Appendix D
Harvested Wood Products

Introduction

Wood product carbon emissions are considered under the 1996 (Revised) IPCC Guidelines for the United Nations Framework Convention on Climate Change (IPCC 1997) and associated Good Practice Guidance (IPCC 2003) and are reported in the *Land Use, Land Use Change and Forestry* component of Australia's National Greenhouse Gas Inventory where they arise from the service life of products. Emissions from landfill are reported under the Waste section of the inventory.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since 1944. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Jaakko Poyry Consulting were initially engaged by the National Carbon Accounting System (NCAS) of the Australian Greenhouse Office to develop a national carbon accounting model for wood products, and that work provides the precursor model to that adapted and described here. The model development is reported in detail in the National Carbon Accounting System Technical Reports No. 8 (Jaakko Poyry 1999) and No. 24 (Jaakko Poyry 2000). Updates and model refinement were subsequently undertaken by MBAC Consulting in conjunction with the NCAS. Jaakko Poyry subsequently provided a quality assurance review of the model.

Accounting Approaches

Accounting approaches for carbon emissions from timber harvesting and wood products considered include emissions from wood products in Australia (wherever the source). This approach accounts for emissions from all wood products within Australia, regardless of their country of origin. Exported wood products are not accounted for and are the responsibility of the importing country. The amount of material exported is deducted from the total production, with total imports added, to derive the amount of material available for emissions within Australia. The origin of imported wood products is not tracked. However, the total flow of imported wood products into various pools within Australia is monitored.

Model Components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g. sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and
- other losses to atmosphere.

Life Cycles and the Wood Products Carbon Pool

Estimates of the life cycles appropriate for each class of wood product have been made and methods for estimating the initial pool of carbon, as represented by wood products in use since 1943, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data.

Cypress pine removals are included under the total for coniferous logs and a separate figure is not provided. It is necessary to extract cypress pine volume and analyse separate from softwood sawmilling because:

- Cypress pine is a significant source of wood products;
- Cypress pine is a native conifer and softwood sawmilling largely refers to exotic species plantations; and
- Cypress pine is a denser wood than exotic pines and is used by a totally separate industry supplying different products to the market.

A Cypress pine figure can be developed from the ABARE information by applying a conversion factor to sawnwood consumption and applying a conversion factor to convert back to equivalent log removals.

Wood Flow

The model develops wood flows separately for each sector and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products which are themselves used as resources for other segments of the industry. In conjunction with the carbon pool and life cycle of timber products, this model enables the total and projected carbon pools to be estimated.

In broad terms, the components of the models developed for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., “x”% sawdust, shavings or sander dust for on site energy generation or compost, “y”% woodchips for other manufacturing processes, “z”% of sawn timber products, panel products, paper, etc.;
- an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panelboards for use in furniture and cabinets, newsprint paper, writing and printing paper, etc;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon;
- import and export data were obtained from the ABARE reports by end use categories; and
- details of the flows are shown in Attachment D1.

Treatment of Bark

There has been no accounting for bark in this study. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations, for the following reasons:

- logs are sold with log volumes recorded on an underbark basis;
- in most hardwood operations, logs are debarked in the field;
- in softwood operations, it is estimated that some bark is lost prior to the logs reaching the mill. Most of this loss occurs during the mechanised delimbing and log docking operations; and,
- most softwood bark recovered at the mill is used for garden mulch which it is considered would have decay characteristics similar to that of logging slash.

Softwood bark is a significant source of carbon with total bark varying from about 35% of underbark log volume (not oven dry weight) in Caribbean pine to 20% in radiata pine and hoop pine. It is likely that, in the future, an increasing proportion of softwood bark will be used in the co-generation of energy and it may be reasonable to review this proposal should the situation change.

Basic Density and Carbon Content

Basic density and carbon content estimates are relevant to all of the processing options and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, treated softwood and hardwood poles, etc., weighted basic densities for the species involved have been applied across each category. Basic density is defined as oven dry weight divided by green volume and the values adopted have been based on Ilic et. al., (2000). For board products and paper, however, the situation is different because all have been subjected to varying amounts of compression during manufacture and to compensate for this, their basic densities have been adjusted accordingly from the air-dry density of the finished products.

Carbon content is defined variably throughout the literature with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted as a starting point to use in the model as a median value extracted from Gifford (2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies. The issues addressed included:

- recoveries of green sawn timber, sawdust and chip;
- actual sawn sizes and corresponding dressed sizes; and
- the range and proportions of products produced.

For the softwood sawmilling industry, for example, weighted averages of the information received have provided realistic assumptions. The same applies to the other species/industry sectors, with the exception of hardwood sawmilling.

Table D1: Basic Densities, Moisture and Carbon Contents

Carbon Fractions	
Description	Value
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities *	
Description	Value kg/m^3
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
*** Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)**	
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

Wood Flows from Processing

Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;

- Preservative treated softwood;
- Hardboard;
- Hardwood poles, sleepers and miscellaneous; and
- Export of woodchips and logs.

Softwood Sawmilling

The softwood sawmilling industry in Australia is largely based on plantations of exotic pines, although the native pine, hoop pine, is grown in southern Queensland. Most plantations were initiated around the 1930's. Early development was slow, but momentum was gained in the 1960's and 1970's.

Softwood processing has become very efficient, highly mechanised and well integrated industry, comparable with any of its overseas counterparts. Most softwood mills are large, with up to 500,000 m^3/year log intake. Most of the sawn timber is seasoned and dressed. Value-adding options such as machine stress grading, glue lamination and finger jointing are common.

Nearly all softwood mills are now operating on zero waste, with all slabs and edgings being chipped for paper pulp or panelboard feedstock and the sawdust and shavings being used for boiler fuel to provide energy for kiln drying. In some cases, some of this material is sold for composting, but this is unlikely to continue if the co-generation of electricity becomes more financially attractive.

A basic density of 415 kg/m^3 is used. This is sourced from Ilic et. al., (2000) and Gardner and Ximenes (*pers. comm.*); and is based on a weighted average of the respective densities of radiata pine, slash pine, Caribbean pine and hoop pine that are harvested.

The destinations of sawlogs and sawn timber products were sourced from representative sawmills in South Australia, Tasmania, Queensland and the ACT and from Pine Australia. Import and export figures were derived from ABARE's Forest Products Statistics.

Hardwood Sawmilling

The hardwood sawmilling sector is quite different from the softwood sector being characterised by a large number of small mills; even the very few large hardwood mills are much smaller than the average softwood mill. In recent years, the hardwood industry has undergone considerable change in response to reductions in their traditional resource base and to the impact that softwood framing has had on the traditional green hardwood framing market and also due growing restrictions in the utilisation of native hardwood forests.

As indicated earlier, the hardwood plantation resource is expanding and removals from hardwood plantations have been included in the total hardwood removals. Most of this material is currently of pulp log quality, but more sawlogs will be harvested as the resource matures. There is a reasonable degree of integration in the hardwood industry, however integration is difficult for the smaller more remote mills.

The hardwood sawmilling industry is far more complex and varied than any of the other sectors. There are at least 10 major species throughout the country, all having different densities and shrinkage rates, and to a great extent having different end uses. This sector has not been addressed in nearly the same detail as was applied to the softwood sawmilling sector and the outcome should be regarded as indicative only.

Assumptions on the product out-turn from hardwood sawmilling were sourced from the Victorian Association of Forest Industries and a large sawmilling company operating mills in Queensland, NSW and Tasmania. Sawlog volumes produced and import/export data have been sourced from ABARE.

A basic density of 630 kg/m^3 is assumed for hardwood sawlogs. This is an average of the following ten commonly logged hardwoods: spotted gum (*Corymbia maculata*), blackbutt (*Eucalyptus pilularis*), rose gum (*E. grandis*), jarrah (*E. marginata*), karri (*E. diversicolor*), mountain ash (*E. regnans*), alpine ash (*E. delegatensis*), silvertop (*E. sieberi*), brown barrel (*E. fastigata*) and messmate stringybark (*E. obliqua*). The basic density assumed for poles and sleepers is 790 kg/m^3. This is an average of spotted gum, ironbark and blackbutt - the main species used.

Hardwood chips are lower in average density than either sawlogs or poles and sleepers as they contain a wider range of species as well as younger regrowth and plantation material. An average basic density of 570 kg/m^3 is assumed. This is sourced from Chin (*pers. comm.*) of CSIRO.

Cypress Sawmilling

The Cypress sawmilling industry is restricted to the native cypress pine forests in Queensland and New South Wales. The quantity of logs removed is small and the data are currently included in the coniferous forest information in the ABARE quarterly reports (ABARE *various*).

The industry consists of several relatively small, low technology mills operating on a scattered resource. Because of the distances involved, integration with other processing sectors is difficult; however some Cypress pine chips are being used in panelboard manufacture. The products are principally green framing and high value flooring and dressed panelling.

Plywood (Softwood and Hardwood) and Veneer

The Australian plywood industry is based principally on plantation grown softwoods and about 8% hardwoods, both native and plantation grown. Large, high quality logs for which premium prices are paid, are preferred. In volume terms, the plywood industry is small, but it uses high technology and produces a variety of products.

In addition to plywood veneer, sliced or rotary peeled decorative veneer is produced in small quantities for furniture, door and panel overlays. This production is not recorded separately by ABARE. Jaakko Poyry Consulting (2000) estimated annual production is less than 10,000 m^3. Data sources used in the model for plywood were from ABARE and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panelboards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Both require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and Paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills.

While ABARE data provides some information, the Pulp and Paper Manufacturers Federation of Australia (PPMFA) provided a more detailed source of information. The production figures used are derived from assumed raw material usage and conversion figures rather than reported industry figures. This is important for modelling wood flows through the product cycle and is consistent with the approach used in the model for other industry sectors, apart from export woodchips, which uses ABARE statistics for export quantities in bone dry tonnes.

The model-derived paper production estimates are 15% lower than the ABARE or PPMFA figures. The reason for this is that the model calculates the wood-only raw material requirements for pulp and paper in “oven dry tonnes” while pulp reported figures are in “air dry tonnes” which contain approximately 10% moisture and 2-25% of non-wood fillers depending on the process.

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (≅ 50%) whereas thermo-mechanical mills have a high yield (≅ 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative Treated Softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (NSW). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood Poles, Sleepers and Miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m^3 of log. Railway sleepers also represent a considerable resource, and although concrete sleepers are now used for all new work, timber sleepers will continue to be used for the maintenance of secondary lines. ‘Miscellaneous’ includes a range of products such as mining, fencing and landscaping timbers. The log removals information for this group is conflicting and difficult to uncover. A provisional constant of 184,400 m^3 has been proposed for use in the model and further work is recommended.

Log and Woodchip Exports

Woodchip Exports

Export woodchips constitute a significant proportion of the annual harvest from Australian forests. The ABARE quarterly forest products statistics report both bone dry tonnes (BDt) of softwood chips and BDt of hardwood chips exported. The model uses the ABARE reported export figures directly in bone dry tonnes.

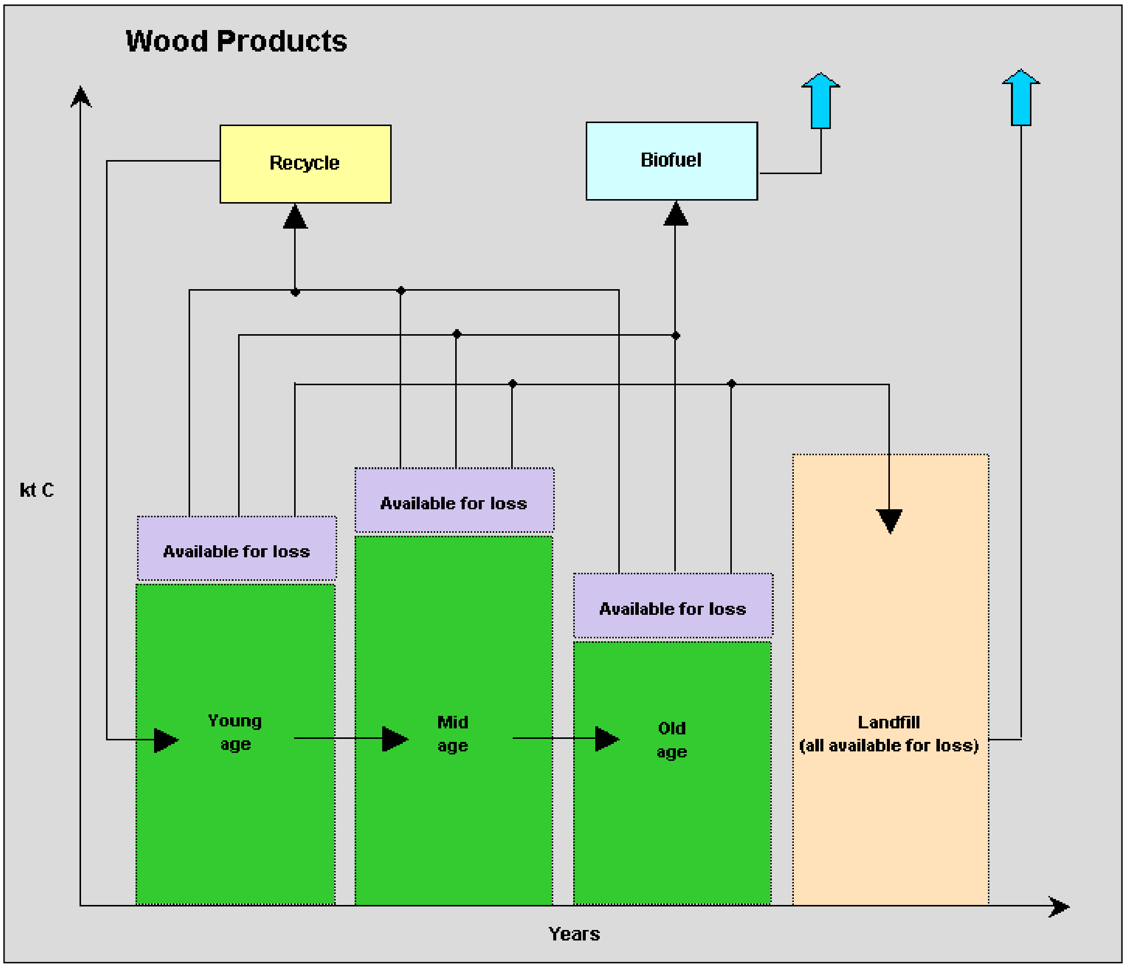
Log Exports

Total exports of coniferous logs reported by ABARE consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m^3 of short length poles / year.

Life Span of Timber Products (Recycling and Landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure D1).

Figure D1. Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the housing pool uses housing starts data. Other pools are also only estimates. The proportion of the pool that has been derived from Australian-grown wood is required in order to implement an approach that separately deals with imported wood products. However, this component is difficult to estimate and estimates should be treated with some caution.

Life Span Pools Assumed for the Carbon Model

Very short-term products – Pool 1
Softwood – pallets and cases.
Plywood – formboard.
Paper and paper products.
Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2
Hardwood – pallets and palings.
Particleboard and MDF – shop fitting, DIY, miscellaneous.
Hardboard – packaging.
Age: young = 3; medium = 6; old = 10

Medium-term products – Pool 3
Plywood – other (noise barriers).
Particleboard and MDF – kitchen and bathroom cabinets, furniture.
Preservative treated pine – decking and palings.
Hardwood – sleepers and other miscellaneous hardwood products.
Age: young = 10; medium = 20; old = 30

Long-term products - Pool 4
Preservative treated pine – poles and roundwood.
Softwood – furniture.
Hardwood – poles, piles and girders.
Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5
Softwood – framing, dressed products (flooring, lining, mouldings).
Cypress – green framing, dressed products (flooring, lining).
Hardwood – green framing, dried framing, flooring and boards, furniture timber.
Plywood – structural, LVL, flooring, bracing, lining.
Particleboard and MDF – flooring and lining.
Hardboard – weathertex, lining, bracing, underlay.
Preservative treated pine – sawn structural timber.
Age: young = 30; medium = 50; old = 90

A specified proportion of material may be lost annually (an exponential loss) from each age class of each product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for ‘steps’ in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial Stock Assumptions

Input data is available for the model since 1944 and this has the benefit of allowing the model to establish new equilibrium pools as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1944) is more important for Pool 5 as this material may remain in use.

Model Calibration

Once the data on production inputs, processing flows and initial stocks is determined other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool;
- the fraction of losses from each age class in-each product pool to each of landfill, recycling, bioenergy and the atmosphere; and
- the rate of loss from landfill.

The model estimates used are presented in Tables D2 and D3.

Table D2. Decomposition Rates and Maximum Possible Loss

	YOUNG		MEDIUM		OLD	
Pool	Loss Yr $^{-1}$	Max. Possible Loss (%)	Loss Yr $^{-1}$	Max. Possible Loss (%)	Loss Yr $^{-1}$	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

Table D3. Fraction of Losses from Product Pool to Landfill, Recycling and Biofuel

Pool	Landfill	Recycling	Bioenergy
1	0.44	0.49	0.04
2	0.75	0.20	0.05
3	0.95	0.05	0
4	0.85	0.15	0
5	0.85	0.10	0.05

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Model Results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated. In broad terms, the components of the models as described for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., “x”% sawdust, shavings or sander dust for on site energy generation or compost, “y”% woodchips for other manufacturing processes, “z”% of sawn timber products, panel products, paper, etc;
- an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data were obtained from the ABARE reports by end use categories.

Table D4 shows the annul additions and losses and carbon pool sizes.

Table D4. Carbon Stock and Emissions Outcomes (ktC)

Year	Domestic Production of New Wood Products	Imports of New Wood Products	Exports of New Wood Products	Increase Due to New Wood Products	Emissions (excl. transfer to landfill, e.g., burning of waste)	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C	kt C
1990	4,837	726	1,591	3,972	358	79,399
1991	4,914	786	1,619	4,082	362	80,395
1992	5,129	824	1,708	4,295	370	81,505
1993	5,369	827	1,856	4,340	373	82,674
1994	5,592	989	2,184	4,397	378	83,848
1995	5,516	778	1,998	4,297	383	84,863
1996	5,640	838	2,137	4,341	389	85,878
1997	6,136	910	2,603	4,442	393	86,973
1998	6,080	894	2,468	4,507	398	88,071
1999	6,228	1,069	2,621	4,676	405	89,280
2000	6,852	944	3,137	4,659	411	90,412
2001	7,089	870	3,090	4,869	419	91,691
2002	7,717	1,020	3,485	5,252	433	93,195
2003	7,262	1,020	3,485	5,297	443	94,686
2004	7,762	1,020	3,485	5,297	450	96,135

Uncertainty Analysis

With the consistent and comprehensive monitoring of wood production in Australia since 1944, and the confidence in this data gained through cross-verification with other datasets, little uncertainty will likely be derived from the production data. The most likely sources of uncertainty will be derived from the allocation to decomposition and recycling pools, and the rates of decomposition in those pools. To test the relative importance of the pool ages and decomposition rates *Monte Carlo* analyses were implemented using the @Risk add-in software (Palisade 1997) to the Excel spreadsheet wood products carbon model. The principal model parameters of interest are the decomposition rates within pools (e.g., losses from service life and landfill) and transfers (e.g., to recycling, bioenergy and landfill). *Monte Carlo* analysis samples values from within specified ranges (probability distributions) for nominated parameters within repeated applications of the model. Probability distributions for values within ranges for each variable can be nominated, as can positive and negative correlations between variables so that sampling can reflect these correlations. In this application the nominated probability distributions were 'triangular', that is, values within the ranges sampled formed a triangular distribution around a central expected value. No correlations between variables were specified, so that value selection was random within the triangular probability distributions.

The life cycle pools affected and the distributions of their possible values for the *Monte Carlo* analyses are shown in Tables 5, 6, 7 and 8. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure D2) shows the relative importance of each input variable to the overall uncertainty in the model outcome.

Table D5. Pool Age Uncertainty Ranges Used in the *Monte Carlo* Analysis

Life Cycle Pool	Lower Bound (yrs)			Expected Value			Upper Bound (yrs)		
	Young	Medium	Old	Young	Medium	Old	Young	Medium	Old
Very Short Term	0.5	1	2	1	2	3	1.5	3	4
Short Term	1	3	5	2	6	10	3	9	15
Medium Term	5	15	20	10	20	30	15	25	40
Long Term	15	20	40	20	30	50	25	40	60
Very Long Term	20	40	75	30	50	90	40	60	105

Table D6. Decomposition Rate Uncertainty Ranges used in the Monte Carlo Analysis

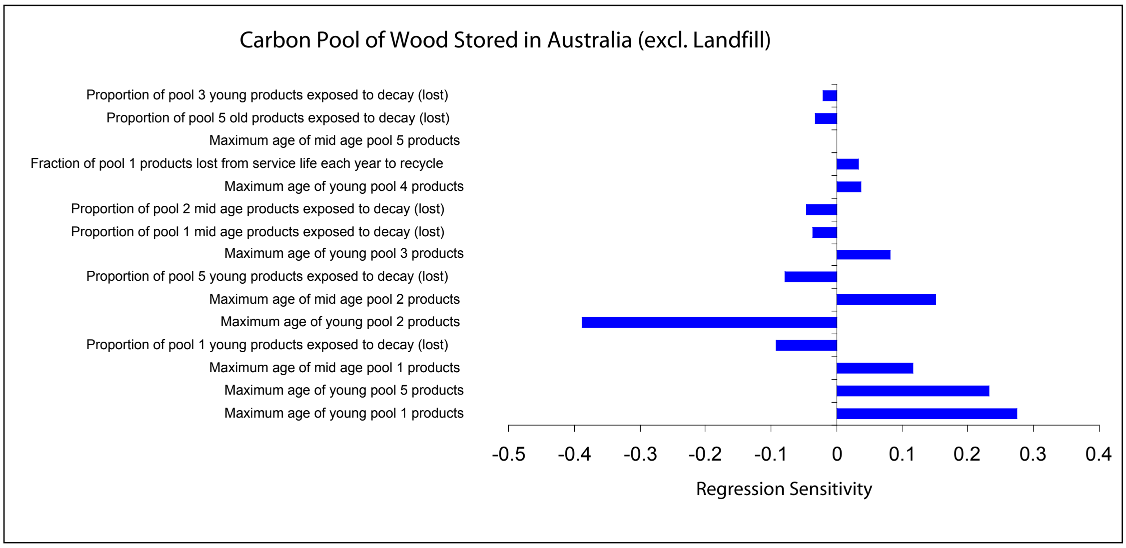
Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2.000	1.000	0.667
	2	1.000	0.333	0.333
	3	0.200	0.100	0.067
	4	0.067	0.050	0.040
	5	0.050	0.033	0.025
Medium	1	1.000	0.500	0.333
	2	0.333	0.167	0.111
	3	0.067	0.050	0.040
	4	0.050	0.033	0.020
	5	0.025	0.020	0.017

Age	Pool	Lower Bound	Expected Value	Upper Bound
Old	1	0.500	0.333	0.250
	2	0.200	0.100	0.067
	3	0.050	0.033	0.025
	4	0.025	0.020	0.017
	5	0.013	0.011	0.010

Table D7. Pool Fractions Exposed to Decomposition Uncertainty Ranges Used in the *Monte Carlo* Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.500	0.600	0.700
	2	0.250	0.300	0.350
	3	0.120	0.150	0.180
	4	0.225	0.250	0.275
	5	0.175	0.200	0.225
Medium	1	0.550	0.650	0.750
	2	0.400	0.500	0.600
	3	0.550	0.650	0.750
	4	0.550	0.650	0.750
	5	0.450	0.550	0.650
Old	1	0.800	0.900	1.100
	2	0.800	0.900	1.100
	3	0.400	0.450	0.500
	4	0.700	0.800	0.900
	5	0.800	0.950	1.150

Figure D2. Results of the @Risk Sensitivity Analyses



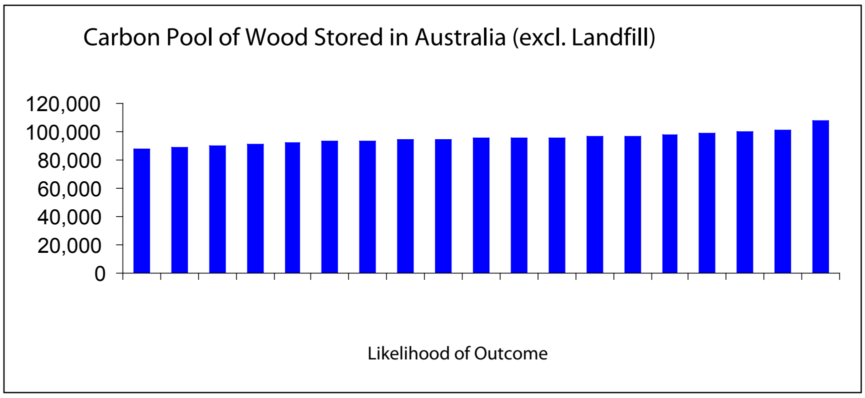


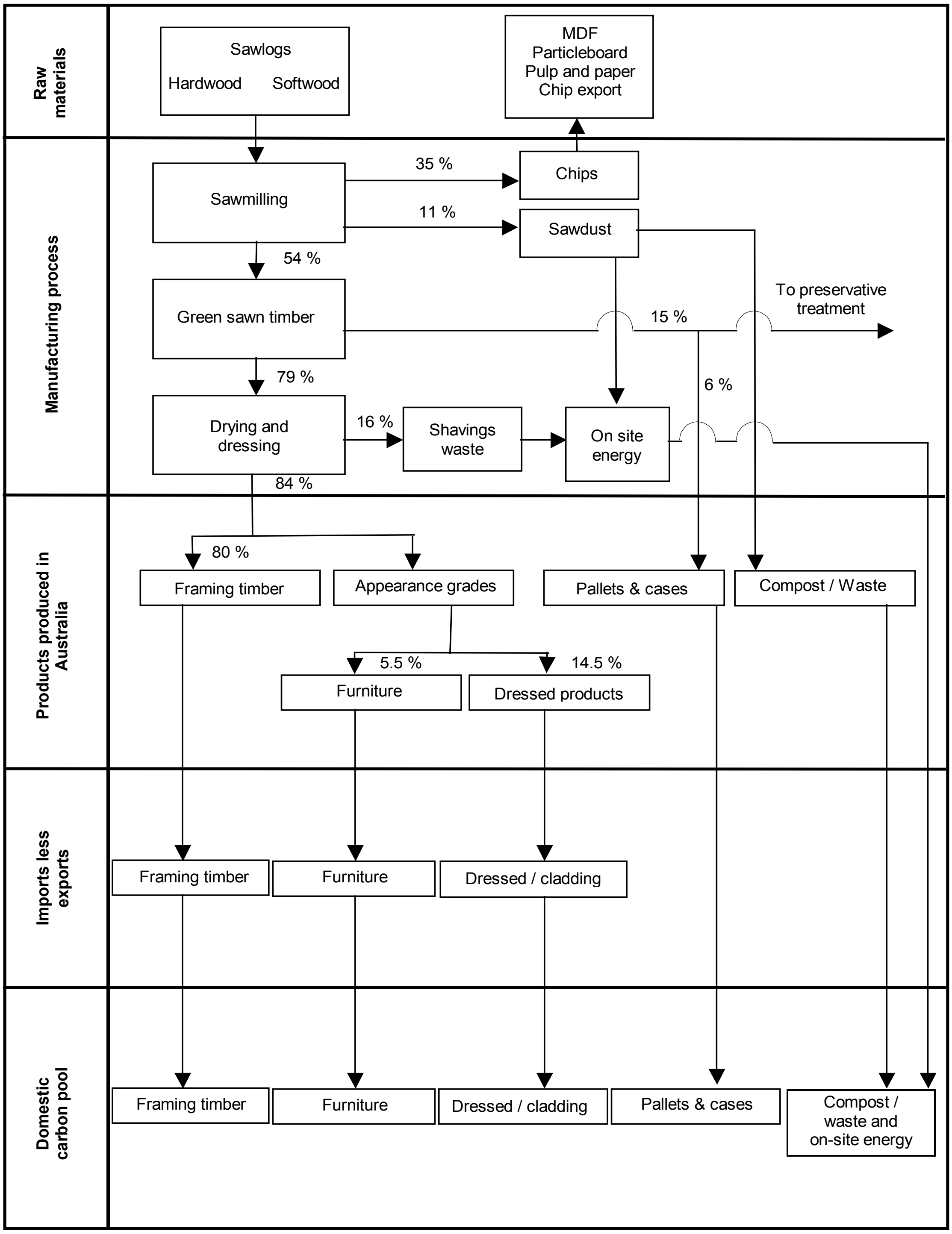
Table D8. Destination Fraction Uncertainty Ranges Used in the *Monte Carlo* Analysis

Age	Pool	Landfill			Recycle			Biofuel		
Young		Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound
	1	0.380	0.440	0.500	0.450	0.490	0.530	0.630	0.040	0.050
	2	0.600	0.750	0.900	0.180	0.200	0.220	0.040	0.050	0.060
	3	0.800	0.950	1.100	0.400	0.050	0.060	-	0	-
	4	0.700	0.850	1.000	0.130	0.150	0.170	-	0	-
	5	0.700	0.850	1.000	0.090	0.100	0.110	0.040	0.050	0.060

The effects of uncertainty in the carbon stock estimates in 1990 and 2004 national harvested wood product emissions estimates can be derived by looking at the annual stock change for the 0.10, 0.50 and 0.90 levels of confidence in potential stock outcome.

Attachment D1: Wood Flows By Sector

Figure 1: National Carbon Accounting Model for Wood Products - Sawmilling Wood Flows *



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 2: National Carbon Accounting Model for Wood Products - Wood Flows in Preservative Treated Products

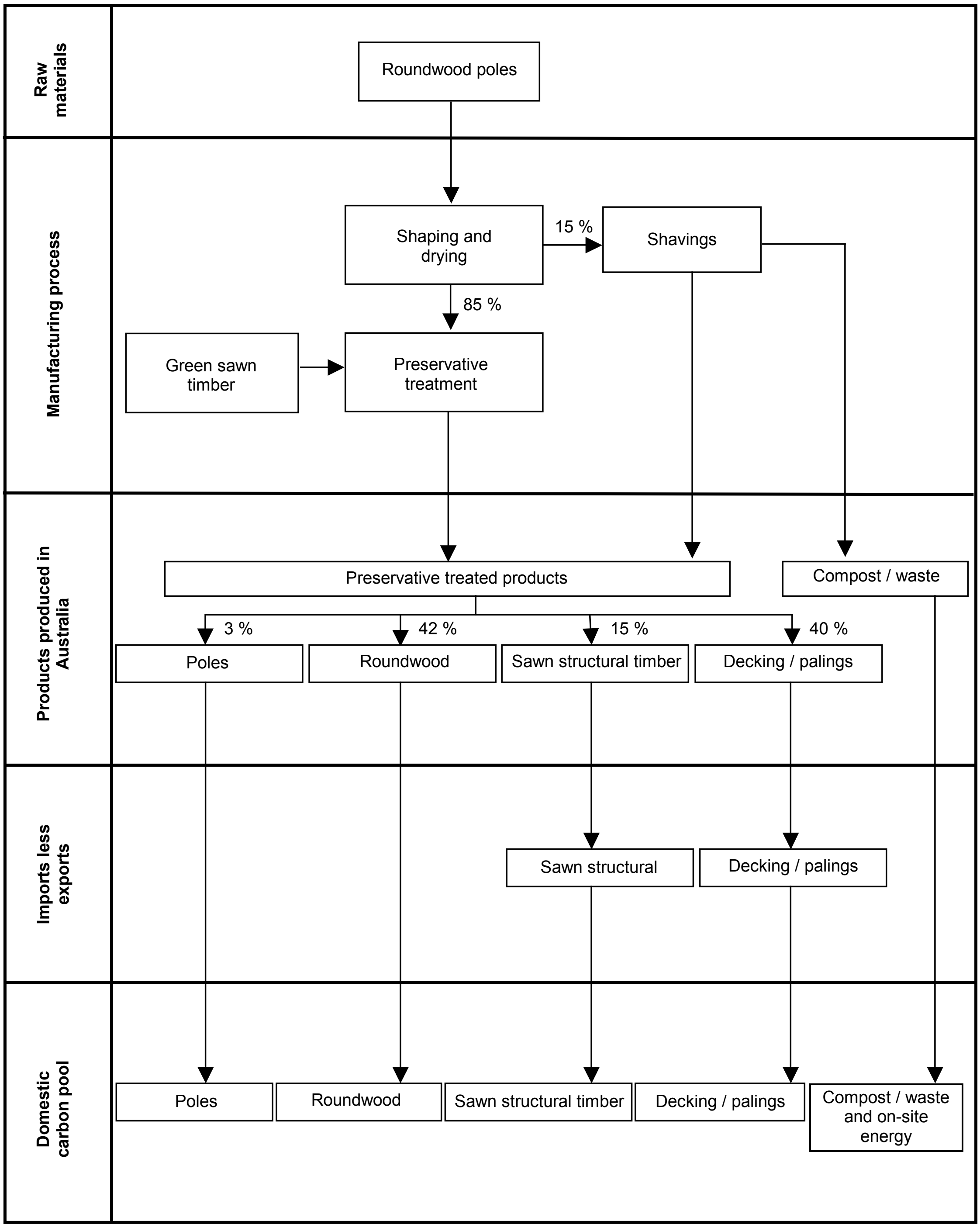


Figure 3: National Carbon Accounting Model for Wood Products - Wood Flows in Plywood Production

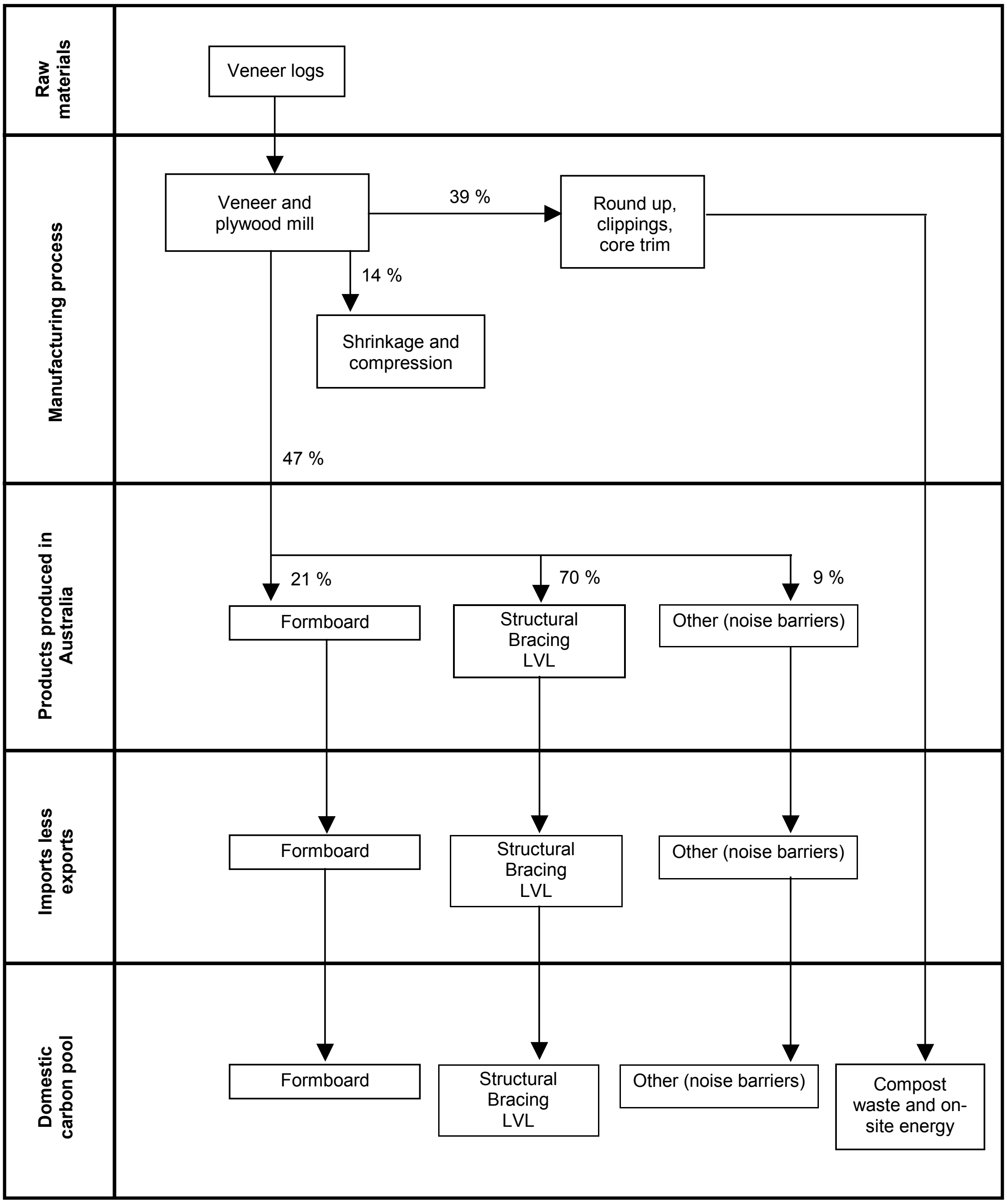
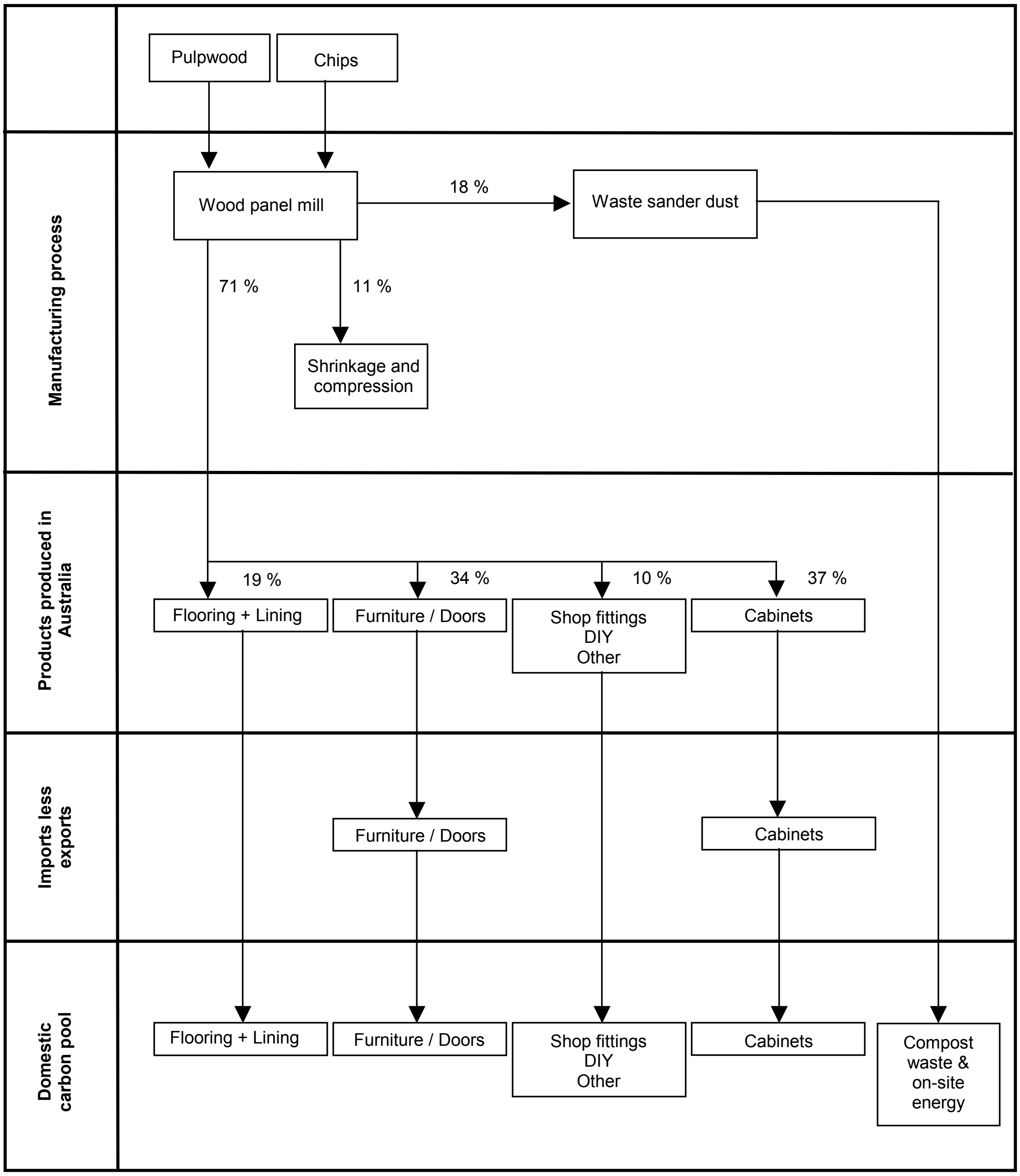


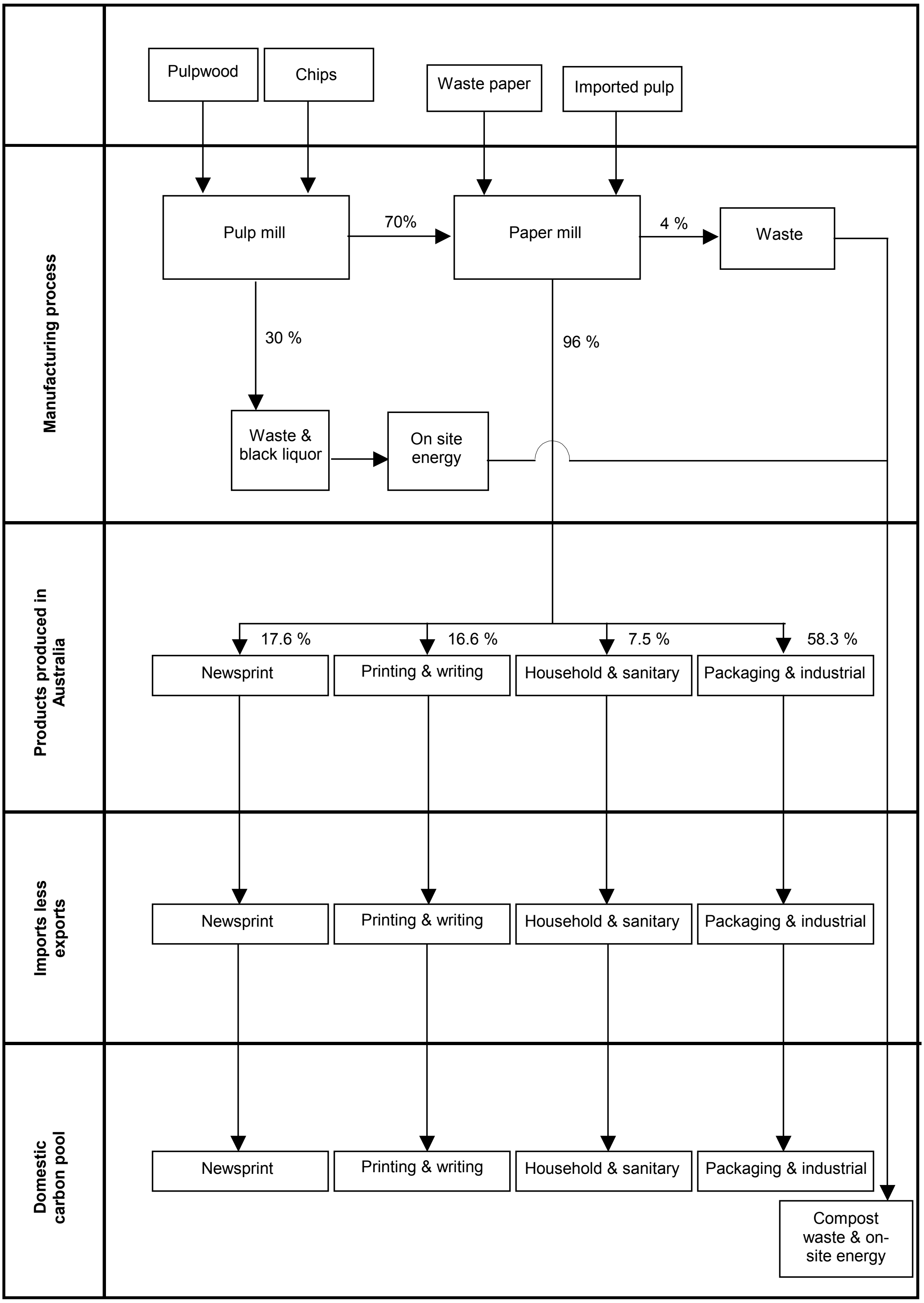
Figure 4: National Carbon Accounting Model for Wood Products - Wood flows in MDF and particleboard



manufacture *

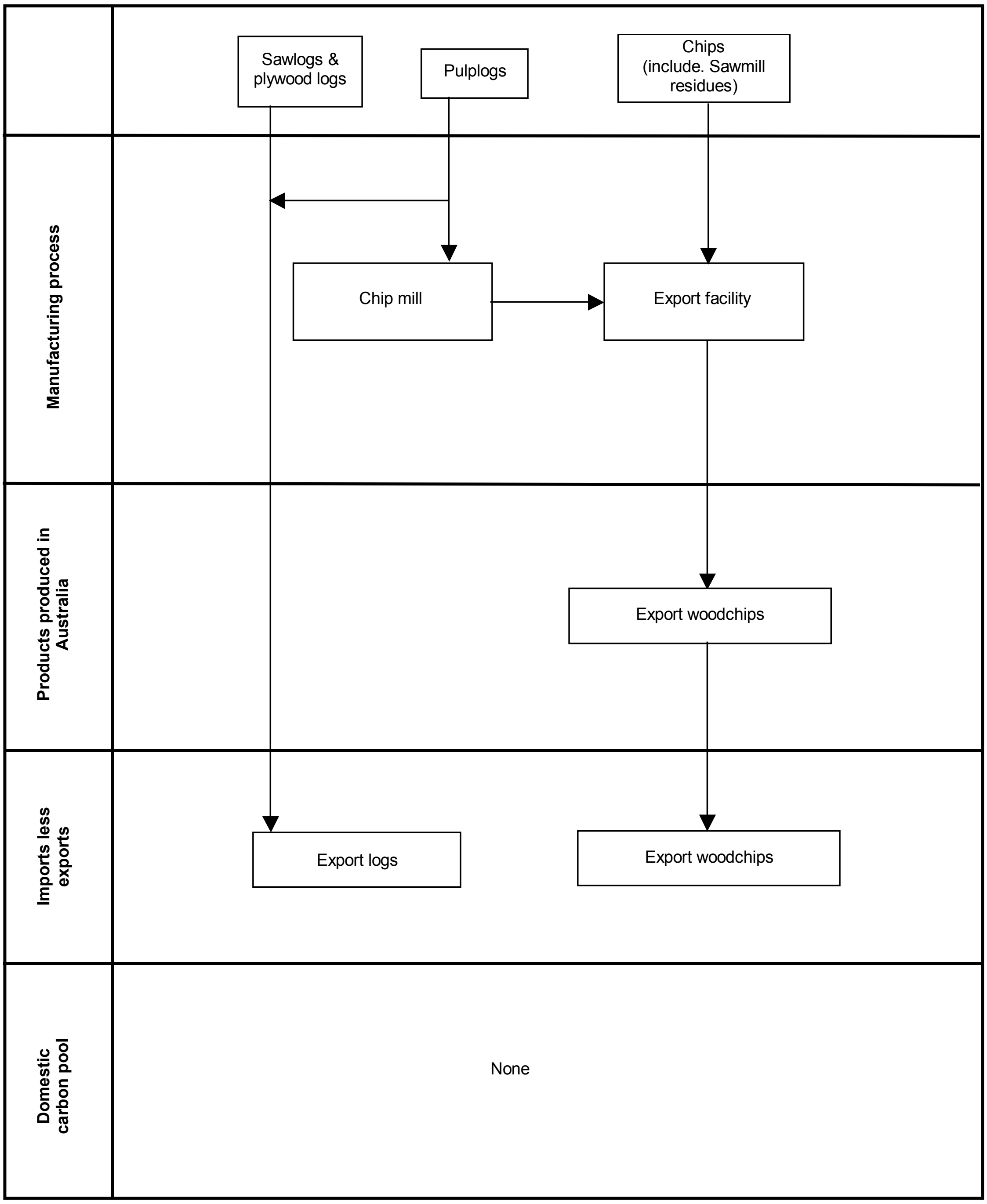
* Percentages shown for particleboard manufacture – see model for details on MDF

Figure 5: National Carbon Accounting Model for Wood Products - Wood Flows in Pulp and Paper



Manufacture

Figure 6: National Carbon Accounting Model for Wood Products - Wood flows in export woodchips and logs



Attachment D1 – Quality Assurance

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Date October 4, 2004

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REVIEW OF WOOD PRODUCTS MODEL – UPDATE 2004

Dear Gary

As agreed Jaakko Pöyry Consulting has reviewed the 2004 update of the AGO's Wood Products Model. The update was made by MBAC Consulting in June 2004.

The focus of Jaakko Pöyry Consulting's work was to check that the updated data were consistent with our understanding of the wood products' industry production, import and export statistics and to consider if any recent changes in the industry necessitated adjustments to assumptions or the structure of the model. However, the underlying integrity of the model's calculations has not been checked.

Pulp and paper worksheet

We have no significant concerns about the updated statistics added to the pulp and paper worksheet. The base data entered since 1998 is consistent with the data collected and published by APIC and changes in the industry over the last six years do not require any changes in the assumptions.

In particular, it was considered that the start-up of the new Visy pulp and paper mill at Tumut may have changed the destination fraction of Raw Material for the industry (rows 38 – 40). However, a check of this indicated the destination fraction of wood to pulp had only changed from 71% to 69% with the start-up of the Visy mill, so that the estimate in the model of 70% remains valid.

Some minor points to note are as follows:

- The industry body which is the reference source for the pulp and paper data, has now changed its name from APIC to A3P, so this could be noted to assist in locating data for any subsequent update.

- Similarly, it is noted that the data listed under a particular calendar year in the model, is actually the data for the financial year commencing 1st July in that year. This is unlikely to have any significant impact on the outputs of the model, but again could be noted to assist in any subsequent update.

- Notes by MBAC refer to correcting some of the units from 1000m^3 to tonnes. In fact the units for wood volumes entered in rows 25 – 30 which are sourced from APIC still need to be shown as kilotonnes rather than $1000m^3$. (That is the numbers entered in the model are in fact kilotonnes.)

The model structure and calculations obviously makes a number of simplifications to the overall complex product flows that occur in the industry. This has introduced some small errors or inconsistencies in the model which are noted below. Overall, the carbon from pulp and paper is possibly overstated by 10%, but given the level of assumptions in the model, this is probably not that significant.

- Some of the data in the model is in dry tonnes and some is in air dried or "as produced" tonnes. Typical moisture content of paper is 4-8%, which could be allowed for in the model.

- Some paper, particularly, printing and writing grades has a significant content of filler or pigment, up to 20%, which is not allowed for. Averaged over all grades, filler content is probably about 3%.

- Waste paper is treated like pulp in that losses to waste stream are only 4% (row 43). In fact average losses in converting waste paper to recovered fibre for use on the paper machine are 12%.

- While the model requires inputs for each specific grade of paper (newsprint, tissue, printing and writing, packaging) in fact all of these grades are considered to have the same input of raw materials, so that the model actually treats them all the same.

- The model does not make any allowance for consumption growth in the future. A typical figure for paper grades is approximately 2%.

Solid wood worksheets

The inputs and percentages of product recovery, residues, domestic market, imports and exports all seem to be in the right order of magnitude and appear to be based on reasonably reliable data sources.

Though it has been noted that there are no inputs recorded for hardboard since 1999, in the covering explanation for that table it is stated that "no data reported in ABARE Statistics; assumed to be included with MDF from 1999 on". JPC is aware that there are two operating hardboard mills in Australia (Weathertex located at Raymond Terrace, NSW – production 14,000 tonnes per annum & Australian Hardboards located at Ipswich, Qld – production 42,500 tonnes per annum). Including those hardboard mills volumes in with MDF will distort the MDF statistics.

Yours sincerely

Steven King
Consultant

Appendix 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 fifteen time epochs from 1972 to 2006, 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 avertage *(P)* (Richards and Brack 2004a):

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

where *P* is the long-term average forest productivity index and *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).

$$MA = M * e^{-k/A}$$ *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; and 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*):

$$I_a = (6.011 * \sqrt{P} - 5.291)^2 * (e^{\frac{-k}{A}} - e^{\frac{-k}{A+1}})$$ *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*):

$$\bar{I}_A = I_A * \frac{P_A}{P}$$ *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).

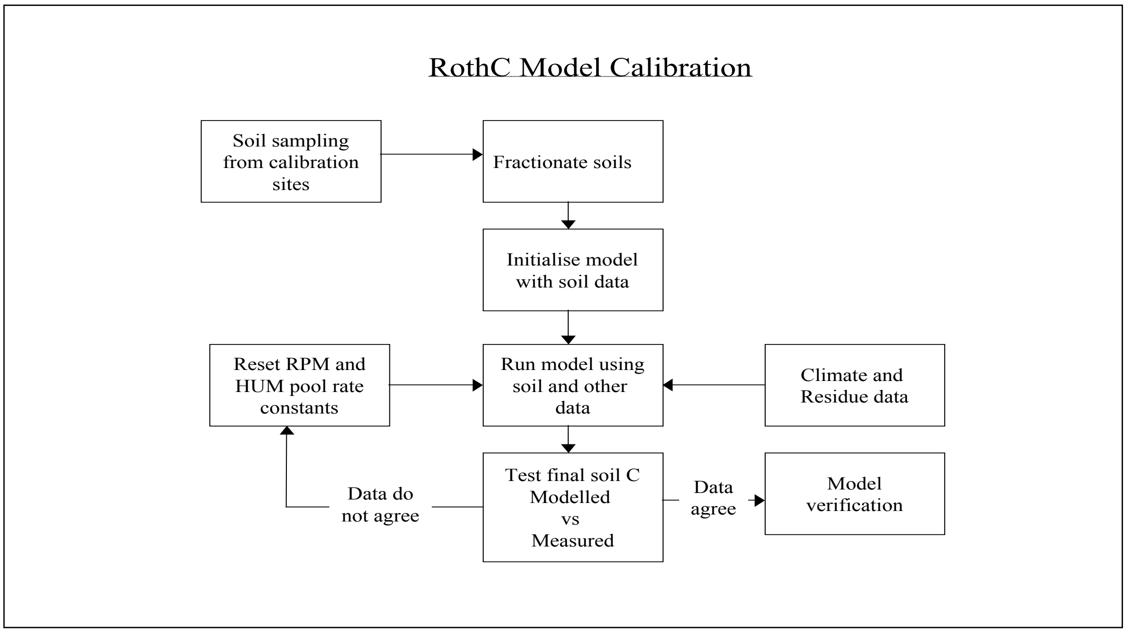
Decomposition rates are dependant on moisture, temperature and litter 'quality' based on the C:N ratio of the mulch pool. Material entering the mulch pool from decomposable debris enters the soluble plant mulch. Material entering from the resistant debris pools can enter either the less-resistant plant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

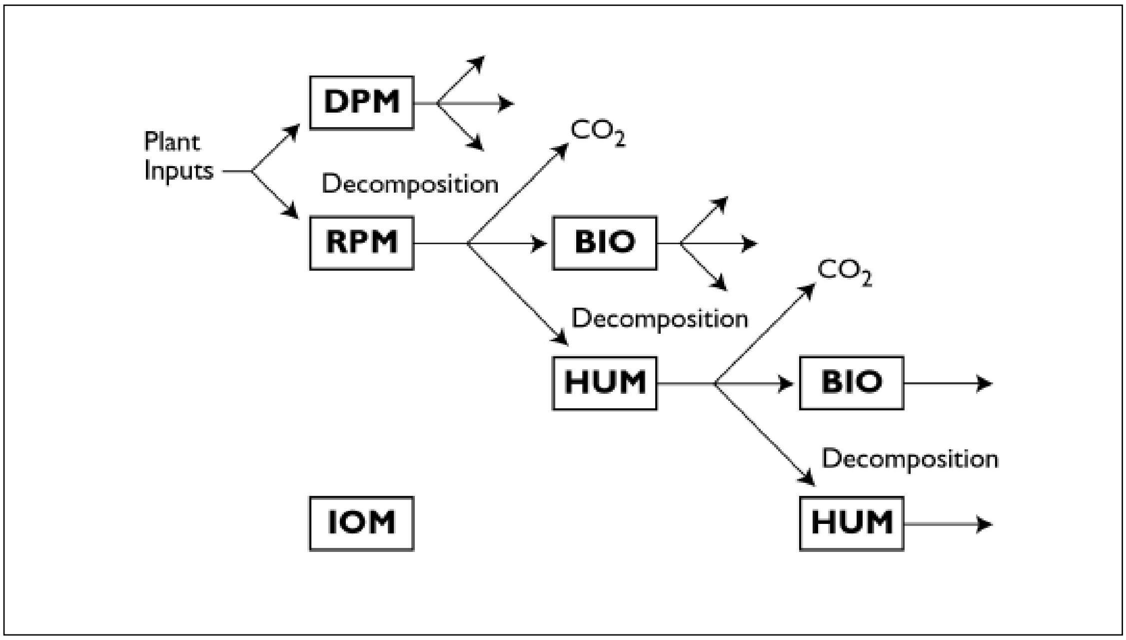
Calibration of the soil carbon model was completed around a structured procedure as shown in Figure E1.

Figure 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 E2.

Figure E2: 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.

Harvested Native Forests

Identification of areas of 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

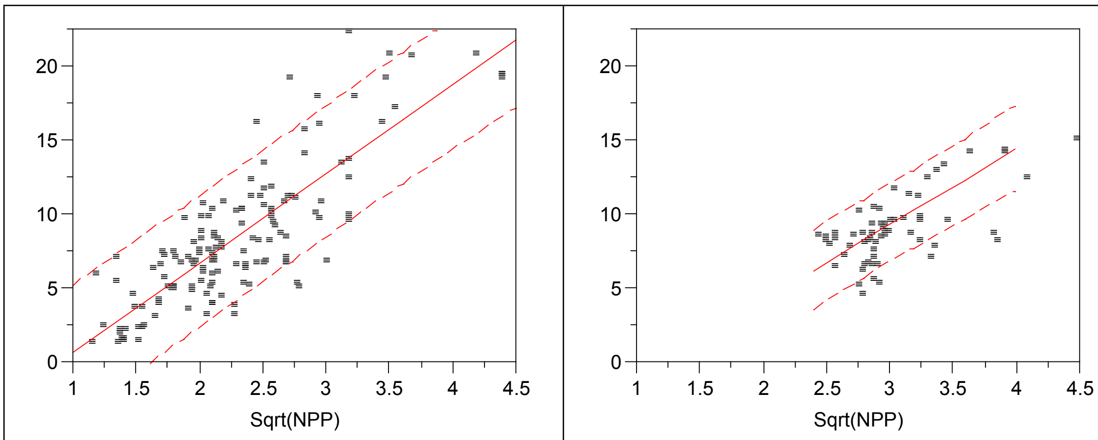
For the purposes of this section, a valid model is one where the model performance or outputs are satisfactory for its intended application. Implicitly, this may mean that the model form is reasonable (verified) and the numerical constants are appropriate (calibrated).

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 E3).

Figure 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	b) Biomass estimated from Snowdon et. al. (2000) allometrics and MBAC Consultants (2003) inventory data
$M = \left(6.011 * \sqrt{P} - 5.291\right)^2$ *Equation (1)*	$\hat{M} = \left(5.132 * \sqrt{P} - 6.106\right)^2$ Equation (6)
[0.346] [0.823]	[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.

Plantations

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

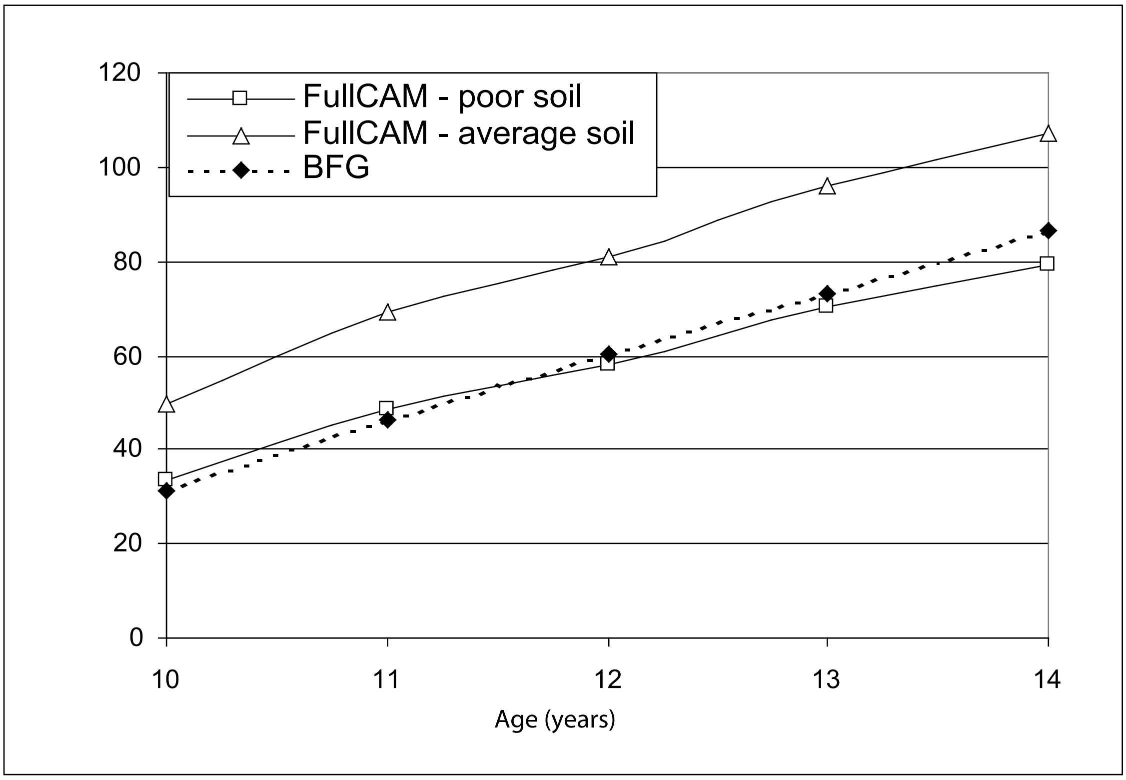
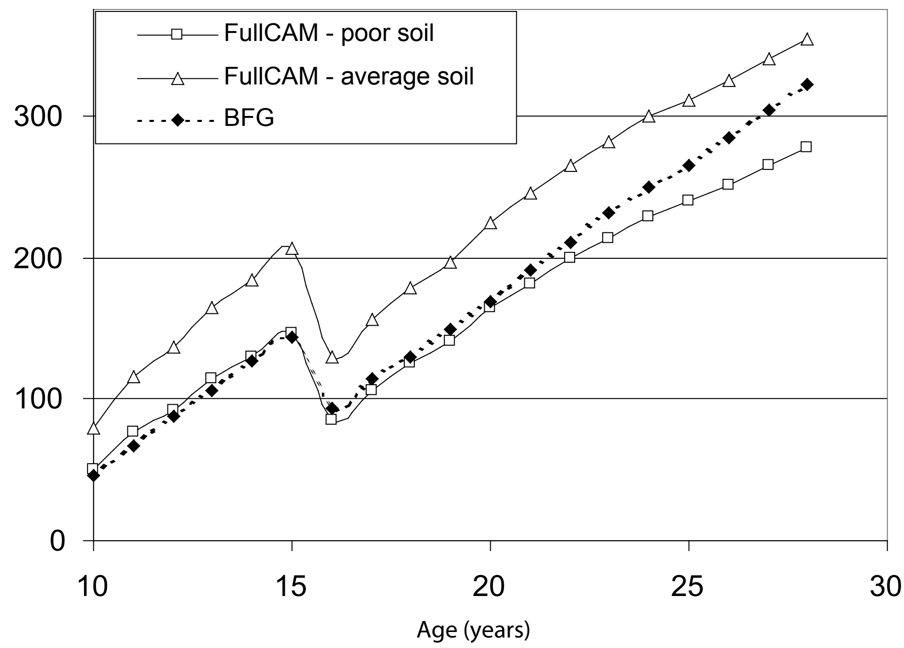


Figure E5. Stem volume at the BFG experiment (control) compared to *FullCAM* estimates assuming poor and average soils.



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. If inappropriate or poorly calibrated parameters of inputs, transfer and losses were used, the mass balance model would, over a long period of time, predict clearly 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+ (1988-2006) 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 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 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 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

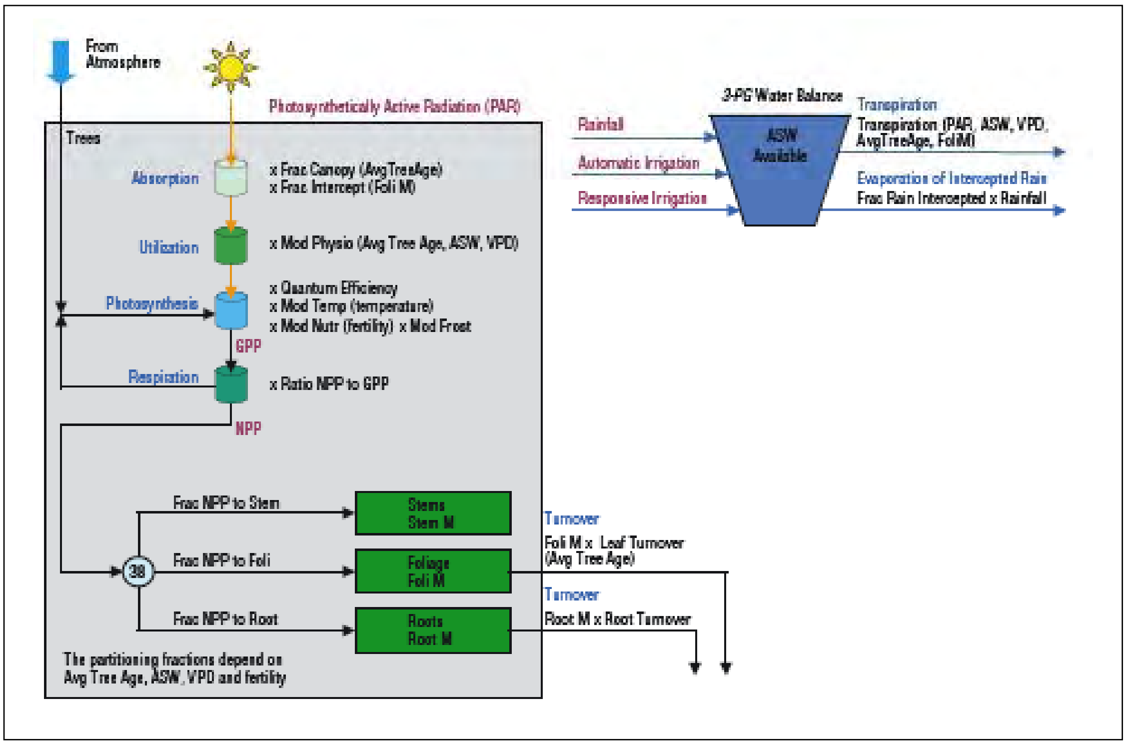
Naming Conventions

Abbreviations used in names

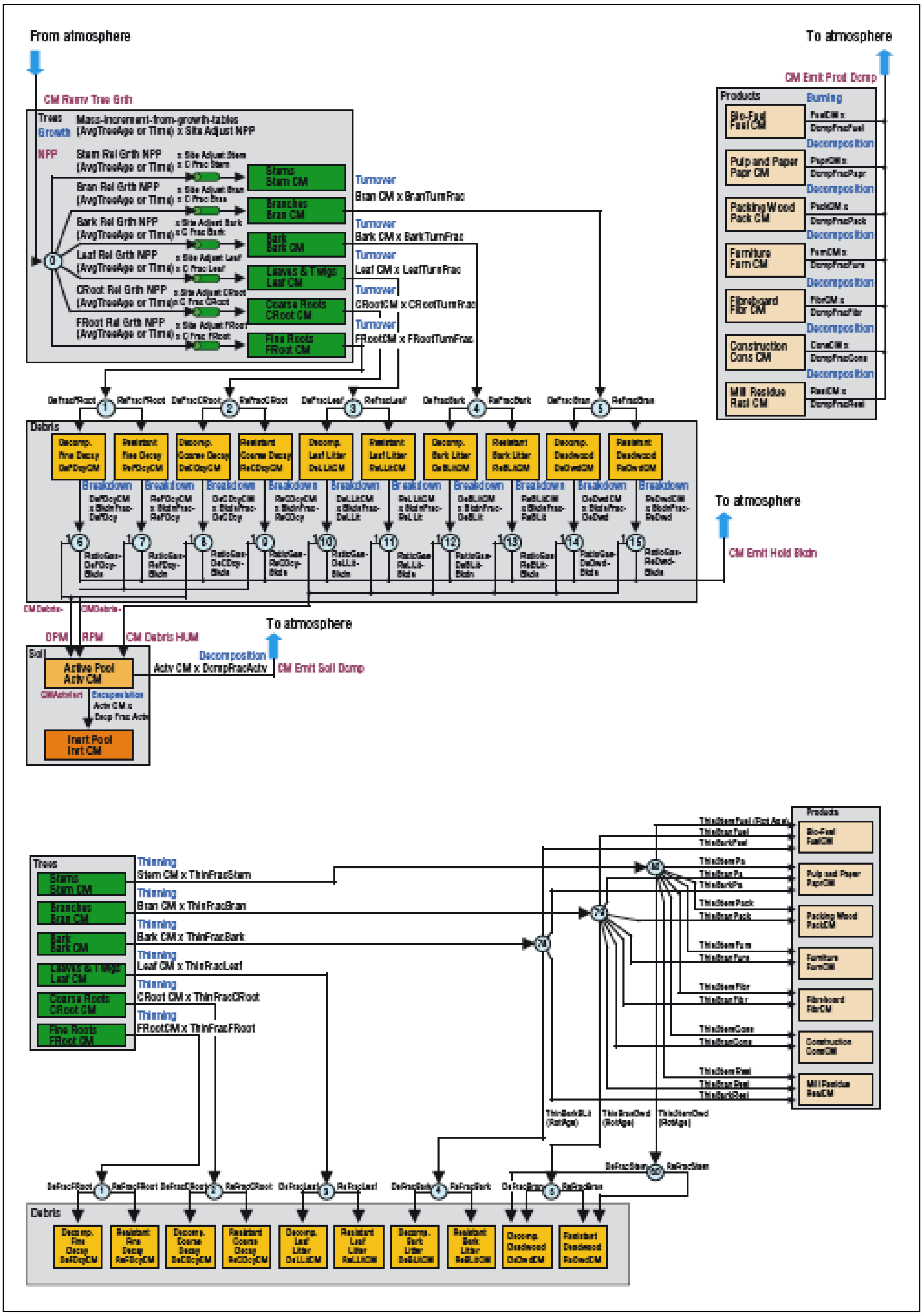
Actv = Active soil carbon
Avg =Average B = Microbes (dead) (see P, Micr)
Bkdn =Breakdown C = Carbon Material whose every atom has six protons
C = Coarse (see Dcy, Root)
Cel = Cellulose (see Lig, Sol)
CM = Carbon mass of material Mass of carbon atoms in the material
Conp = Consumption (of fodder by animals,which 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

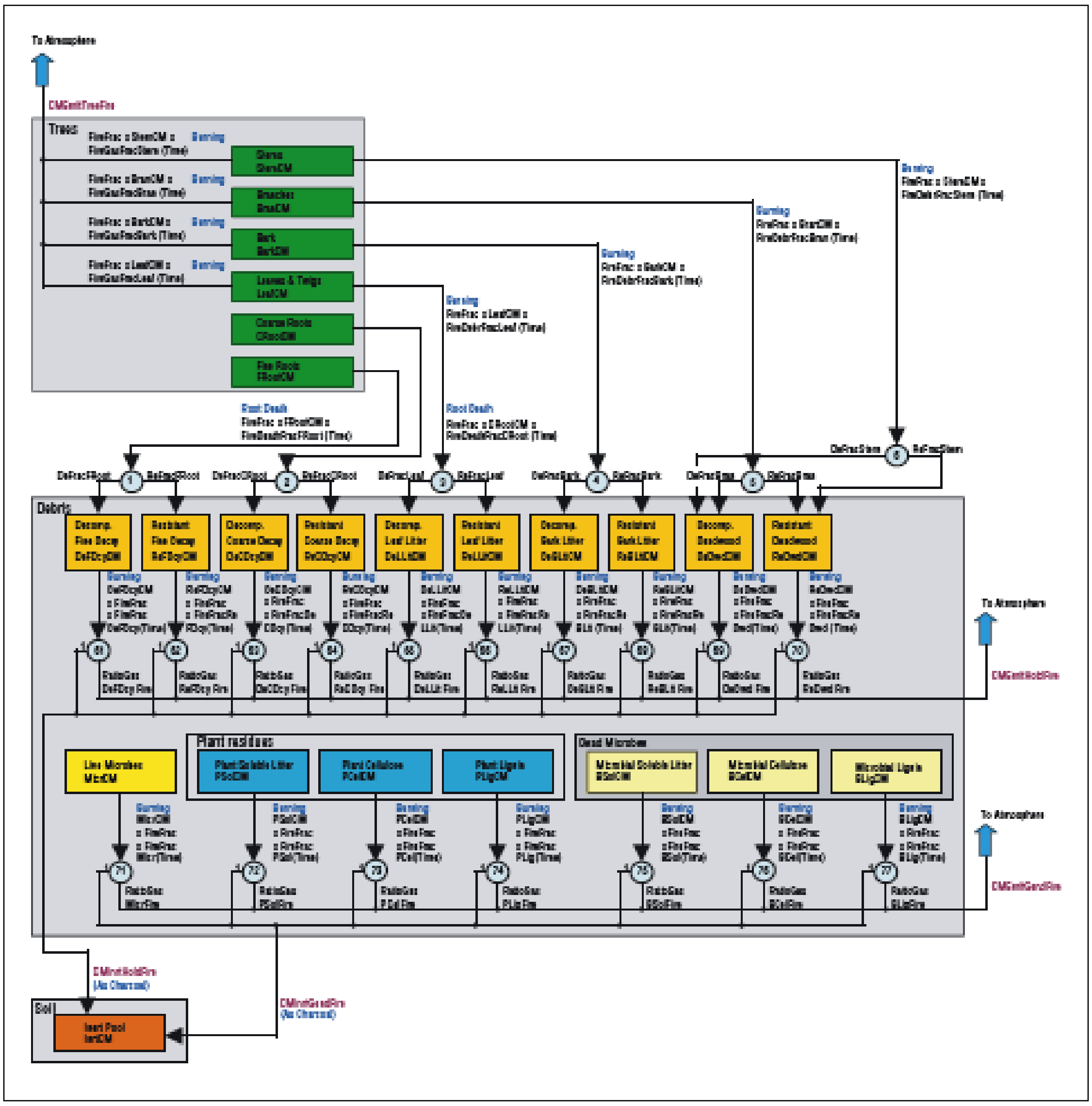
ASW = Available soil water (in mm of rainfall or irrigation) (*3-PG* only)
BIO = Microbial biomass = Fast and slow decomposing biomass combined (BIO-F + BIO-S) (Roth-C only)
BIOF = BIO-F = Fast decomposing biomass (Roth-C only)
BIOS = BIO-S = Slow decomposing biomass (Roth-C only)
CO2 = Carbon dioxide
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)



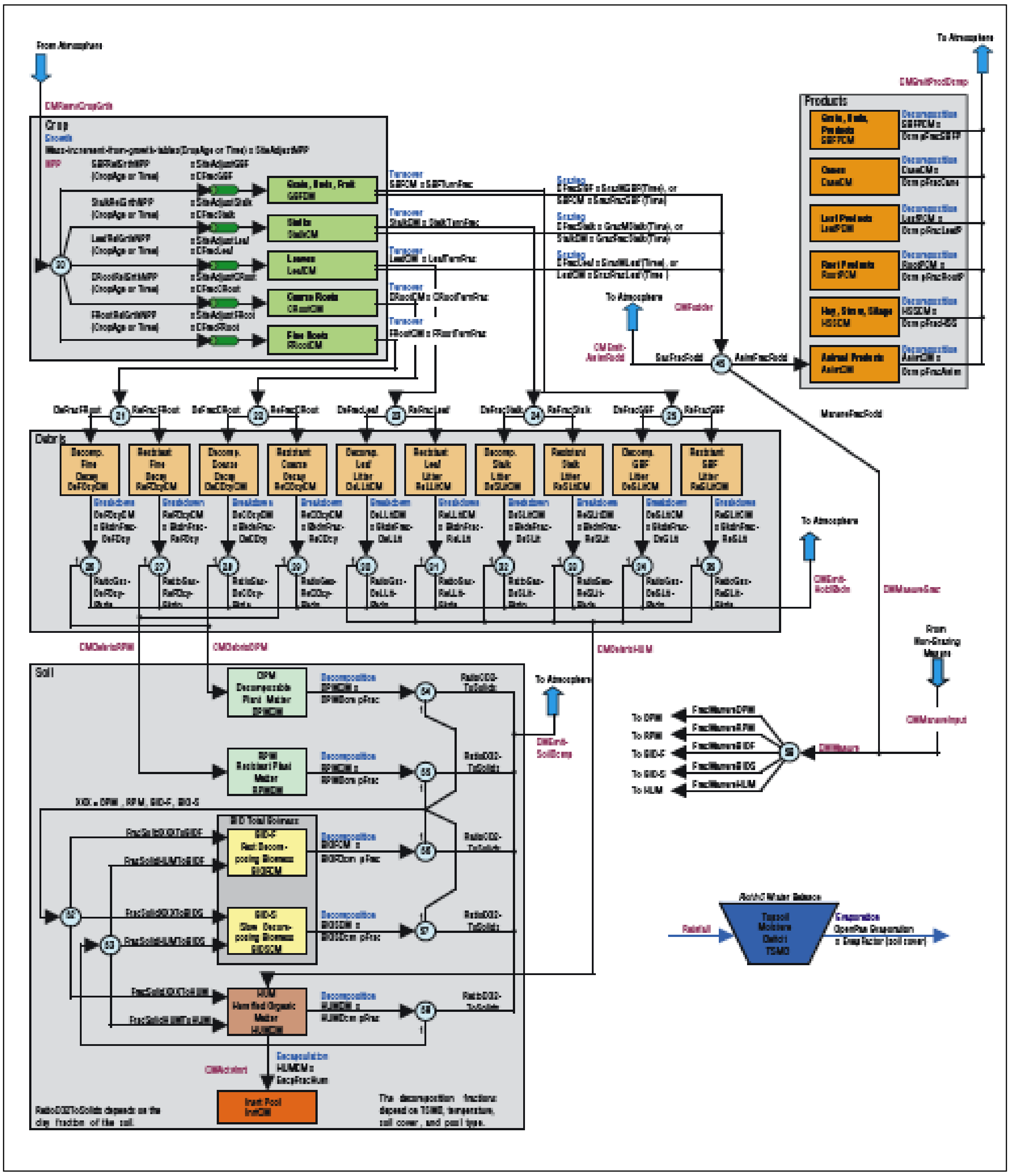
The *3-PG* Model



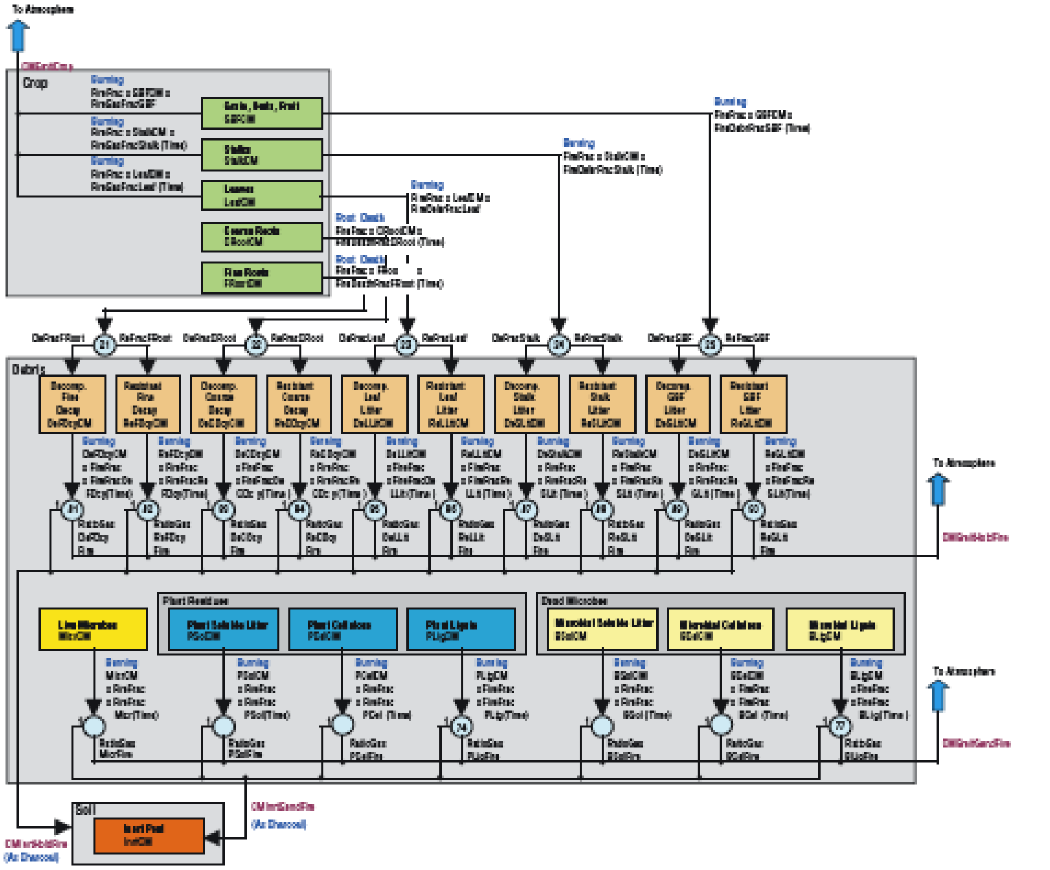
The *CAMFor* Model (a) Thinning



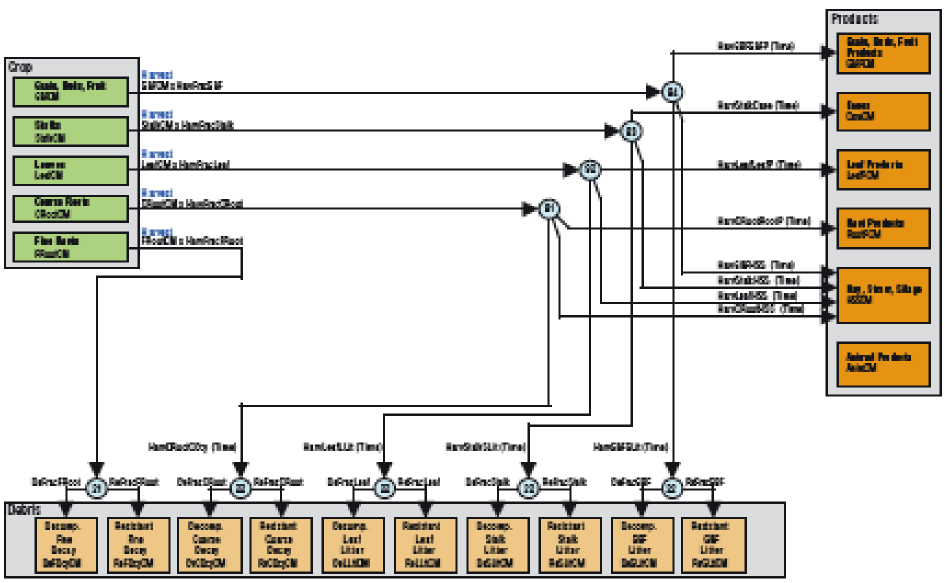
The *CAMFor* Model (b) Fire



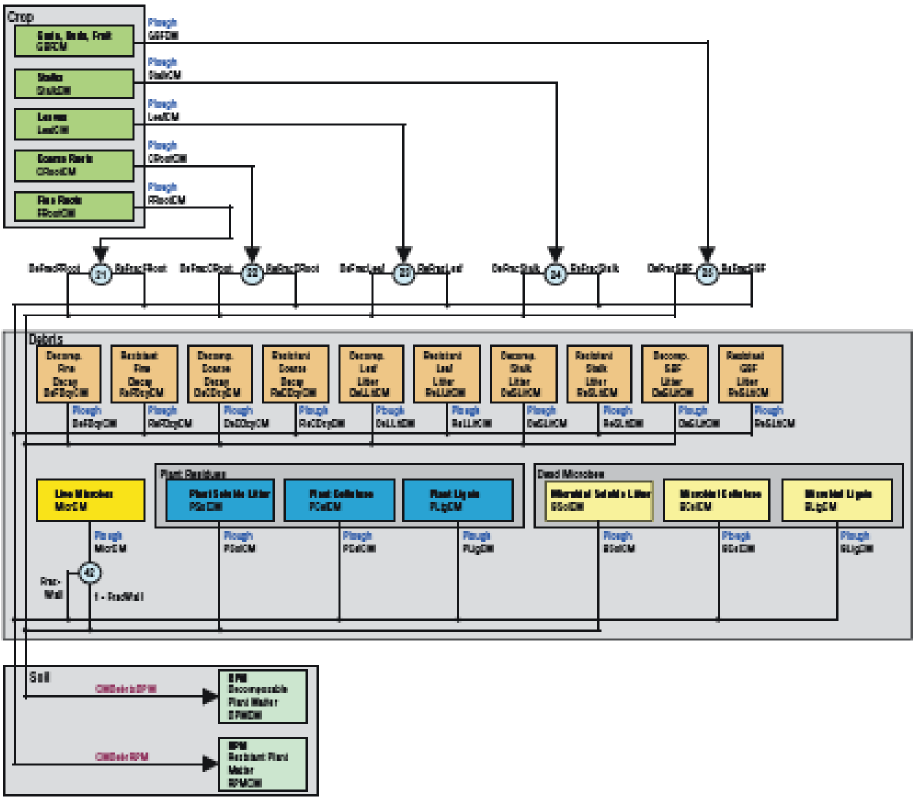
The *CAMAg* Model



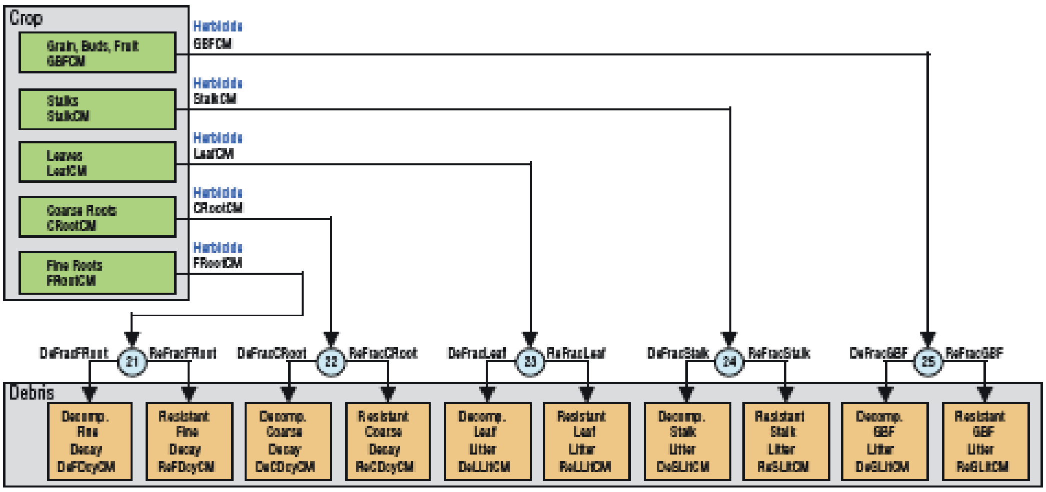
The *CAMAg* Model (a) Fire



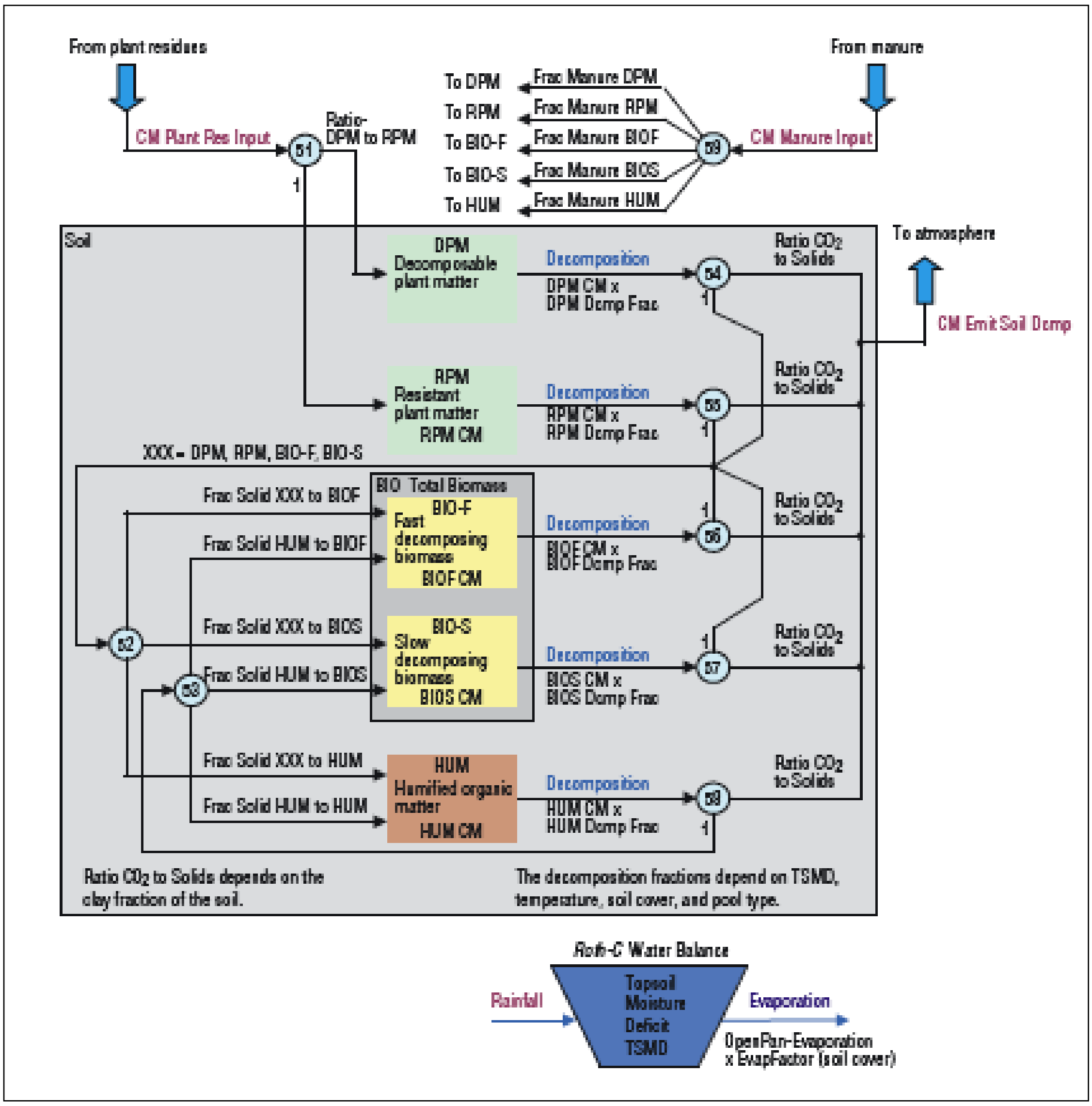
The *CAMAg* Model (b) Harvest



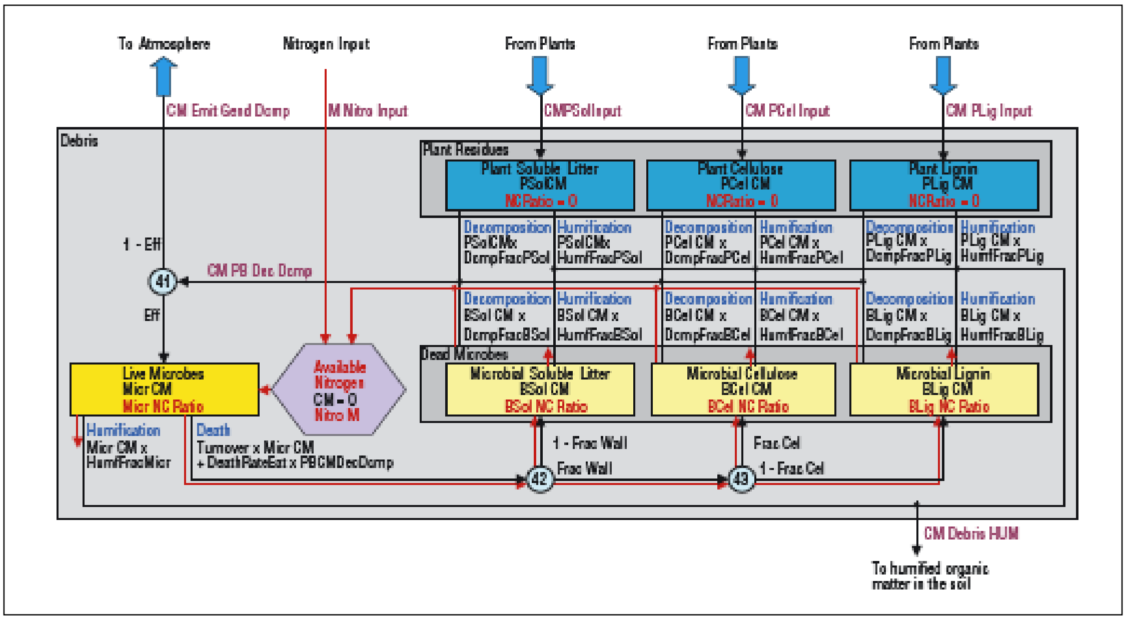
The *CAMAg* Model (c) Plough



The *CAMAg* Model (d) Herbicide



The *GENDEC* Model



The *Roth-C* Model

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