, 20
Cropland conversion (CO_2, CH_4, N_2O)	±10, 20

Waste

Estimates for uncertainty for emissions from solid waste disposal were estimated by Burnbank Consulting. Uncertainty in the sold waste sector has been reduced markedly in this Inventory, reflecting the incorporation of State Government and ABARE data and IPCC default methodologies for emissions generation. The full implications of non-linearities in the solid waste methodology are still to be satisfactorily explored, however, and further work into the sold waste estimates are likely in future.

Table A.15: Relative uncertainty in emission estimates for key waste subsectors

Greenhouse gas source and sink categories	Uncertainty (%)				
	CH_4	N_2O	NO_x	CO	NMVOC
6. Waste					
A. Solid waste disposal on land a	± 3.25%	NA	NA	NA	NA
B. Wastewater	± 50%				
C. Incineration	NA				

a Source Burnbank Consulting 2006

Table A.16: Specific distributions, parameters and results: Solid Waste

Variable	Distribution and parameters	2sd	M-2sd	M+2sd	2sd/M	M-/2.5 perc	M+/97.5 perc
Emission Generated / 2004 - ACT		0.70	12.85	14.26	5.19%	1.00	1.00
Emission Generated / 2004 - NSW		16.55	277.85	310.95	5.62%	1.00	1.00
Emission Generated / 2004 - NT		0.26	4.63	5.14	5.26%	1.00	1.00
Emission Generated / 2004 - QLD		7.84	163.61	179.30	4.57%	1.00	1.00
Emission Generated / 2004 - SA		4.92	45.95	55.79	9.68%	1.00	1.00
Emission Generated / 2004 - TAS		1.72	15.75	19.19	9.84%	1.00	1.01
Emission Generated / 2004 - VIC		16.57	163.14	196.29	9.22%	1.00	1.00
Emission Generated / 2004 - WA		8.94	78.13	96.01	10.27%	1.00	1.00
Emissions Generated - Australia		26.59	792.84	846.03	3.25%	1.00	1.00
DOCfood	Normal (0.15,0.05*0.15)	0.01	0.13	0.16	10.00%	1.00	1.00
DOCpaper&text / DOCpaper&text	Normal (0.4,0.05*0.4)	0.04	0.36	0.44	10.00%	1.00	1.00
DOgGarden / DOgGarden	Normal (0.17,0.05*0.17)	0.02	0.15	0.19	10.00%	1.00	1.00
DOCwood / DOCwood	Normal (0.43,0.05*0.43)	0.04	0.39	0.47	10.00%	1.00	1.00
Standard Mix - MSW- food	Triang (0.15,0.21,0.27)	0.05	0.16	0.26	23.33%	0.99	1.01
Standard Mix - MSW-p&t / Standard Mix - MSW-p&t	Triang (0.07,0.11,0.15)	0.03	0.08	0.14	29.69%	0.98	1.01
Standard Mix - MSW-gg / Standard Mix - MSW-gg	Triang (0.14,0.19,0.24)	0.04	0.15	0.23	21.49%	0.99	1.01
Standard Mix - MSW-wood / Standard Mix - MSW-wood	Triang (0.02,0.03,0.04)	0.01	0.02	0.04	27.22%	0.98	1.01

Variable	Distribution and parameters	2sd	M-2sd	M+2sd	2sd/M	M-/2.5 perc	M+/97.5 perc
Standard Mix - MSW-other / Standard Mix - MSW-other	Triang (0.38,0.46,0.54)	0.07	0.39	0.53	14.20%	0.99	1.01
DDOC	Normal(0.5,0.1*0.5)	0.10	0.40	0.60	20.00%	1.00	1.00
Half-life	Triang(3,4,6)	1.25	3.09	5.58	28.78%	0.94	0.99
Half-life	Triang(10,12,14)	1.63	10.37	13.63	13.61%	0.99	1.01
Half-life	Triang(6,7,9)	1.25	6.09	8.58	17.01%	0.97	1.00
Half-life	Triang(17,23,35)	7.48	17.52	32.48	29.93%	0.94	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(3,4,6)	1.25	3.09	5.58	28.78%	0.94	0.99
Half-life	Triang(10,12,14)	1.63	10.37	13.63	13.61%	0.99	1.01
Half-life	Triang(6,7,9)	1.25	6.09	8.58	17.01%	0.97	1.00
Half-life	Triang(17,23,35)	7.48	17.52	32.48	29.93%	0.94	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(1,2,4)	1.25	1.09	3.58	53.45%	0.85	0.99
Half-life	Triang(8,10,12)	1.63	8.37	11.63	16.33%	0.99	1.01
Half-life	Triang(3,4,5)	0.82	3.18	4.82	20.41%	0.99	1.01
Half-life	Triang(14,20,23)	3.74	15.26	22.74	19.69%	1.01	1.03
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(1,2,4)	1.25	1.09	3.58	53.45%	0.85	0.99
Half-life	Triang(8,10,12)	1.63	8.37	11.63	16.33%	0.99	1.01
Half-life	Triang(3,4,5)	0.82	3.18	4.82	20.41%	0.99	1.01
Half-life	Triang(14,20,23)	3.74	15.26	22.74	19.69%	1.01	1.03
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01

Source: Burnbank Consulting.

ANNEX 8: REFERENCES

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ANNEX 8

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