Australian National University

TOWARDS A COMPREHENSIVE AND FULLY INTEGRATED STOCK AND FLOW FRAMEWORK FOR **CARBON ACCOUNTING IN AUSTRALIA**

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Revised September 2014

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This discussion paper was prepared as a partnership project between the Australian Bureau of Statistics, the Australian Department of the Environment and The Australian National University. The views presented in this Discussion Paper are those of the authors and should not be taken for those of the Australian Government or its agencies.

June 2014

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Disclaimer:

Much of the information presented in this Discussion Paper is the outcome of experimental research. The objective was to facilitate discussion about advancing carbon accounting in Australia and to inform data users about the potential information so they could provide feedback. The authors do not vouch for the accuracy of the information.

To cite this paper:

Ajani J. and Comisari P. 2014, 'Towards a comprehensive and fully integrated stock and flow framework for carbon accounting in Australia', a Discussion Paper, Australian National University, Canberra Australia.

KEY POINTS

1. Australia faces a very real opportunity to build a comprehensive carbon stock and flow accounting system fully integrated with our economic information system. Regularly reporting such data will enhance significantly the information for policy making, public understanding and debate.

2. For countries undertaking carbon stock accounting for their jurisdiction, the primary reservoirs in the geosphere (geocarbon in largely fossil fuels) and the biosphere (biocarbon in biomass and soils) are the most important. The release of carbon by human activity from primary reservoirs is the primary cause of global warming. The long experience in national economic accounting confirms that accounting frameworks with comprehensiveness (completeness) built in from the start are highly desirable. This does not mean that all carbon stocks and flows should be or need to be reported. The purpose of the statistics and resources available for information collection and reporting will determine coverage and priorities. As these priorities change or new information and understanding becomes available, comprehensive accounting frameworks can more readily accommodate such changes and therefore better serve the multiple information needs of users.

3. The carbon classification system is fundamental for generating useful information from the accounts. With climate mitigation being the primary purpose of the information, criteria that separates the different carbon reservoirs (for example, in different fossil fuels, ecosystems and economic products) by their carbon stock stability/longevity/restoration capacity attributes is important. Such science-based criteria should be consistent across both geocarbon and biocarbon. Further disaggregation in the classification for biocarbon should be science-based using the same criteria of stock stability/longevity/restoration capacity.

4. Australia's carbon stock and flow information is reported using IPCC designed industry activity or product classifications. DoE and the ABS have developed concordance tables to enable linkages with economic data (ex post). Benefits in information quality, and ease and cost of reporting are likely to be realised by designing the carbon classification system to be consistent with the product classifications used to generate Australia's economic information (ex ante).

5. The Australian Greenhouse Energy Information System (AGEIS), managed by DoE to meet the Australian Government's reporting commitments under the UNFCC, contains information that could populate large components of an Australian carbon stock account. This is particularly the case for biocarbon in the land sector (coverage of the marine sector is under development) with stock-based models underpinning the reporting of flow information. Geocarbon stock information is not available with the main exception being DoE work to estimate carbon in non-energy products such as plastics, lubricants and fertilisers. AGEIS contains limited information on biocarbon-based products that accumulate in the economy: the primary one being wood products. The ABS experimental work to populate the fossil fuel component of an Australian carbon stock account fills a major information gap. Feedback on the questions accompanying the exercise is keenly sought.

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ABBREVIATIONS

3PG	a physiological growth model
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
AGEIS	Australian Greenhouse Emissions Information System
ALUM	Australian land use and management map
ANU	The Australian National University
ANZIC	Australian and New Zealand Standard Industrial Classification
API gravity	American Petroleum Institute gravity or density measure of petroleum
ASNA	Australian System of National Accounts (economic)
bbl	barrel
BREE	Bureau of Resources and Energy Economics
C	carbon
CAMag	agricultural component of FullCAM
CAMfor	forestry component of FullCAM
CCC	carbon carrying capacity
CCS	carbon capture and storage
CH_4	methane
cm	centimetre
CO	carbon monoxide
CO_2	carbon dioxide
CRF	common reporting format tables
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoE	Department of the Environment
EDR	economically demonstrated resource
EPA	US Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FullCAM	full carbon accounting model
g	gram
GENDEC	general decomposition model
GIS	geographic information system
GPP	gross primary production
Gl	gigalitre
GLMZ	grazing land management zones
Gt	gigatonne
Ha	hectare
HFC	hydrofluorocarbon
IBRA	Interim Biogeographic Regionalisation for Australia
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
km	kilometre
L	litre
Lidar	light detection and ranging
LPG	liquid petroleum gas
LULUCF	Land Use, Land Use Change and Forestry
m^3	cubic metre
Mt	million (mega) tonne
n.d.	no date

NEB	net ecosystem balance
NEE	net ecosystem exchange
NEP	net ecosystem production
NGERS	National Greenhouse and Energy Reporting system
NGL	natural gas liquids
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NPP	net primary production
n.r.	not reported
NT	Northern Territory
NVIS	National Vegetation Information System
OECD	Organisation for Economic Co-operation and Development
OSCAR	Online System for Comprehensive Reporting
PFC	perflurocarbon
Qld	Queensland
REDD	Reducing Emissions for Deforestation and Degradation
RothC	soil carbon component of FullCAM
SCaRP	Soil Carbon Research Program
SDR	sub-economic demonstrated resource
SEEA	System of Environmental-Economic Accounting
SEEA EEA	System of Environmental-Economic Accounting Experimental Ecosystem Accounting
SI	International System of Units (scientific)
SNA	System of National Accounting (economic)
SOC	soil organic carbon
t	tonne
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

Since only the mid-1990s, national governments have invested substantially in information systems to meet their reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. These systems, developed under Intergovernmental Panel on Climate Change (IPCC) guidance, generate considerable amounts of information and undergo constant refinement and coverage. They are designed to report flow information, i.e. greenhouse gas emissions to and removals from the atmosphere. This information is crucial not just for reporting against climate change mitigation commitments but also for understanding the climate change process. The information system, however, is incomplete because data users – be they policy makers, researchers or the public – need stock and flow information. Our core objectives are usually expressed in stock terms. How we get there is usually expressed in flow terms. For example, the economic wealth of a country (a stock) is built through a combination of processes (various flows such as investing and working).

At the country level, carbon flow information needs complementing with information about carbon stocks in fossil fuels and in ecosystems to provide policy makers and other data users with a complete set of information. Recent advances in understanding and research have made the reporting of comprehensive carbon stock and flow information a real possibility. These include: DoE work to progressively develop a comprehensive carbon accounting framework to support multiple information needs; the stock-based modelling underpinning much of the flow information reported by DoE for the land sector; the experience and skills in the ABS developed over many decades of economic accounting in the principles of comprehensiveness and linking multiple stock and flow accounts; the endorsement and publication in 2012 of the *System of Environmental-Economic Accounting* (*SEEA*) *Central Framework* by the United Nations, European Commission, FAO, OECD, IMF and World Bank as a global statistical standard and the subsequent *SEEA* work to develop stock accounting frameworks for various 'assets' including carbon as presented in *SEEA Experimental Ecosystem Accounting* and published by the European Commission, OECD, United Nations and World Bank in 2013. The consistency in concepts, standards and classifications between the *SEEA* and the economic *System of National Accounts* (*SNA)* presents a real opportunity to fully integrate carbon and economic information to enhance research and policy making in Australia.

In November 2012, officers from the ABS, DoE and ANU agreed on a partnership project to investigate the potential for reporting Australia's carbon stocks. This Discussion Paper was prepared to support discussions with data providers and consultations with information users. It includes the results of an experiment to populate a carbon stock account with indicative estimates to assist discussion about methods for regularly reporting carbon stocks and the usefulness of the information. We identified numerous methodological issues which are presented as questions within the text to encourage feedback and advice.

We limited the experiment to investigating Australia's carbon stocks in the primary reservoirs[1] of:

> geocarbon (carbon in the geosphere), and further limited to fossil fuel resources, and
> biocarbon (carbon in the biosphere): comprehensively across all biomass and soil organic carbon to 30 cm (100 cm for marine ecosystems) irrespective of ecosystem type and land/water use.

Our results are presented in Table ES 1. The experiment did not cover carbon stocks in the economy, for example in concrete, plastics and wood products. We did however identify opportunities to apply DoE's existing information systems to populate this part of a carbon stock account and in ways that could assist DoE in data verification.

[1] A glossary is presented in Appendix A.

Table ES 1 Estimated carbon stocks in Australia's primary reservoirs today (million tonnes C)[a]. An experimental exercise to provide an indicative picture to assist discussion about methods for regularly reporting carbon stocks and the usefulness of the information.

Primary reservoir	Geocarbon (Mt C)	Hectares (million)	Biomass carbon (Mt C)	Soil organic carbon (Mt C)	Total biocarbon (Mt C)
Geocarbon					
Fossil fuel					
Black coal	97,400				
Brown coal	58,100				
Crude oil[b]	145				
LPG[c]	90				
Natural gas	1,559				
Shale oil	82,287				
Total fossil fuel	**239,581**				
Carbonate rocks					
Limestone	n.r.				
Other carbonate rocks	n.r.				
Total carbonate rocks	n.r.				
Other (includes methane clathrates)	n.r.				
Biocarbon					
Natural ecosystems					
Rangelands		596.3	6,374	6,603	12,977
Non rangelands:					
Eucalypt native forests		16.7	4,671	3,753	8,424
Shrub lands & woodlands		14.7	500	636	1,137
Grass, shrub & heath lands		1.6	37	51	87
Rainforests		2.3	1,225	252	1,477
Other		0.7	15	16	32
Marine ecosystems		1.8	114	1,084	1,198
Fresh water ecosystems		9.9	4	7	11
Total Natural ecosystems		**644.0**	**12,941**	**12,402**	**25,343**
Semi-natural ecosystems					
Highly modified rangelands		50.0	750	1,500	2,250
Grazing in modified pastures outside rangelands		32.9	132	1,315	1,447
Total Semi-natural ecosystems		**82.9**	**882**	**2,815**	**3,697**
Agricultural ecosystems					
Cropping		25.5	102	1,022	1,124
Irrigated agriculture		2.6	12	105	117
Plantation wood		2.4	177	120	296
Reservoir/dam		0.6	1	6	7
Other		6.3	120	244	363
Total Agriculture ecosystems		**37.4**	**412**	**1,497**	**1,907**
Settlements		2.6	30	79	108
Other		0.5	7	19	26
Total Settlements and Other		**3.1**	**37**	**98**	**134**
Total biocarbon[d]		**767.4**	**14,270**	**16,811**	**31,081**

a. Coal estimates are for 30 June 2011. Oil and gas estimates are for 30 June 2009. Biocarbon estimates have been derived using various information sources mostly in the 2000s.
b. Includes naturally-occurring condensate.
c. Comprises LPG naturally occurring in crude and natural gas production fields.
d. Numbers do not add due to rounding.

The main finding from our investigation is the very real potential for Australia to build a comprehensive carbon stock and flow accounting system fully integrated with our economic information system. Generating such information requires drawing multiple threads together into a comprehensive and consistent framework, populating the accounts with existing information and working, overtime, to fill the gaps and address the methodological issues identified in this Discussion Paper.

Carbon stock information has many uses. Of importance is its capacity to support government policy and implementation. The Australian Government's mitigation policy, which aims to address climate change and improve the environment by rewarding abatement at the lowest cost, attracts a diverse range of competing abatement actions in both the energy and land/marine sectors. Comprehensive carbon stock and flow information can support Australian Government policy by providing comparable information on carbon stocks in fossil fuels and all ecosystems and land uses across Australia's land and marine scape. Scenario analysis can be used to examine policy options expressed as stock changes over periods of time and, by linkage with economic information, the economic and employment impacts of these options can be estimated.

Information about carbon stocks in Australia's terrestrial and marine ecosystems today can be combined with comparable information about their carbon carrying capacity (a stock) to help the Australian Government shape priorities for the long term storage of carbon in the land and marine sector in biomass and soils. The Australian Government can be supported with information to better understand the implications of different abatement options for Australia's agricultural land and water assets.

Interest in carbon stock information is not all about climate change. Agronomers with their focus on food production have a long-standing interest in soil organic carbon levels as a soil health measure and tracking soil erosion risk. Historically, State Governments through their soil conservation agencies collected information on carbon stocks in agricultural soils but this service ended with changed funding and institutional arrangements between the Commonwealth and States. Carbon stock accounting creates an opportunity to revisit the provision of soil carbon information to support Australian agriculture.

1 INTRODUCTION

National governments have invested substantially in information systems to meet their reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. These systems, developed under Intergovernmental Panel on Climate Change (IPCC) guidance, are designed to report flow information, i.e. greenhouse gas emissions to and removals from the atmosphere. This information is crucial not just for reporting against climate change mitigation commitments but also for understanding the climate change process. The information system, however, is incomplete because data users – be they policy makers, researchers or the public – need stock and flow information. Our core objectives are usually expressed in stock terms. How we get there is usually expressed in flow terms.

A disjuncture exists between carbon information serving humanity as a global whole and carbon information meeting individual country UNFCCC treaty commitments. The stock of carbon in the atmosphere (the focus of the core objective of the UNFCCC) is measured globally whereas carbon flows (mostly in the form of CO_2) are country specific in source. At the country level, carbon flow information needs complementing with information about carbon stocks in fossil fuels and in ecosystems to provide policy makers and other data users with a complete set of information.

Recognition of the disjuncture between carbon information systems at the global scale and carbon information meeting individual country requirements has been building whilst other important understandings and developments have also occurred. These include:

- DoE work to progressively develop a comprehensive accounting framework to support multiple information needs, including Australia's international greenhouse gas reporting obligations under the UNFCCC and Kyoto Protocol.
- Recognition of the substantial stock information embedded in the systems DoE uses to generate flow information and DoE's systems for quality improvement across all information sets.
- Recognition of the experience and skills in the ABS developed over many decades of economic accounting: particularly valuing the principles of comprehensiveness and linking multiple stock and flow accounts.
- The endorsement and publication in 2012 of the *System of Environmental-Economic Accounting* (*SEEA*) *Central Framework* by the United Nations, European Commission, FAO, OECD, IMF and World Bank as a global statistical standard.
- The subsequent *SEEA* work to develop stock accounting frameworks for various 'assets' including carbon as presented in *SEEA Experimental Ecosystem Accounting* and published by the European Commission, OECD, United Nations and World Bank in 2013.
- Recognition that the consistency in concepts, standards and classifications between the *SEEA* and the economic *System of National Accounts* (*SNA)* presents a real opportunity to fully integrate carbon and economic information to enhance research and policy making in Australia.

It was timely for Australia to investigate the potential to build a carbon stock accounting framework to complement our existing carbon flow information and reporting system.

In November 2012, officers from the ABS, DoE and ANU agreed on a partnership project with the following objectives:

- To identify the need for carbon stock information and potential data users.

> To undertake an experiment to populate the *SEEA* carbon stock account and in so doing identify research and information priorities, and further refine the account classifications, terminology and methods.
> To present the findings to the UN Statistics Division aimed at improving the accounting methodology and information quality.
> To assess what is needed for regularly producing a carbon stock account for Australia.

This Discussion Paper was prepared to meet these objectives directly and to support discussions focussed to information user consultation and engagement.

Section 1 presents introductory information about carbon, system dynamics, the global carbon cycle and carbon stock information uses. Sections 2 to 9 present information and analysis specific to Australia and contain technical questions to prompt discussion. A glossary, schedule of units and conversion factors, details on the information sources and methods used to estimate Australia's biocarbon stocks and the main information providers for Australia's greenhouse gas reporting are presented in the Appendices.

1.1 What is carbon?

The word carbon is derived from the Latin *carbo* which means charcoal or coal. Scientifically, carbon (C) is a chemical element (basic substance that cannot be simplified) with 6 protons in each atom (its unique atomic number). Carbon is notable for the immense number and diversity of compounds it can make with other elements (Moore 1978).

Carbon is a component of the Earth's crust in the form of carbonates of calcium, magnesium, and iron. Furthermore, the compounds formed by carbon and other elements such as hydrogen, oxygen and nitrogen are essential for life. Carbon exists in all living matter, in vegetation and organisms, and the soils that support life. It is found as carbon dioxide (CO_2) in the Earth's atmosphere and dissolved in waters.

Australia's fossil fuel resources are our largest carbon reservoirs[2]. Of these, coal is the most significant. Coal originates from the dense forests growing in the Carboniferous Period 360 to 280 million years ago. Over millions of years of natural processes, these forests were buried under soil becoming more compressed with more depositing, sinking deeper and experiencing increased temperatures as Australia's land mass moved further away from the south. Mud or acidic water prevented the dead plants degrading (oxidising) thereby trapping the carbon in huge bogs that became buried by sediments. The high pressure and temperature converted dead plants into coal and methane (CH_4). Similarly, biological organisms such as phytoplankton and zooplankton accumulated on the ocean or lake floor over millions of years in huge amounts. Layered with mud, they decomposed anaerobically and were buried by heavy layers of sediment. The resulting pressure and heat changed chemically the organic material into kerogen found in oil shales and, with further heat, into liquid and gaseous hydrocarbons (Schobert 1987). Human combustion of fossil fuels is transferring carbon accumulated over millions of years in the geosphere into the atmosphere and ocean waters mainly in the form of CO_2 (for a human history of coal see Freese 2003). Similarly, but on a significantly smaller scale, our land use practices have transferred carbon accumulated in the biosphere – in plants and soils – into the atmosphere and ocean waters.

[2] A glossary is presented in Appendix A.

Quantitative information about the different carbon reservoirs is derived using different methods with varying reliability (Figure 2). Carbon in the atmosphere is measured information and is the most accurately reported quantity in the global carbon cycle (Global Carbon Project). Carbon in the oceans is estimated through calibrated modelling. For country level information systems, geocarbon and biocarbon reservoirs are the main focus. Their qualitative differences require different methods for generating information and the level of accuracy of the information is likely to vary. The spatial variability in geocarbon stock densities can be significant, however geocarbon stocks are largely inert and stock changes are almost entirely anthropogenic. The number of entities processing geocarbon for energy and other products such as cement is relatively small. Biocarbon stocks encompass the entire land and marine scape and stock changes are caused by complex interactions of human activities, natural disturbances and climate variability that can be difficult to separate (Ajani *et al*. 2013). Carbon emissions and removals due to human land use activities can occur over many years, whereas most emissions from fossil fuels occur immediately (Höhne *et al*. 2007). For biocarbon, the number of entities, in terms of spatial units of analysis, is large and their spatial and temporal variability means that estimation is difficult and comes with relatively large standard errors and confidence intervals. These quality differences should be taken into account when designing information systems serving multiple purposes, including policy formulation.

1.2 Stocks, flows and system dynamics

Understanding the difference between stocks and flows and their relationship is critical for understanding the dynamics of systems. Stocks are quantities of material or other accumulations. Their measurement applies to a point in time. Flows are the rates at which these quantities change over a period of time. We may not use system dynamic language, but stocks and flows are familiar to all of us in our everyday activities. The number of people in a train carriage at 5 pm on 29 June 2013 (a stock) is the accumulation of people entering the carriage less the people leaving the carriage over the day to 5 pm (the flows). Our bank balance at any point in time (a stock) is the accumulated deposits less removals (flows) since we opened the account.

John Sterman in *Business Dynamics: Systems Thinking and Modeling for a Complex World* (2000) presents an articulate account of the nature of stocks and flows and their relationships. The following discussion draws on his work. Stocks characterise the state of a system. Stocks inform decision makers about where they are: the information that tells them they need to act. A corporation's balance sheet reports its financial health in stock terms: e.g. cash, inventory, debts, assets: key information informing management decisions and actions. Similarly for an agricultural ecosystem where stock information about soil composition, soil organic carbon, nutrient content and soil moisture informs farmer decision making.

A system in equilibrium means that the rate of inflows and outflows are equal and therefore the stock is unchanged. In human systems, disequilibrium is often the reality because inflows and outflows are governed by different decision processes. Economic production and consumption (flows) are rarely equal for a period of time and inventories (stocks) along the production chain work as a buffer. Whenever two coupled activities are controlled by different decision makers, involve different resources or are subject to different random shocks, the buffer (a stock) between them accumulates the difference. Information about the changing size of the buffer feeds back in various ways to influence the inflows and outflows.

Stocks give systems inertia by accumulating the difference between the inflow to a process and the outflow. All delays involve stocks. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in a system. Understanding stock-flow relationships reduces the tendency to underestimate time delays, to focus on the short term and to policy resistance.

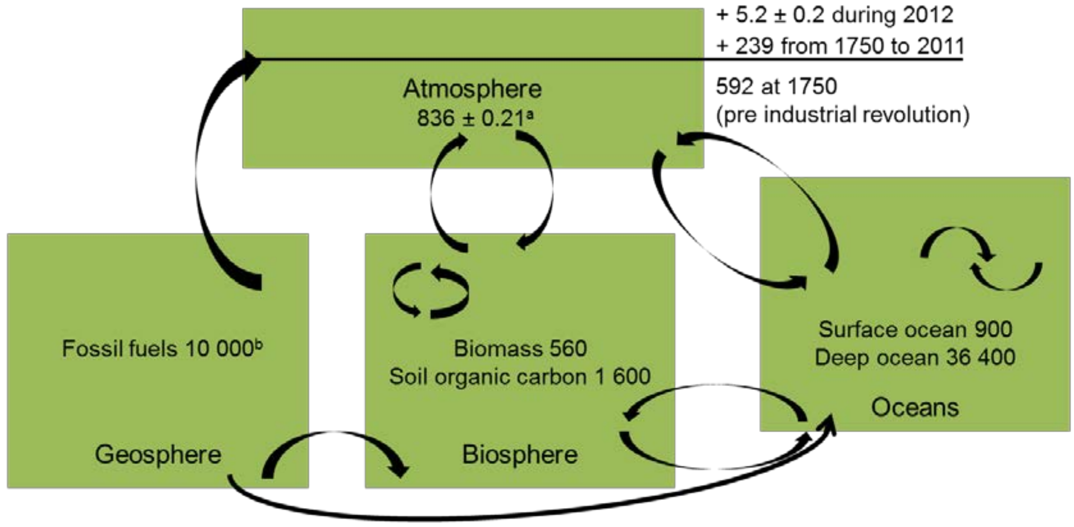
To summarise: objectives are focussed to stocks whilst the means to the end is via flows. Decision makers use both sets of interconnected information.

1.3 Global carbon cycle

Carbon flows through and within the reservoirs where carbon is stored in the geosphere, the biosphere, the atmosphere and the oceans. Globally, the carbon cycle is a closed system: the amount of carbon is fixed and so accumulations in one reservoir mean reductions in another. Natural processes, which may occur over very long periods of time, and human activity over relatively shorter periods of time work to change the size of the carbon stocks in the different reservoirs. An aggregated portrayal of the stocks and flows making up the global carbon cycle is presented in Figure 1. The stocks are represented by the green boxes. The carbon stocks in the different reservoirs can be scaled relative to the stock in the atmosphere by maintaining the size of the box representing the atmospheric stock of carbon whilst increasing the ocean box 45 times; the fossil fuels in the geosphere box 12 times (and by orders of magnitude to include carbon in methane clathrates, carbonate rocks, the Earth's crust and marine sediments); and biomass and soil carbon in the biosphere 3 times. The flows (within and between the stocks) created by human and non-human activity are depicted by the black arrows. They make up the global carbon cycle.

Figure 1 The global carbon cycle and carbon stocks**.**

All figures are billion tonnes (gigatonnes) carbon



a. Atmospheric CO_2 reported in parts per million (ppm) was converted to tonnes C using Carbon Dioxide Information Analysis Centre (n.d.).
b. For carbon stocks in soil inorganic carbon, methane clathrates, carbonate rocks, marine sediments and Earth's crust, see Ajani *et al.* 2013, Figure 1 and cited references.

Source: Prepared using Global Carbon Project; Holmém 2000; Lal 2004.

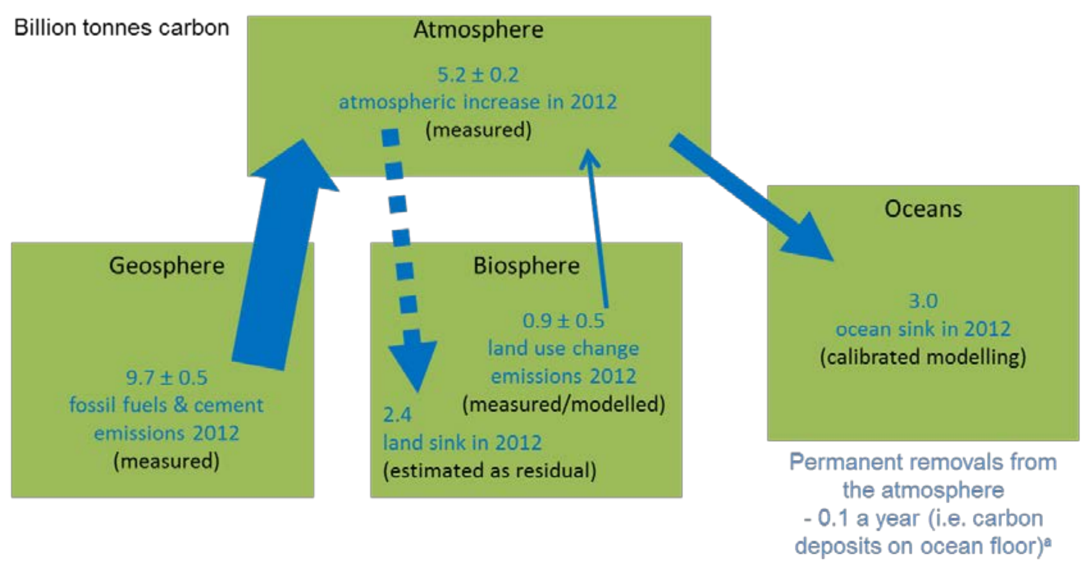
The carbon flows between the reservoirs over 2012 are depicted by the blue arrows in Figure 2. These arrows are to scale. Standard errors are presented where this information is available.

Globally, an estimated 9.7 ± 0.5 billion tonnes of carbon was emitted into the atmosphere from fossil fuel combustion and cement production during 2012. Reported emissions from land use change – principally deforestation – generated additional emissions of an estimated 0.9 ± 0.5 billion tonnes of carbon. These human perturbations, combined with flows generated from previous human and non-human activity, saw the carbon stocks in the atmosphere and oceans increase by 5.2 ± 0.2 billion tonnes and 3.0 billion tonnes respectively over 2012. The dotted blue line represents unreported biocarbon flows that are estimated as a residual sink of 2.4 billion tonnes (discussed in Section 1.4.3).

The essence of the climate change problem is that permanent removals from the atmosphere as carbon deposits on the ocean floor are not sufficient to neutralise fossil fuel stock losses which are not recoverable on a human time scale (Archer *et al*. 2009; Feely *et al*. 2004). Much of the fossil fuel emissions that find their way into the biosphere and oceans are stored there only temporarily: only an estimated 0.1 billion tonnes of C a year is removed permanently as ocean sediments (Feely *et al*. 2004), representing only 1.9 per cent of the current (2012) annual increase in atmospheric concentrations.

It is possible to recapture lost carbon stocks due to past land practices, although there are limits because of competing human demands for land and water for food production, settlements and infrastructure and because of permanent degradation of some ecosystems including their soil. A limit also exists on the biosphere's capacity to absorb the carbon stock changes from fossil fuel combustion. This is over and above the temporal issue of substituting highly stable carbon stocks in fossil fuel reserves with less stable and shorter-lived carbon stocks in the biosphere.

Figure 2 Global carbon flows, decoupling and climate system inertia**.**



a. Estimated by Freely *et al*. 2004 as a long term annual average.

Source: Prepared using Global Carbon Project; Houghton 2007; Archer *et al*. 2009; Feely *et al*. 2004.

1.4 Uses for carbon stock accounting and information

The uses for carbon stock accounting divide into two groupings: (1) as a system providing information, and (2) as an opportunity to enhance information quality through the process of building a comprehensive stock and flow accounting framework and populating it.

1.4.1 Information

Irrespective of what the system is, data users be they policy makers, researchers or the interested public need both stock and flow information because objectives are focussed to stocks whilst the means to the end is via flows.

Australia reports greenhouse gas flow information to meet our United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol commitments. As set out in detail in this discussion paper, DoE collects and generates a significant amount of stock information to help prepare these reports. Although gaps exist in the stock information and its assemblage for public availability is underdeveloped, this information provides an important platform for Australia to build a comprehensive and integrated carbon stock and flow accounting framework. Making the decision to invest is heavily dependent on the usefulness of carbon stock information and the nature of the accounting framework.

Supporting Government policy implementation – climate change mitigation policy

The Australian Government's Emissions Reduction Fund aims to address climate change and improve the environment by rewarding abatement at the lowest cost (Australian Government 2013f). A diverse range of competing abatement actions in both the energy and land/marine sector exists as does a capped budget of $2.55 billion over the forward estimates period. Comprehensive carbon stock and flow information can support Government policy both over the shorter term (i.e. focussed to meeting our emissions reduction target by 2020) and longer term. It can do this by providing comparable information on carbon stocks in fossil fuels and all ecosystems and land uses across Australia's land and marine scape. Scenario analysis can be used to examine policy options expressed as stock changes over periods of time and by linkage with economic information, the economic and employment impacts of these options can be estimated.

Information about carbon stocks in Australia's terrestrial and marine ecosystems today can be combined with information about their carbon carrying capacity (a stock) to help Government shape priorities for the long term storage of carbon in the land and marine sector in biomass and soils. If a spatially fixed statistical unit is adopted (discussed in Section 2.2), the Government can be supported with information to better understand the implications of different abatement options for Australia's agricultural land and water assets.

The economic and employment implications of the array of choices available through Direct Action, including in the energy sector, can be investigated with the linking of carbon stock and flow accounts to Australia's economic accounts.

Adding value to carbon stock and flow information by linking with economic statistics

The carbon stock accounting framework developed within the UN Statistics Division's *SEEA* (*System of Environmental-Economic Accounting*) (discussed in Section 5) is compatible with the *System of National Accounts* (*SNA*) which is used to prepare Australia's economic statistics. This compatibility exists because the UN Statistics Division oversees the development and refinement of both the *SNA* and the *SEEA* and promotes the development of common concepts, classifications and methods. Linked carbon and economic accounts will enhance the quality of Australia's economic research, including into the economic and employment effects of climate change policy options and the application of input-output analysis.

Public understanding

The ultimate objective of the UNFCCC is expressed in stock terms: to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (United Nations 1992, Article 2). It makes sense for countries to generate and report information consistent with this objective, i.e. to report stocks together with flows. Stock information should help public understanding of the climate change challenge because of its direct connection to objectives: analogous to our everyday experiences such as the size of our bank balance and amount of food in the fridge. Comparable information about carbon stocks in the different reservoirs of geocarbon and biocarbon will also help public discussion about priorities for climate change mitigation and the inevitable trade-off decisions.

Soil organic carbon

Interest in carbon stock information is not all about climate change. Agronomers with their focus on food production have a long-standing interest in soil organic carbon levels as a soil health measure and tracking soil erosion risk. Historically, State governments through their soil conservation agencies collected information on carbon stocks in agricultural soils but this service ended with changed funding and institutional arrangements between the Commonwealth and States. Carbon stock accounting creates an opportunity to revisit the provision of soil carbon information to support Australian agriculture.

1.4.2 Benefits for information providers

The information systems developed to support Australia's UNFCCC and Kyoto Protocol reporting commitments using IPCC guidelines are focussed to flows because the increase in atmospheric stocks of greenhouse gases is caused by human-generated exchanges of greenhouse gases from the geosphere (mainly fossil fuels and limestone) and the biosphere (biomass and soils). Scientific attention is focussed to measuring these flows. In generating this information under these reporting arrangements, three things are notable: (1) the demands on the information providers (in Australia's case, DoE) escalate with each global negotiation leading to changed reporting requirements and therefore new information collection/estimation tasks, (2) the substantial amount of stock information that exists within the information systems developed by DoE to help generate the flow information, and (3) the increasing demand for stock information (e.g. for climate change mitigation policy). With these experiences, DoE is building comprehensiveness into its information systems to meet multiple user needs, including Australia's UNFCCC and Kyoto Protocol reporting commitments.

Carbon stock accounting can help DoE keep order as they measure/estimate and report on a system more complicated and bigger than our economy (the *SNA* is a linked series of stock and flow accounts). DoE has already moved into a stock and flow model approach, most notably in the land sector (discussed in Section 6) but also for fossil fuel resources for example to net out non-energy uses of coal, oil and gas from Australian energy production statistics to estimate emissions from fossil fuel combustion (discussed in Section 6.1). This approach also assists information quality checks because the flows into and out of a stock must equal the stock changes over a defined time period.

Investing in a comprehensive and integrated carbon stock and flow accounting system is a decision yet to be made. With the features of comprehensiveness, linkage to economic statistics and a spatially fixed statistical unit (all discussed below), Australia's diverse information needs would be well met. DoE, as information supplier, would have an ordered and complete accounting framework to provide this service over time using a framework with the potential for an inbuilt quality check.

1.4.3 Improving current data and information

Carbon stock accounting at the country level could help address current information gaps at the global level. Information on ocean carbon stocks and flows is derived through measurement and calibrated modelling (Global Carbon Project; Holmém 2000, Feely *et al*. 2004). In contrast, carbon stock and flow information concerning the biosphere is highly deficient. Flows have been estimated as a residual item, taking advantage of the fact that the global carbon cycle is a closed system and therefore must 'balance'. The residual item is large, approximately equal to half the increase in atmospheric concentration of carbon in 2012 (Figure 2 on page 8). Houghton (2007) points out that the practice of calculating the flows for the biosphere as a residual could mask errors in measuring carbon stock changes for the land sector or in the ocean modelling. Furthermore, although the residual item is in aggregate a large sink, it may mask substantial emissions or removals in any or all reservoirs by anthropogenic or non-anthropogenic drivers that cancel out.

2 MAPPING AUSTRALIA'S CARBON STOCKS AND FLOWS AND OTHER PRELIMINARIES

2.1 Mapping Australia's carbon stocks and flows

In Figure 3 we aim to present a complete mapping of Australia's stocks and flows of carbon. The stocks, represented by boxes, are connected by processes that generate the flows of carbon, represented by arrowed lines. The flows of carbon are mostly in the form of CO_2, but also occur as CH_4, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs): mentioned here for completeness and discussed further in Section 8.

We have presented the map at this early stage to help ground the discussion about statistical units and reporting units: crucial issues that need to be considered early as they influence the structure of the account. A detailed discussion of the classification system and terminology is presented in Section 3 and a glossary is presented in Appendix A.

In the mapping, stocks have been classified as follows:

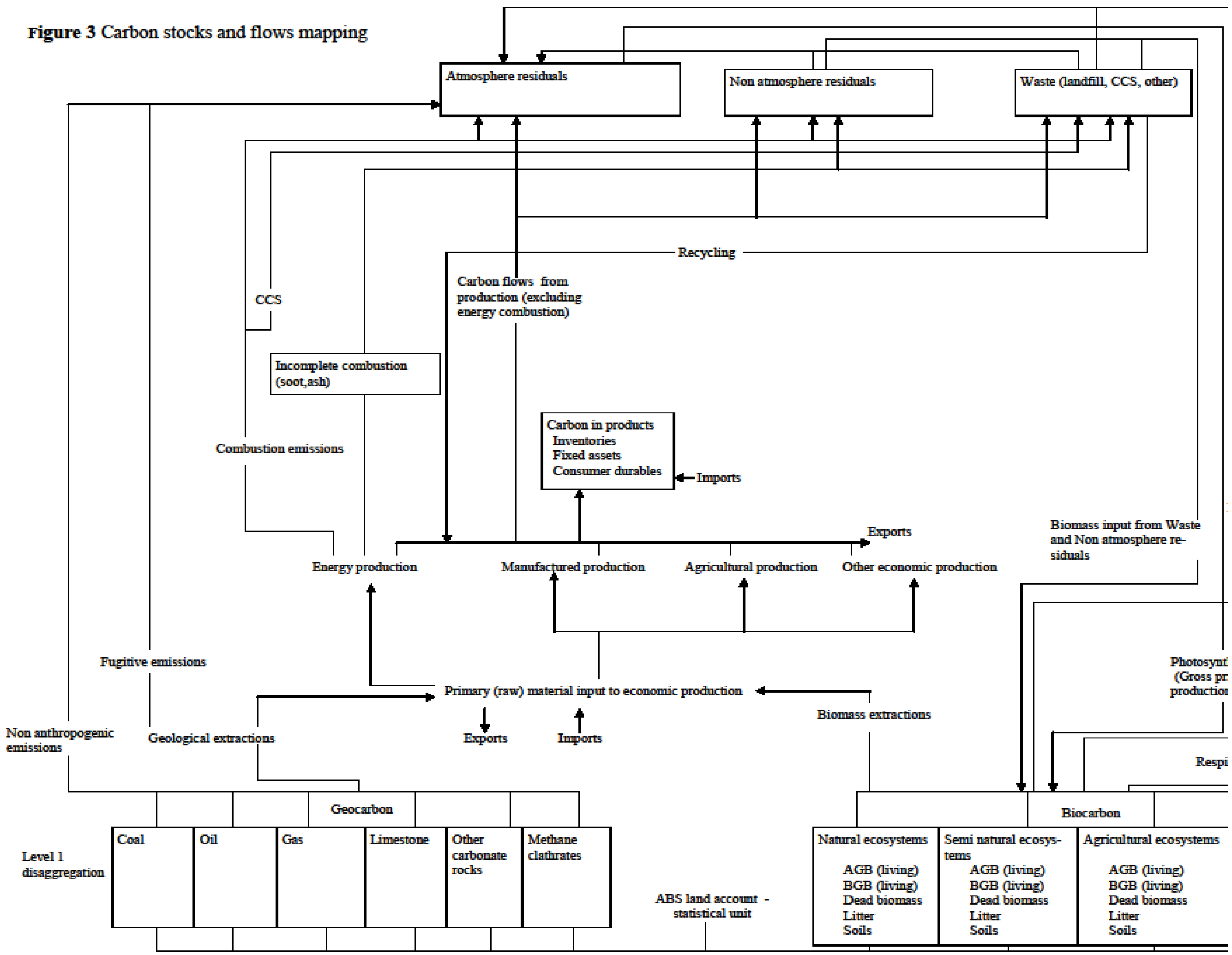
A. Primary reservoirs
   a. Geocarbon – carbon in the geosphere
      i. Coal
      ii. Oil
      iii. Gas
      iv. Limestone
      v. Other carbonate rocks
      vi. Methane clathrates
      vii. Other
   b. Biocarbon – carbon in the biosphere
      i. Natural ecosystems
      ii. Semi-natural ecosystems
      iii. Agricultural ecosystems
      iv. Human settlements
      v. Other
B. Accumulation in economy
   a. Inventories
   b. Fixed assets
   c. Consumer durables
   d. Waste
C. Residuals
   a. Atmosphere
   b. Other

For carbon stock accounting purposes, the primary reservoirs in the geosphere and biosphere are the most important. The release of carbon by human activity from primary reservoirs is the primary cause of global warming. The primary reservoirs, presented in Figure 3, are a full articulation of the carbon stocks in the geosphere and biosphere. Whilst 'built in from the start' comprehensiveness in the framework is highly desirable from a statistical accounting perspective, this does not mean that all stocks should be or need to be reported. The purpose of the statistics and resources available for information collection and reporting will determine coverage and priorities. We can expect, for example, a low need for statistics about carbon in carbonate rocks other than limestone. But if this changes, comprehensiveness in the accounting framework will accommodate such shifting preferences.

DoE's National Carbon Balance (see Australian Government 2014c, Annex 6) aligns with a comprehensive mapping Australia's carbon stocks and flows. Australia's National Carbon Balance records the amount of carbon from prioritised activity entering the economy and tracks the movement of that carbon into the atmosphere as greenhouse emissions, increments to the stock of carbon in products and increments to the stock of carbon in waste (discussed further in Section 7). DoE also uses the National Carbon Balance for quality control.

Before developing the carbon stock classifications into a finer disaggregation, we need to consider the statistical unit and reporting unit.

Figure 3 Carbon stocks and flows mapping



2.2 Statistical units

Statistical units are the entities about which data is sought, collected and subsequently aggregated in meaningful ways. The statistical unit could be, for example, a spatially fixed unit, a land cover/land type unit or an institutional unit. The *SEEA Experimental Ecosystem Accounting* (*SEEA EEA*) discusses the importance of choosing the statistical unit prudently and the challenges for land sector or environmental accounting (European Commission *et al*. 2013 Section 2.3).

The primary reservoirs of carbon in the geosphere and biosphere are spatially located. Maps locate Australia's primary fossil fuel reserves and limestone deposits. Information about Australia's ecosystems (natural, agricultural and other) whilst collected at varying scales using varying methods (for example remote sensing, on ground assessment, surveys of land owners and administrative data) is also largely spatially based. If meaningful information is gained by connecting the reporting of carbon stocks in these reservoirs to a spatial reference, then a spatially fixed statistical unit has merit. For example, the potential for carbon accumulation in degraded rangeland ecosystems is likely to vary spatially (reflecting differences in landscape and weather) as may the carbon density of Australia's coal and crude oil resources (reflecting different environmental histories).

How the carbon stock account statistical unit is settled will determine whether other statistics relating to different fields can be linked to provide more useful information. This includes opportunities to link carbon accounts to ecosystem information systems (e.g. biodiversity) and also economic information. The statistical units used to report Australia's economic information are institutional units: the various establishments, enterprises, government, and household entities. For example, in business statistics the individual factories making products are the statistical unit but these are aggregated together to form the manufacturing industry. Information at the aggregate industry level is available for valued added, sales, employment, etc. but not for the individual factories.

Australia's economic information system is built on a statistical unit that links institutions to the product and industry classifications. A spatial statistical unit does not underpin Australia's economic information, but with some investment, it could. The ABS is investigating the potential to develop a spatially based statistical unit on which to pin social, environmental and economic information. The ABS is currently geocoding the Business Register and working through the challenges from there not being a one to one relationship of business units to spatial area. One business can operate in several areas, while one area can be used by many businesses. Information needs to be untangled in time and space.

In the absence of spatial criteria in the statistical unit, some mechanism will be required to connect human-generated and spatially referenced geocarbon and biocarbon stock changes to the product and industry classifications used in Accumulations in economy. This is discussed further in Section 8.

1. **How can information from businesses be linked to spatial areas for carbon accounting?**

2. **What resources are required to develop and implement a spatial statistical unit for carbon accounting?**

Geographic and institutional coverage

Populating a carbon stock account for Australia also requires defining the geographic coverage of the account. In terms of geographic coverage, the ABS defines the Australian territory as land under the effective control of Australian governments. This includes islands belonging to Australia which are subject to the same fiscal and monetary authorities as the mainland; the land area, airspace, territorial waters, and continental shelf lying in international waters over which Australia enjoys exclusive rights or over which it has, or claims to have, jurisdiction in respect of the right to fish or to exploit fuels or minerals below the sea bed; and territorial enclaves in the rest of the world. Using this definition, the economic territory of Australia consists of geographic Australia including Cocos (Keeling) Islands and Christmas Island, Norfolk Island, Australian Antarctic Territory, Heard Island and McDonald Islands, Territory of Ashmore Reef and Cartier Island and Coral Sea Islands.

Australia's National (greenhouse) Inventory Report prepared to meet our obligations under the UNFCCC and Kyoto Protocol, covers the States, mainland territories and associated coastal islands. The Report also includes the emissions from the external territories of Norfolk Island, Christmas Island, Cocos Island and Herd and McDonald Islands and Australia's Antarctic Program operations as well as the Coral Sea Islands (Qld) and Ashmore and Cartier Islands (NT). For external territories, the coverage of greenhouse gas emissions and removals is for fuel combustion, waste and HFC associated with refrigeration.

Preparing a carbon stock account for Australia requires a decision about the treatment of the Timor Sea Joint Petroleum Development Area where both Australia and East Timor claim full sovereignty.

3. **What geographic area definition should Australia adopt for carbon stock accounting?**

4. **What principles should be used to account for carbon stocks in the JPDA?**

Linking geocarbon and biocarbon stocks and stock changes to the economy (Accumulation in economy) requires an institutional unit. The ABS uses a resident institutional unit to record Australia's economic activity and wealth. Activity is tagged to that country with which the institution has the strongest connection. In contrast, Australia's reporting of covered greenhouse gas emissions and removals is done on a national territory basis irrespective of institutional residency.

5. **How can the different approaches to residency be reconciled?**

2.3 Reporting unit

In choosing the reporting unit for Australia's carbon stock account we should consider jointly the needs of information users, the scale and quality of the information used to populate the account, and the reporting units of associated information systems. These considerations comprise:

- Australia's geocarbon stocks will be large relative to our biocarbon stocks which in turn will be large relative to biocarbon stock changes. Given the policy, researcher and public interest in biocarbon stock changes (for e.g., the change in the amount of carbon stored in mallee woodlands and shrublands as a result of changed land use; the carbon stock losses resulting from forest fires and the subsequent stock recovery; the carbon stock changes in agricultural soils from changed management practices), a reporting unit of million/mega tonnes may be appropriate.
- DoE in our *National Inventory Report*, reports in millions of tonnes of CO_2 but reports annual emissions in gigagrams (1000 tonnes) in the accompanying Common Reporting Format (CRF) tables prepared under IPCC guidelines.

- Whilst Australia uses the scientific International System of Units (SI) to report our greenhouse gas emissions, we use non-scientific everyday language of thousands, millions and billions to report social and economic information. (A schedule of units is presented in Appendix B.)

6. What is the appropriate unit for reporting Australia's carbon stocks?

7. Should the information be reported in scientific units or everyday language?

2.4 Reporting year and frequency

1990 is the base year for Australia's reporting of greenhouse gas emissions under the Kyoto Protocol. Relevant questions about the first carbon stock reporting year and reporting frequency are presented below but making a decision requires more consideration of the nature of the reservoirs, their natural variability and cost of information collection and generation as discussed later in the paper.

The fiscal year ending 30 June is used in the *National Inventory Report* consistent with data sources from the National Greenhouse and Energy Reporting (NGER) system and mineral and agricultural statistics from the ABS and ABARES. However Land Use, Land-Use Change and Forestry (LULUCF) flows are produced on a calendar year basis. Australia's national economic accounts work to a fiscal year but much information is reported quarterly thereby enabling information users to work with fiscal or calendar year information. DoE has also developed quarterly Kyoto protocol reporting and now produces *Quarterly Updates of Australia's National Greenhouse Gas Inventory* that present preliminary estimates updated on a quarterly basis.

8. What year should Australia commence reporting carbon stocks?

9. How frequently should Australia's carbon stocks be reported?

10. If fiscal years are used, how should biocarbon stocks be included in the national aggregation?

3 CARBON RESERVOIR CLASSIFICATION SYSTEM

3.1 Criteria for classifying primary reservoirs

Generating meaningful information requires classification systems grounded in a scientifically, economically or socially coherent framework, depending on the nature of the system being reported. Science should inform the classifications for the primary carbon reservoirs of geocarbon and biocarbon. These reservoirs differ fundamentally in the amount and stability of their carbon stocks and the reversibility of stock losses: that is whether the stock can be restored and over what time period (a full discussion is included in Sections 3.2 and 3.3). When disturbed by human activities, the different primary reservoirs will therefore influence the climate to differing degrees (Prentice 2007). Capturing these qualitative differences in the reservoir classification system is fundamental for data users seeking carbon stock information for climate change policy, research and public understanding.

Using the reservoir definitions presented immediately below (Section 3.2 and 3.3), reservoir types can be classified against the criteria of stability, restoration time and carbon density as presented in Table 1. Australia's rangelands merit special comment. Large areas still function as natural ecosystems with their largely undamaged canopies: their carbon densities (t C/ha) are relatively low but rangeland carbon stocks in total are significant because the rangelands account for most of Australia's land area.

Table 1 Criteria for classifying primary reservoirs of geocarbon and biocarbon**.**

Reservoir		Criteria		
		Stability	Restoration Time	Carbon Density
Geocarbon		High	Geological	High
Biocarbon	Natural ecosystems	High – moderate	Decades to millennia	High
	Semi-natural ecosystems	Moderate	Years to centuries	Potentially high
	Agricultural systems	Low	Annual to decades	Low - moderate

Source: Ajani *et al*. 2013.

11. Are the criteria for classifying primary reservoirs scientifically robust and complete?

3.2 Geocarbon classifications

Without human intervention, geocarbon reservoirs are generally stable and inert (fugitive emissions from gas deposits and volcanic activity are exceptions). Stock losses from geocarbon reservoirs are effectively irreversible over time scales relevant to climate change and human society. Australia's fossil fuels will be the most important in the geocarbon classification. Geoscience Australia reports Australia's fossil fuel resources in the form of coal, oil and gas.

12. **Does the first level disaggregation into Coal, Oil and Gas provide a complete coverage of Australia's fossil fuel resources in the geocarbon reservoirs?**

Coal

Because the carbon density of coal varies markedly across lignite (brown coal), sub-bituminous coal, bituminous coal and anthracite, a classification system that disaggregates coal into these four groupings is meaningful. Geoscience Australia reports Australian reserves of brown coal but does not report separately the reserves of the three types of black coal.

13. **Is it important from the perspective of data quality and information use to disaggregate black coal into sub-bituminous coal, bituminous coal and anthracite?**

14. **Would a spatial statistical unit be helpful in reporting carbon stocks for each coal type?**

Oil

Oil encompasses the range of liquid hydrocarbons and includes Crude oil, Condensate and the less thermally matured Shale oil. Geoscience Australia defines Crude oil as a naturally-occurring liquid consisting mainly of hydrocarbons derived from the thermal and chemical alteration of organic matter buried in sedimentary basins. It is formed as organic-rich rocks are buried and heated over geological time. The weight and therefore carbon density of crude oil varies between deposit sites. Geoscience Australia defines Condensate as a liquid mixture of pentane and heavier hydrocarbons found in oil fields with associated gas or in gas fields. It is a gas in the subsurface reservoir, but condenses to form a liquid when produced and brought to the surface. Condensates are liquid hydrocarbons somewhere between crude oil and natural gas liquids (NGL). There are various types of condensates. Typically, 'condensates' refers to lease condensates, so described because they are produced at the lease level from oil or gas wells. These condensates can be produced along with significant volumes of natural gas and are typically recovered at atmospheric temperatures and pressures from the wellhead gas production. These "raw" condensates leave the earth as mixtures of various hydrocarbon compounds including NGLs, pentanes (C_5s, so called because they have five carbon atoms), C_6s (hexanes), and depending on the condensate, a menagerie of heavier hydrocarbons in the C_7, C_8 and even heavier range. A lease condensate has an API gravity ranging between 45 to 75 degrees. Those with a high API contain many NGLs (including ethane, propane and butane) and not many of the heavier hydrocarbons. These condensates are clear or translucent in colour. The condensates with a lower API gravity, down at the 45 degree level, look more like crude oil (black or near black) and have much higher concentrations of the heavier C_7, C_8 and heavier compounds (Braziel 2012). Natural gas condensate has a specific gravity that varies somewhat, and may contain a range of elements and compounds, particularly liquid methane (the major constituent of natural gas).

Oil shale is a fine-grained sedimentary rock containing large amounts of organic matter (kerogen), potentially yielding substantial quantities of hydrocarbons. Oil shale is essentially a petroleum source rock which has not undergone the complete thermal maturation required to convert organic matter to oil. Also, the further geological processes of hydrocarbon migration and accumulation which produce conventional crude oil resources trapped in subsurface reservoirs has not yet occurred. The unconventional shale oil resource can be transformed into liquid hydrocarbons by mining, crushing, heating, processing (i.e. 'retorting') and refining, or by *in situ* heating, oil extraction and refining.

Gas

Australia's Gas reserves comprise naturally-occurring Liquid petroleum gas (LPG) and Natural gas. Geoscience Australia reports LPG that occurs naturally in crude oil and natural gas production fields. It is a 'wet' conventional gas made up of the 'wet gas' components ethane, propane, butanes and condensate (Geoscience Australia n.d.). Natural gas is a combustible mixture of hydrocarbon gases. It consists mainly of methane (CH_4), with varying levels of heavier hydrocarbons and other gases such as carbon dioxide. Natural gas is formed by the alteration of organic matter either through biogenic or thermogenic processes. Biogenic gas is created by methanogenic organisms in marshes, bogs, and shallow sediments. Deeper in the earth, at greater temperature and pressure, thermogenic gas is created from buried organic material (US Energy Information Administration n.d.). When accumulated in a subsurface reservoir and extracted, this gas is known as conventional gas (Geoscience Australia n.d.).

The following questions should be considered together with the discussion on methods (Section 4.2).

15. Given the variation in material composition and carbon density in Australia's oil and gas fields and the reality of joint product extraction, is a meaningful and useful classification for oil and gas possible?

16. If a spatial statistical unit was adopted, would the resultant data collected by basin be a useful approach to addressing the carbon density variations in Australia's oil and gas reserves?

Carbonate rocks

Carbonate rocks are also mined and used in economic production, notably limestone for cement.

17. Should Australia report stocks and stock changes for carbonate rocks? If so which ones, when and what data sources will be useful?

Indirect impacts

Fossil fuels and limestone deposits used for cement production will comprise most, perhaps all, of the geocarbon entries in a national carbon stock account. The indirect impacts of human intervention that alter climate conditions, such as warming of the permafrost, may generate changes in other geocarbon reservoirs.

18. Is it appropriate for Australia to report stocks and stock changes for geocarbon reservoirs that may be indirectly affected by climate change? If so, what criteria should be used to inform the classification? And what data are available to help populate the account?

3.3 Biocarbon classifications

Biocarbon reservoirs are spatially located in terrestrial, fresh water and marine ecosystems. These reservoirs contain carbon in biomass (plants and animals) and soil organic matter. Biocarbon reservoirs can be meaningfully classified using the criteria applied to the geocarbon reservoirs of stock stability, restoration time and density. Where systems are connected (e.g. the biosphere and geosphere through the global carbon cycle) consistency in criteria for the classification system is important for information users.

It is the interaction of environmental and human land use factors that determines the stability of biocarbon stocks and here an ecosystem type (natural, semi-natural, agricultural, other) classification is scientifically meaningful. However, words such as 'natural' and 'agricultural' can have vastly different meanings for different cultures. *SEEA EEA* (A4.5) notes that the key attribute that distinguishes natural from semi-natural and agricultural ecosystems is the mechanism of 'management'. Whether an ecosystem is 'managed' by natural and ongoing evolutionary and ecological processes or is human maintained will largely determine its carbon stock stability, restoration time and density.

SEEA EEA (A4.5) defines the different ecosystem types as follows:

Natural ecosystems: largely the product of natural and ongoing evolutionary, ecological and biological processes. The key mechanism of 'management' in natural ecosystems is natural selection operating on populations of species which has the effect over time of optimising system level properties and the traits of component species. System-level properties which are naturally optimised with respect to, among other things, environmental conditions include canopy density, energy use, nutrient cycling, resilience, and adaptive capacity. Natural processes dominate natural ecosystems within which human cultural and traditional uses also occur. Natural ecosystems include terrestrial and marine ecosystems.

Semi natural ecosystems: human modified natural ecosystems. Natural processes, including regenerative processes, are still in operation to varying degrees. However, the system is often prevented from reaching ecological maturity or is maintained in a degraded state due to human disturbance and land use. Thus, the vegetation structure may not reflect natural optima, and the taxonomic composition may be depauperate.

Agricultural ecosystems: human designed, engineered and maintained systems on agricultural lands that grow animals and crops mainly for food, wood and fibre and as feedstocks for biofuels and other materials. Plantations of trees for timber or fruit production (e.g. orchards) are included in the agricultural ecosystem.

Other ecosystems: including settlements and land with infrastructure.

For natural ecosystems, biodiversity supports the stability of biocarbon stocks by conferring resilience, and the capacity for adaptation and self-regeneration (Secretariat of the Convention on Biological Diversity 2009). The biocarbon stocks of natural ecosystems are in a dynamic equilibrium and relatively stable over long time periods. However, losses from mature natural ecosystems may only be recoverable over centuries to millennia (Righelato and Spracklen 2007) and in some cases are not completely recoverable (Lindenmayer *et al*. 2011). Semi-modified and highly modified ecosystems are likely to be less resilient and less stable (Thompson *et al*. 2009). On the criterion of reversibility, biocarbon stock losses are in principle recoverable to the extent permitted by land management and prevailing environmental conditions. On the criterion of carbon density, the current biocarbon stock is influenced by the degree of ecosystem disturbance as well as vegetation and soil condition compared to its carbon carrying capacity (see Appendix A for definition). Under common conditions, natural ecosystems have larger carbon stocks per unit area than agricultural systems and semi-natural ecosystems.

SEEA EEA (para 4.94) notes that carbon accounting and ecosystem accounting more generally should take these qualitative differences between the different stores of carbon into account. However with there being no internationally agreed classification of ecosystems, the document notes (A4.5) the desirability to recognise varying degrees of human modification of the ecosystem and to introduce these aspects into a classification.

19. **Should the following ecosystem classification type be adopted for the carbon stock account:**
    - **Natural ecosystem**
    - **Semi-natural ecosystem**
    - **Agricultural ecosystem**
    - **Other ecosystems (settlements, land with infrastructure, other)?**

20. **Are the *SEEA EEA* ecosystem type definitions appropriate?**

Ecosystem types can be further disaggregated, with for example agricultural ecosystems disaggregated into irrigated agriculture, dryland grazing and cropping, plantation wood etc. and natural ecosystems further disaggregated for example into grasslands, shrublands, open forests, closed forests, wood lands, marine ecosystems etc. Questions about disaggregation follow the methods discussion in Section 4.3.

Ecosystem carbon stocks can then be further disaggregated into carbon pools using the same criteria of stability, restoration time and density. Generically, these pools at their first level of disaggregation comprise:

- Above ground living biomass
- Below ground living biomass
- Above ground dead biomass
- Below ground dead biomass
- Soil

Stock losses from short-lived pools such as leaves and litter are quickly reversible and of less significance from a climate perspective than an equivalent amount of carbon lost from long-lived pools such as the woody stems of trees and soil.

21. **What classification should be used for the carbon pools?**

It may be valuable to incorporate other characteristics that influence a reservoir's stability and longevity. For example, remnant natural vegetation in a largely cleared landscape could be considered more at risk from land use impacts relative to a comparable area embedded within an intact natural landscape. From the perspective of maintaining carbon stocks, the intact natural landscape would be prioritised for protection.

22. **Is there a demand for such information from a carbon stock account? If so, how can the accounting system be developed to provide it, for example, through a spatial statistical unit?**

3.4 Accumulation in economy

Accumulation in economy are the stocks of carbon in products made through economic activity. They can be disaggregated into the *SNA* components: Fixed assets (e.g. concrete in buildings, bitumen in roads); Inventories (e.g. petroleum products in storage); Consumer durables (e.g. wood and plastic products); and Waste.

Boundary setting decisions are required to avoid double counting. This is particularly relevant for carbon in agricultural ecosystems: for example wood grown in plantations where inventories of wood in standing plantations are recorded in the *ASNA* (Australian *SNA*) but would also be recorded as biocarbon in agricultural ecosystems in a carbon stock account. Boundary decisions do not result in loss of information. *SEEA EEA* (footnote to table 4.5) makes the boundary decision to report all carbon stocks in agricultural ecosystems (e.g. plantations for wood, orchards and livestock) in biocarbon, and not in Accumulations in economy. For geocarbon, the boundary decision is the point before reservoirs containing geocarbon are mined.

23. What products require boundary decisions to avoid double counting in the primary reservoirs and Accumulations in economy? How should they be reconciled?

The level at which geocarbon and biocarbon stock changes are linked to the economy will affect the policy usefulness of the carbon stock account. This is particularly relevant in cases where raw materials can be extracted from more than one ecosystem type (e.g. wood from natural ecosystems or agricultural ecosystems; meat from agricultural ecosystems or semi-natural ecosystems) or from geocarbon reservoirs with different carbon contents and emissions profiles.

24. Are there products that cross ecosystem types or geocarbon types that should be kept disaggregated when carbon stock changes in the primary reservoirs are linked to Accumulations in economy?

The *SNA* and *SEEA Central Framework* treat waste products from economic activities (e.g. discarded concrete, paper products and plastic) that are disposed in controlled land fill sites as part of the economy. *SEEA EEA* (A4.8) adopts this approach to account for carbon stored through geosequestration. Stocks of carbon created by managed injecting of CO_2 into the geosphere are treated as part of the waste sector of the economy.

Importing and exporting of products can generate carbon stock changes in Accumulations in economy be they Inventories, Fixed assets or Consumer durables. With minor exceptions (e.g. live botanical specimens), neither importing nor exporting directly changes Australia's geocarbon or biocarbon stocks as defined.

25. What is the priority in Australia's carbon stock account for reporting stocks and stock changes in Accumulations in the economy?

26. Are there particular products that should receive reporting priority?

3.5 Residuals

Residuals are the direct flows of carbon from the biosphere or geosphere to the atmosphere and the indirect flows via the economy (Figure 3 on page 14). They may be in the form of CO_2, CH_4, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs). The direct flows from the geosphere are effectively one way and therefore relatively easy to treat. Accounting for the residuals from the biosphere are significantly more complicated because each land unit/ecosystem type generates flows of emissions through respiration and removals through photosynthesis, concurrently. The following ecosystem flow definitions and accounting identities are relevant:

- Gross primary production (GPP) = annual amount of carbon uptake by photosynthesis.
- Net primary production (NPP) = GPP - respiration by plants (autotrophic respiration). This carbon is used to produce new biomass.
- Net ecosystem exchange (NEE) = NPP - respiration by herbivores and micro-organisms that consume biomass (heterotrophic respiration). The remaining carbon contributes to soil carbon accumulation.
- Net ecosystem production (NEP) = NEE - fire emissions.
- Net ecosystem balance (NEB) = NEP - biomass extractions + biomass input from waste and non-atmosphere residuals.

Under IPCC guidelines, Australia reports carbon flows for covered sectors in its annual *National Inventory Report* of greenhouse gases. The systems used to estimate net emissions are discussed in Section 7 together with their potential to populate a carbon stock account.

4 AUSTRALIA'S PRIMARY RESERVOIR CARBON STOCKS

4.1 Experimental exercise

Table 2 presents the results on an experimental exercise to estimate Australia's geocarbon stocks in fossil fuel reserves and biocarbon stocks. We had two aims in undertaking this experiment. The first was to use the learning experience to identify the tasks for building the detailed accounting framework and methods; to identify relevant researchers; and to identify and understand existing information sets and their capacity to help populate the account. The experimental exercise has informed the discussion and questions presented in this paper. The second aim was to present an indicative picture of Australia's stocks of carbon in fossil fuels and the land sector at a meaningful level of disaggregation to facilitate understanding about the uses for carbon stock information. We anticipate that potential information users will provide more focussed feedback to enable us to refine the methods for carbon stock accounting.

In generating the estimates, we have been alert to:

> The *SNA* and *SEEA Central Framework* principle of completeness (meaning for this exercise, covering all fossil fuel stocks and all biocarbon stocks in the Australian territory, including marine ecosystems);

> Testing the feasibility of adopting an ecosystem type classification (natural, semi-natural, agricultural and settlements) given the strength of its scientific underpinnings, its policy relevance and the encouragement of *SEEA EEA* to incorporate the reservoir qualitative differences in the accounting framework;

> The potential for using the information systems and models DoE has developed to report on greenhouse gas flows to populate the stock account; and

> Identifying researchers who measure carbon stocks in natural or agricultural ecosystems in Australia and who have high knowledge about how their particular ecosystems function and the factors generating stock changes.

After Table 2, we present the methods used to estimate carbon in fossil fuels with the aim of seeking input from those with expertise to advance or refine the methods. The approach taken for the biocarbon stock follows.

Table 2 Estimated carbon stocks in Australia's primary reservoirs today (million tonnes C)[a]. An experimental exercise to generate an indicative picture to assist discussion about methods for regularly reporting carbon stocks and the usefulness of the information.

Primary reservoir	Geocarbon (Mt C)	Hectares (million)	Biomass carbon (Mt C)	Soil organic carbon (Mt C)	Total biocarbon (Mt C)
Geocarbon					
Fossil fuel					
Black coal	97,400				
Brown coal	58,100				
Crude oil[b]	145				
LPG[c]	90				
Natural gas	1,559				
Shale oil	82,287				
Total fossil fuel	**239,581**				
Carbonate rocks					
Limestone	n.r.				
Other carbonate rocks	n.r.				
Total carbonate rocks	n.r.				
Other (includes methane clathrates)	n.r.				
Biocarbon					
Natural ecosystems					
Rangelands		596.3	6,374	6,603	12,977
Non rangelands:					
Eucalypt native forests		16.7	4,671	3,753	8,424
Shrub lands & woodlands		14.7	500	636	1,137
Grass, shrub & heath lands		1.6	37	51	87
Rainforests		2.3	1,225	252	1,477
Other		0.7	15	16	32
Marine ecosystems		1.8	114	1,084	1,198
Fresh water ecosystems		9.9	4	7	11
Total Natural ecosystems		**644.0**	**12,941**	**12,402**	**25,343**
Semi-natural ecosystems					
Highly modified rangelands		50.0	750	1,500	2,250
Grazing in modified pastures outside rangelands		32.9	132	1,315	1,447
Total Semi-natural ecosystems		**82.9**	**882**	**2,815**	**3,697**
Agricultural ecosystems					
Cropping		25.5	102	1,022	1,124
Irrigated agriculture		2.6	12	105	117
Plantation wood		2.4	177	120	296
Reservoir/dam		0.6	1	6	7
Other		6.3	120	244	363
Total Agriculture ecosystems		**37.4**	**412**	**1,497**	**1,907**
Settlements		2.6	30	79	108
Other		0.5	7	19	26
Total Settlements and Other		**3.1**	**37**	**98**	**134**
Total biocarbon[d]		**767.4**	**14,270**	**16,811**	**31,081**

e. Coal estimates are for 30 June 2011. Oil and gas estimates are for 30 June 2009. Biocarbon estimates have been derived using various information sources mostly in the 2000s.
f. Includes naturally-occurring condensate.
g. Comprises LPG naturally occurring in crude and natural gas production fields.
h. Numbers do not add due to rounding.

4.2 Methods for geocarbon stock estimation

4.2.1 Overview

The geocarbon stock estimates are focussed to Australia's fossil fuel reserves: carbon in rocks, notably limestone deposits has not been estimated. The same basic methodology has been used to estimate the carbon content for all types of fossil fuel reserves. The first step involves estimation of physical quantities of various types of fossil fuels (billions of cubic metres, gigalitres etc.). We then convert these physical measures into a tonnes-equivalent, and finally we apply appropriate conversion factors for each type of fossil fuel in order to determine the carbon content by weight for each of these reserves.

27. Is this broad methodology the best approach to use, or should a different methodology be used in respect of some (or all) geocarbon?

4.2.2 Complete or limited reporting

It is currently not economically viable to exploit all of Australia's fossil fuel stocks. For example, Geoscience Australia data reveal the economic viability of extracting coal resources, following McKelvey Box principles and terminology i.e. economically demonstrated resources (EDR); sub-economic demonstrated resources (SDR); and inferred resources. That is, some stocks will only be extracted if market prices rise and/or production techniques generate relative cost reductions. Nevertheless, the estimates of carbon presented in Table 2 relate to all fossil fuel reserves in Australia and not just those that are currently rated as EDR. The broadest notion of geocarbon has been adopted here because this provides a comprehensive picture of the full potential for increased concentrations of greenhouse gas emissions in the atmosphere and oceans. Realistically, we can expect extraction techniques to improve and to become more cost effective. Similarly, we could reasonably expect products made from some fossil fuels to increase in price as their scarcity grows. The example of shale oil is a case in point: it has generally been considered an uneconomic source of energy production and the very large reserves of shale oil held by various countries have historically been classified as SDR. However, it is clear that the extraction techniques used in respect of shale oil have recently made dramatic improvements and it is possible that a significant portion of the world's reserves of shale oil will now be reclassified as EDR.

28. Do you agree that carbon contained in fossil fuel reserves should be estimated for all such reserves and not just those that are currently deemed economically feasible to exploit?

4.2.3 Estimating carbon in Australia's coal reserves

The broad methodology adopted involves extracting estimates of Australia's coal resources expressed in gigatonnes from *Australia's Identified Mineral Resources* produced by Geoscience Australia and applying conversion factors to derive the carbon content of these coal resources. This approach requires a number of additional steps to account for a range of factors.

Geoscience Australia data are recorded as at the end of the calendar year, and this has been converted to the preferred end-of-financial year basis to allow better integration with economic information. Geoscience Australia does not report Australia's black coal resources by their different carbon densities: sub-bituminous, bituminous and anthracite. Anthracite makes up around one per cent of the world's coal resources. Although Australia has significant coal resources, it does not rank among the largest holders of anthracite resources: Russia, China, USA and Ukraine have the largest recoverable reserves of anthracite (World Coal Institute 2005). We have assumed that Australia's coal resources comprise one per cent anthracite. The World

Energy Council presents data on the proportion of sub-bituminous coal resources held by different world regions. It estimates that 5 per cent of Australia's EDR coal reserves are made up of sub-bituminous coal (World Energy Council n.d.). The World Energy Council does not estimate the proportion of Australia's SDR and inferred coal reserves that are made up of sub-bituminous coal. It is assumed that for these classes of coal reserves, 10 per cent are sub-bituminous. By deduction, 94 per cent of Australia's EDR coal reserves (and 89 per cent of SDR plus inferred coal reserves) are comprised of bituminous coal.

Brown coal (lignite) resources are directly estimated by Geoscience Australia.

29. Are data available to support a more rigorous breakdown of Australia's coal reserves into the categories of anthracite, bituminous coal, non-bituminous coal and lignite?

Conversion factors: tonnes of coal to tonnes of carbon

The carbon content of coal varies not just by the class of coal (lignite, sub-bituminous, bituminous and anthracite) but within each class. Without extensive sampling across Australia for carbon content of coal deposits, we are restricted to applying conversion factors for tonnes of coal to tonnes of carbon that are indicative only. The figures presented in Table 3 are those used by the Department of the Environment and as published in the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Australian Government 2008).

Table 3 Carbon content of Australian coal.

	Carbon content of coal as applied in National Greenhouse and Energy Reporting (Australian Government 2008) (% carbon by weight)
Anthracite	71.2
Bituminous coal	66.3
Sub-bituminous coal	51.5
Brown coal	26.0

30. Are the assumptions on carbon content across each type of coal reasonable for Australia's coal reserves? Is additional information available to guide estimation of these factors?

The estimates presented in Table 4 are our preliminary results of the carbon content of known coal reserves in Australia.

Table 4 Australia's carbon stocks in coal resources at 30 June 2011. Estimation for illustrative purposes to assist discussion about methods and information use.

	Unit	Economic Demonstrated Resources	Sub-economic Demonstrated Resources	Inferred Resources	Total
Resource stock					
Black coal	Gt[a] coal	63.6	7.0	79.0	149.6
Brown coal	Gt coal	46.7	59.0	118.1	223.8
Carbon content					
Black coal					
Anthracite	% by weight	0.712	0.712	0.712	
Bituminous	% by weight	0.663	0.663	0.663	
Sub-bituminous	% by weight	0.515	0.515	0.515	
Brown coal	% by weight	0.260	0.260	0.260	
Carbon stock					
Black coal	Gt carbon	41.7	4.5	51.2	97.4
Brown coal	Gt carbon	12.1	15.3	30.7	58.1
Total	Gt carbon	53.8	19.8	81.9	155.1

a. One Gt (gigatonne) equals one billion tonnes.

4.2.4 Estimating carbon in Australia's oil and gas reserves

The broad methodology adopted involves extracting estimates of Australia's oil and gas resources from Geoscience Australia publication *Oil and Gas resources of Australia – 2010*. These units are converted to a kilogram-equivalent weight. A conversion factor is then applied to derive the weight of carbon contained in these reserves. This approach requires a number of additional steps to account for a range of factors.

Geoscience Australia data are recorded as at the end of the calendar year, and this has been converted to the preferred end-of-financial year basis to allow better integration with economic information. A two-step process is needed to estimate the weight (in tonnes) of carbon contained within Australia's oil and gas reserves. Firstly, Geoscience Australia's estimates of Australia's oil (expressed in gigalitres) and gas (billions of cubic metres) reserves are converted to tonnes, and then the percentage of carbon (by weight) is applied to derive the weight in tonnes of carbon contained within the resource. Both specific gravity and carbon content (by weight) vary markedly between various types of oil and gas resources. The different oil and gas resources present unique measurement challenges and are described in turn.

Shale oil

The Geoscience Australia estimate for shale oil is presented in gigalitre units. This appears to be the estimate of a synthetic crude (syncrude is similar in character to crude oil) derivable from thermal processing (retorting) of the shale oil to convert the kerogen contained within the rock into a usable energy product. The production and use of shale oil potentially releases carbon into the atmosphere across three distinct stages: (1) retorting the kerogen from the shale to derive 'shale oil' (syncrude); (2) the processing of this shale oil to create refined energy products;

and (3) the combustion of these refined energy products. We are concerned here only with stages (1) and (2).

Some of the carbon contained in the kerogen is lost (as carbon dioxide) during the process of converting kerogen to a crude oil-proxy (which can then be further refined into petroleum products). The Geoscience Australia numbers are an estimate of the fuel oil derivable from the shale feedstock. That is, they relate to a product that has already released some geocarbon to the atmosphere (i.e. stage (1)). This is important to note, because we do not estimate here the extent of this additional carbon. That is, we attempt to estimate only the carbon contained in the fuel oil derived from shale. The carbon emitted to the atmosphere in the stage 1 process is significant and has been estimated to account for approximately 25 to 40 per cent of total carbon emissions associated with shale oil use (Brandt *et al*. 2010). Attempting to measure the carbon lost during retorting of kerogen requires assumptions about the processing techniques used and the chemical composition of the shale deposit. The technical aspects of shale oil processing are currently rapidly evolving.

The Geoscience Australia estimate of gigalitres of 'shale oil' is assumed to be the oil product derived from retorting. Shale oil is described as being very similar to crude oil in its weight and carbon characteristics and is therefore assumed to have the same weight and carbon content as for crude oil (Stevens *et al*. 1952). Shale oil can then be further refined to derive various petroleum products which, for carbon stock accounting purposes, would be recorded in Accumulations in economy.

31. **Are these methods and assumptions used to derive carbon contained in shale oil valid? In particular, should an estimate be incorporated for carbon emissions related to retorting of kerogen from shale to derive shale oil? If so, what is a reasonable basis for estimating these emissions?**

Crude oil

The weight of crude oil varies spatially across deposit sites. Australian sites range in American Petroleum Institute (API) gravity from 47.7 degrees (Cossack) to 61.2 degrees (NW Shelf). Crude at the Bayu Undan site has an API gravity of 55.9 degrees (Statoil 2013). From this, we assume an average API gravity of 55 degrees for Australian crude oil, which equates to a weight of 141.5 / (55 + 131.5) grams per litre of crude: i.e. 759 grams per litre of crude. The volume of crude in gigalitres is multiplied by 0.759 to derive weight in mega tonnes.

Condensate

While natural gas condensate has a specific gravity that varies somewhat, and may contain a range of elements and compounds, liquid methane (the major constituent of natural gas) has a weight of one gallon = 1.6 kilograms: i.e. 1 litre = 420 grams.

Condensate is 75 per cent carbon by weight (Biomass Energy Centre n.d.).

The volume of condensate in gigalitres is multiplied 0.420 to derive its weight in mega tonnes, and this weight is multiplied by 75 per cent to derive the weight in mega tonnes of carbon contained in condensate.

LPG

The LPG resources included in the estimates of geocarbon are those that occur naturally in crude oil and natural gas production fields. Geoscience Australia reports the reserves in litres.

To calculate its weight of carbon:

From USA EPA (2004): 66.60 kg per barrel (bbl) of LPG.

From British Petroleum (2013): weight of a barrel of LPG = 11.6 barrels per tonne
i.e. one barrel of LPG = 86.207 kg.

Carbon content of LPG = 77 per cent [i.e. 66.60 / 86.207]

The volume of LPG in gigalitres is multiplied by 0.505 to derive its weight in mega tonnes and this weight is multiplied by 77 per cent to derive the weight in mega tonnes of carbon contained in LPG reserves.

Natural Gas

Geoscience Australia reports natural gas in billion cubic metres (Geoscience Australia 2010). Using USA EPA (2004), natural gas has the following carbon weight by volume:

0.0149 kg carbon/cubic feet
1 cubic metre = 35.3147 cubic feet
Therefore: natural gas has 0.5262 kg of carbon per cubic metre.

The weight of a cubic metre of carbon is calculated as follows:

1,000 litres in one cubic metre. 22.4 litres of any gas is equal to 1 mole**, according to molar volume. Molar mass tells us that the main component of natural gas, methane, or CH_4, has a molar mass of 12+1+1+1+1, or 16g per mol.
$16g/mol * 1,000l/m^3 / 22.4 L/mol = 714g/m^3 = 0.714kg/m^3$
Therefore, there are 0.714 kilograms in a cubic metre of natural gas.
(**Assuming: atmospheric pressure (1atm) and standard temperature (0 Celsius)).

One cubic metre of natural gas weighs 0.714 kg and contains 0.5262 kg carbon i.e. natural gas is 74 per cent carbon by weight.

The volume of natural gas in billions (giga) cubic metres is multiplied 0.714 to derive weight in mega tonnes. This weight is multiplied by 74 per cent to derive the weight in mega tonnes of carbon contained in natural gas.

32. Are these methods and assumptions used to derive carbon contained in crude oil, condensate, LPG and natural gas valid?

The estimates presented in Table 5 are our preliminary results of the carbon content of known oil and gas reserves in Australia.

Table 5 Australia's carbon stocks in oil and gas resources at 30 June 2009. Estimation for illustrative purposes to assist discussion about methods and information use.

	Unit		Economic Demonstrated Resources	Sub-economic Demonstrated Resources	Inferred Resources	Total
Resource stock						
Shale oil	GL[a]			3,107.3	123.0 693.5	
Crude oil	GL		179.0	45.0		
Condensate	GL		341.5	96.0		
LPG	GL		171.5	60.0		
Natural gas	Billion m^3		2,951.0			
Weights, specific gravity						
Shale oil	t/L	0.759				
Crude oil	t/L	0.759				
Condensate	t/L	0.420				
LPG	t/L	0.505				
Natural gas	t/m^3	0.714				
Carbon content						
Shale oil	% by weight	0.855				
Crude oil	% by weight	0.855				
Condensate	% by weight	0.750				
LPG	% by weight	0.770				
Natural gas	% by weight	0.740				
Carbon stock						
Shale oil	Mt[b] carbon			2,016.5	80,270.3	82,286.7
Crude oil	Mt carbon		116.2	29.2		145.4
Condensate	Mt carbon		107.6	30.2		137.8
LPG	Mt carbon		66.7	23.3		90.0
Natural gas	Mt carbon		1,559.2			1,559.2
Total	Mt carbon		1,849.7	2,099.2	80,270.3	84,219.1

a. One GL (gigalitre) equals one billion litres.
b. One Mt (megatonne) equals one million tonnes.

4.3 Methods for biocarbon stock estimation

4.3.1 Overview

Variability, temporal and spatial, across Australia's diverse ecosystems presents major challenges for developing the methods for estimating their carbon stocks. Our approach was to develop an experiment in populating a carbon stock account as a learning process with four main aims:

> To use the biocarbon stock numbers together with the preliminary estimates of geocarbon stocks to stimulate discussion with information users, be they policy practitioners, researchers or the public, and to use this feedback to shape the actual methods for estimating Australia's biocarbon stocks.

> To establish the comprehensiveness principle with all carbon pools across all ecosystems included in the account.

> To identify existing information systems that may enable the qualitative differences (as discussed in Sections 3.1 and 3.3) between the different stores of carbon to be taken into account.

> To identify researchers in the field who measure carbon in natural, semi-natural and agricultural ecosystems and tap their knowledge about ecosystem function and the factors generating stock changes.

We took a stepwise approach as follows:

> Set the area of Australia to 767.7 million ha (ALUM Version 6) and use GIS tools to disaggregate strategically selected areas into vegetation groups (NVIS Version 4.1), land uses (ALUM Version 6) or IBRA regions. This enabled the disaggregation of Australia's land, marine and fresh water areas into ecosystem type, and for agricultural ecosystems a further disaggregation by land use.

> Estimates of the carbon density (t C/ha) of these different ecosystems, land uses or IBRA regions were applied to the area data.

> All biomass and soil organic carbon pools were included. Soil organic carbon stocks were estimated to 30 cm, except for mangroves which were estimated to 100 cm.

The results of the exercise are presented in Table 2 (see page 26). A more detailed description of our approach follows and should be considered together with Appendix C which provides the sources and methods used to estimate the biocarbon densities for the different ecosystems and land uses. Because the biocarbon stock estimates are for illustrative purposes and not a proposed method, questions about estimating biocarbon stocks are presented after the discussion on Australian Greenhouse Emissions Information System (AGEIS) (Section 6.3) which would be a major information source for populating a stock account.

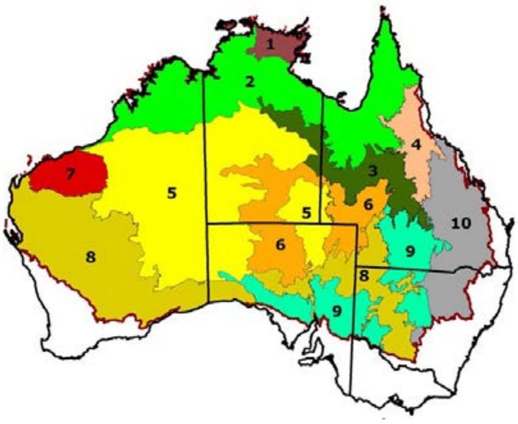
Since the experimental exercise, the findings of CSIRO research generating spatially explicit estimates of soil organic carbon stocks across Australia to 30 cm depth have been published (Viscarra Rossel *et al*. 2014). The research is a substantial contribution to Australia's work on continent-wide biocarbon stock estimation. Most importantly, its spatial referencing facilitates the presentation of the data into an ecosystem type classification. The findings of Viscarra Rossel *et al*. 2014 were not used in the biocarbon stock estimation experiment undertaken for this discussion paper because of our interest in testing the viability of reporting information using the ecosystem classification. Whilst our experimental exercise was a scoping exercise not aimed at generating actual estimates of carbon stocks but rather fit-for-purpose estimates using consistent criteria across the geocarbon and biocarbon stocks, it should be noted that the carbon stock estimate for Australia presented in Table 2 (see page 26) lies below the 95 per cent confidence limit of the estimate generated by Viscarra Rossel *et al*. 2014.

4.3.2 Carbon in Natural ecosystems

Carbon in rangeland terrestrial Natural ecosystems

Australia's rangelands covering 85 per cent of the continent was our starting point for this stepwise approach. Fisher *et al*. 2004 used IBRA regions to divide the rangelands into ten grazing land management zones (GLMZ) (Figure 4).

Figure 4 Grazing Land Management Zones of the Australian rangelands**.**



Source: Fisher *et al*. 2004, Figure 4.1 p. 22.

From these IBRA defined areas, we used ALUM Version 6 to identify and deduct areas used for:

Cropping
Intensive animal production
Intensive horticulture
Irrigated cropping
Irrigated modified pastures
Irrigated perennial horticulture
Irrigated plantation forestry
Irrigated seasonal horticulture
Perennial horticulture
Plantation forestry
Seasonal horticulture
Reservoir/dam
Settlements
Manufacturing and industrial
Residential
Services
Transport and communication
Utilities
Waste treatment and disposal
Mining Blank (no data)

Fisher *et al*. 2004 used a similar approach. Estimated carbon densities for the different carbon pools were applied to each of the ten GLMZ as detailed in Appendix 3. We aggregated the estimated carbon stocks in GLMZ regions 1 to 9 to generate an estimate of carbon stocks in rangeland Natural ecosystems, making the assumption that on the whole the canopy cover of these regions has not been damaged irrevocably. We allocated the estimated biocarbon stocks in GLMZ 10 (highly modified rangelands) to the classification Semi natural ecosystems.

Carbon in terrestrial Natural ecosystems outside rangelands

Terrestrial Natural ecosystems outside the rangelands were identified by laying NVIS 4.1 (showing present vegetation cover and jurisdiction) over the ALUM Version 6 non-GLMZ areas used for Conservation and Natural Environments (comprising Nature conservation, Managed resource protection, Other minimal use) and Production from Relatively Natural Environments (comprising Livestock Grazing and Production forestry). Guided by the ecosystem definitions presented in Section 3.3, we categorised these areas as Natural ecosystems. This GIS exercise generated information on the area (hectares) and State/Territory location of Natural ecosystems with the following vegetation types:

Eucalypt native forests
Shrublands & woodlands
Grass, shrub & heath lands
Rainforests
Other

Estimated carbon densities (t C/ha) were applied to different vegetation types as detailed in Appendix 3. The State/Territory disaggregation was used to manage boundary issues particular to Tasmania's rainforests in which a significant number of eucalypt trees are located. Their carbon stocks are reported in Rainforests, not Eucalypt native forests.

Carbon in fresh water Natural ecosystems

NVIS 4.1 was used to establish the vegetation coverage of inland aquatic areas: freshwater, salt lakes, and lagoons. A carbon density (t C/ha) estimate, presented in Appendix 3, was applied to this area. All of the estimated biocarbon stock was allocated to Natural ecosystems.

Carbon in marine Natural ecosystems

NVIS 4.1 was used to establish the vegetation coverage of mangrove, sea and estuary ecosystems. A carbon density (t C/ha) estimate, presented in Appendix 3, was applied to this area. All of the estimated biocarbon stock was allocated to Natural ecosystems.

4.3.3 Carbon in Semi-natural ecosystems

Carbon in Semi-natural ecosystems comprises estimated biocarbon stocks in GLMZ 10 (Highly modified rangelands) (see Figure 4) and Grazing in modified pastures outside rangelands GLMZ (area identified using ALUM Version 6). Estimated carbon densities (t C/ha) were applied to these areas as detailed in Appendix 3.

4.3.4 Carbon in Agricultural ecosystems

Carbon in terrestrial Agricultural ecosystems

ALUM Version 6 was used to identify the area (hectares) and jurisdiction of land used for Dryland Agriculture and (wood producing) Plantations and Irrigated Agriculture and Plantations (both disaggregated into Plantations, Grazing modified pastures, Cropping, Perennial horticulture, Seasonal horticulture), and Intensive uses for agricultural production (disaggregated into Intensive horticulture, Intensive animal production). Rangelands areas used for these agricultural activities were included but double counting was avoided using the process described in Section 4.3.3 and excluding the rangeland area of modified pastures used for grazing. Estimated carbon densities (t C/ha) were applied to different agricultural land uses as detailed in Appendix 3. The resulting carbon stock estimates were aggregated into ecosystem type (Agricultural ecosystems and Semi-natural ecosystems) by allocating all areas to Agricultural ecosystems except Dryland grazing in modified pastures which was allocated to Semi-natural ecosystems.

Carbon in fresh water Agricultural ecosystems

Carbon stored in water reserves and dams (area identified through ALUM Version 6) was allocated to Agricultural ecosystems. A carbon density (t C/ha) estimate, presented in Appendix 3, was applied to this area.

4.3.5 Carbon in Settlements and Other

The focus in this Section is to the biocarbon stocks in primary reservoirs: not the carbon stocks in building and infrastructure which are included in Accumulation in economy (discussed in Section 8.1). ALUM Version 6 was used to establish the residential area of Australia and to this was applied an estimate of the carbon density of the biomass and soils as presented in Appendix 3.

ALUM Version 6 was used to identify all other areas to meet the requirement of completeness. Other includes Mining and Unknown/no data areas. An estimate of the carbon density of the biomass and soils in these areas was made using the carbon density estimates presented in Appendix 3.

33. **Whilst GIS information exists to enable reporting to the ecosystem type classification (Natural ecosystems, Semi-natural ecosystems, Agricultural ecosystems, Settlements and other), what further disaggregation would be useful and feasible?**

5 *SEEA EEA* CARBON STOCK ACCOUNTING FRAMEWORK

5.1 Overview

Concerns about the environment disjunction in economic statistics have been widely expressed for a long time (Costanza *et al*. 1997). The 1992 Earth Summit hosted by the UN Conference on Environment and Development recommended, amongst other things, the development of national environmental-economic accounts. Through an extensive process and interim reports prepared by the UN Statistics Division, the *SEEA Central Framework* was adopted as an international standard in 2012 (European Commission *et al*. 2012). It is the first international statistical standard for environmental-economic accounting and is jointly published under the auspices of the European Commission, Food and Agricultural Organization, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank[3]. The *SEEA Central Framework* is an important advance in economic-environment accounting: as a global and integrated institutional learning process and in its development of frameworks to account for stocks and stock changes for selected environmental assets including minerals and energy resources, soils, timber, water and various biological resources.

SEEA EEA builds on the SEEA Central Framework. It aims to explicitly link ecosystems to economic and other human activity (European Commission *et al*. 2013). Within this challenging task (hence the encouragement for countries to 'experiment' and build knowledge and skills in this particular accounting field) lay the relatively easier task of developing a carbon stock accounting framework (see European Commission *et al*. 2013, Section 4.4 and Annex A4.1). The carbon stock account framework draws heavily on the *SEEA Central Framework* and the *SNA*. In particular it enacts the principle of completeness or comprehensiveness in presenting an accounting framework that covers all stocks of geocarbon and biocarbon (individual countries can choose not to populate parts of the account or set priorities according to their needs). It also applies the *SEEA Central framework's* stock change classification system which draws on many decades of experience in economic accounting. Stock changes are grouped as being due to managed (human) expansion or contraction and natural expansion or contraction; discoveries; upwards and downwards reappraisals; and reclassifications. The *SEEA EEA* carbon stock account reports in physical units (Gigagrams of C, in line with the IPCC reporting unit).

Although ecosystem accounting is the focus of *SEEA EEA*, the accounting framework links important differences in ecosystems for ecosystem accounting purposes and the wider needs of the users of carbon stock information (geocarbon and biocarbon). *SEEA EEA* advances a Natural ecosystems, Semi-natural ecosystems, Agricultural ecosystems and Settlements ecosystem classification as articulated in Section 3.3 but recognises that this may be difficult for some countries to report using current information. Our experimental exercise in biocarbon stock estimation (Section 4) was partly aimed at understanding Australia's capacity to adopt such a classification system using existing GIS information and tools.

[3] Australia's economic statistics are prepared using a global statistical system (the *System of National Accounts* (*SNA*)) developed by the same institutional organisations and arrangements.

5.2 *SEEA EEA* carbon stock account

The structure of the *SEEA EEA* carbon stock account is presented in Table 6. It provides a complete articulation of carbon stocks; is grounded on a scientific understanding of the carbon cycle; and presents a classification system that recognises the quality differences in the carbon reservoirs. Opening and closing stocks of carbon are recorded with the various changes between the beginning and end of the accounting period recorded as either additions to the stock or reduction in the stock.

Table 6 SEEA EEA carbon stock account *(Source:* European Union et al. 2013, Table 4.5.).

Gigagrams carbon (GgC)	Geocarbon					Biocarbon			Atmosphere	Water in Oceans	Accumulation in economy				TOTAL
	Limestone	Oil	Gas	Coal	Other	Terrestrial ecosystems	Aquatic ecosystems	Marine ecosystems			Inventories*	Fixed assets	Consumer durables	Waste	
Opening stock															
Additions to stock															
Natural expansion															
Managed expansion															
Discoveries															
Upwards reappraisals															
Reclassifications															
Total additions to stock															
Reductions in stock															
Natural contraction															
Managed contraction															
Downwards reappraisals															
Reclassifications															
Total reductions in stock															
Imports and exports															
Imports															
Exports															
Closing stock															

*Excludes inventories included in biocarbon (e.g. plantation forests, orchards, livestock, etc)

Carbon stocks are disaggregated to geocarbon (carbon stored in the geosphere) and biocarbon (carbon stored in the biosphere, in living and dead biomass and soils). Geocarbon is further disaggregated into limestone (the main carbonate rock mined for economic production); fossil fuels (oil, gas, coal) and Other which includes other carbonate rocks and methane clathrates. For accounting purposes where the information generated from the accounts is policy focussed, *SEEA EEA* advises that the priority should be to reporting those stocks that are being impacted by human activity (e.g. fossil fuels). It also aligns Peat stocks and flows with the biocarbon sector because peatland vegetation is associated with a variety of ecosystems, including forests, grasslands, mossbeds, mangroves, saltmashes and paddies.

Biocarbon is classified by ecosystem, at the broadest level being Terrestrial, Aquatic and Marine. These can be further disaggregated by ecosystem type based on the degree of human modification of the ecosystem, namely Natural ecosystems, Semi-natural ecosystems, Agricultural ecosystems and Other ecosystems (settlements and land with infrastructure). We have used this ecosystem classification in our experiment to populate the carbon stock account (Section 3.3 and Table 2 on page 26).

The Atmosphere and Ocean are the receiving environments for carbon released from the primary reservoirs and Accumulations in economy.

Accumulations in economy are the stocks of carbon in anthropogenic products and are further disaggregated into the *SNA* components: Fixed assets (e.g. concrete in buildings, bitumen in roads); Consumer durables (e.g. wood and plastic products); Inventories (e.g. petroleum products in storage, but excluding those in agricultural ecosystems (a boundary decision was made to include these stocks in primary reservoirs)); and Waste. Accounting for waste follows the *SEEA Central Framework* where waste products (e.g. disposed plastic and wood and paper products) stored in controlled land fill sites are treated as part of the economy. Carbon stored through geosequestration (i.e. injecting gaseous CO_2 into the surface of the Earth) is similarly treated. The *SEEA EEA* treatment of carbon stocks in Accumulation in economy has been used to inform Figure 3 (see page 14).

The row entries in the *SEEA EEA* account follow the basic form of the asset account in the *SNA* and *SEEA Central Framework*: opening stock, additions, reductions and closing stock. Additions to and Reductions in stock have been split between managed and natural expansion. Additional rows for imports and exports have been included, thus making the table a stock account, as distinct from an asset account. Section 9.2 discusses the stock change classification in detail.

6 THE AUSTRALIAN GREENHOUSE EMISSIONS INFORMATION SYSTEM (AGEIS)

6.1 Energy and industrial processes

AGEIS was designed for Australia to meet IPCC requirements for national greenhouse inventory systems and reporting emissions. In this Section, we discuss the Energy and Industrial processes components of AGEIS, highlighting its potential to populate the carbon stock account.

The National Greenhouse Energy Reporting System (NGERS), established under the *National Greenhouse and Energy Reporting Act 2007*, is the core information source feeding into AGEIS. Under the Act, companies whose energy production, energy use or greenhouse gas emissions meet a threshold must report facility-level information to the Clean Energy Regulator. Companies use an Online System for Comprehensive Reporting (OSCAR) tool to report activity information (e.g. fuel combustion and consumption, fuel inventories and emissions factors at a facility level) annually, in fiscal years. Time series data are available from 2008/09.

Bureau of Resources and Energy Economics (BREE) energy consumption data published in *Australian Energy Statistics* are also used in Australia's emissions reporting. BREE reports energy consumption data using the ANZSIC industry classification: concordance tables are required to work the information into the IPCC sector classification. In addition to preparing Australia's *National Inventory Report* to IPCC requirements, DoE reports greenhouse gas (flow) information using the ANZSIC classification (Australian Government 2013b). The ABS is also researching this area to build an input-output model to estimate greenhouse gases embodied in final products consumed domestically (e.g. by households) and exported products (ABS 2012). DoE uses additional information from a diverse array of government, industry and research organisations to prepare the Energy and Industrial processes components of Australia's *National Inventory Report*.

As Australia moves into more refined IPCC tiers to report emissions for the Energy and Industrial processors sectors and the IPCC Guidelines are updated to improve the accuracy of reported information, the information systems become increasingly sophisticated, complex and challenging. An example of importance for stock accounting is netting-off from the fossil fuel production statistics presented in BREE's *Australian Energy Statistics* the amount of coal, oil and gas not combusted but used and stored in non-energy products such as plastics, solvents and bitumen (see for example Australian Government 2014a pp 48, 61-2). This task is complicated because of the diversity of products, technology and feedstocks and temporal changes. The complexity of the production systems, well documented in Australia's *National Inventory Report 2012*, requires linked stock and flow mapping across multiple products to keep track.

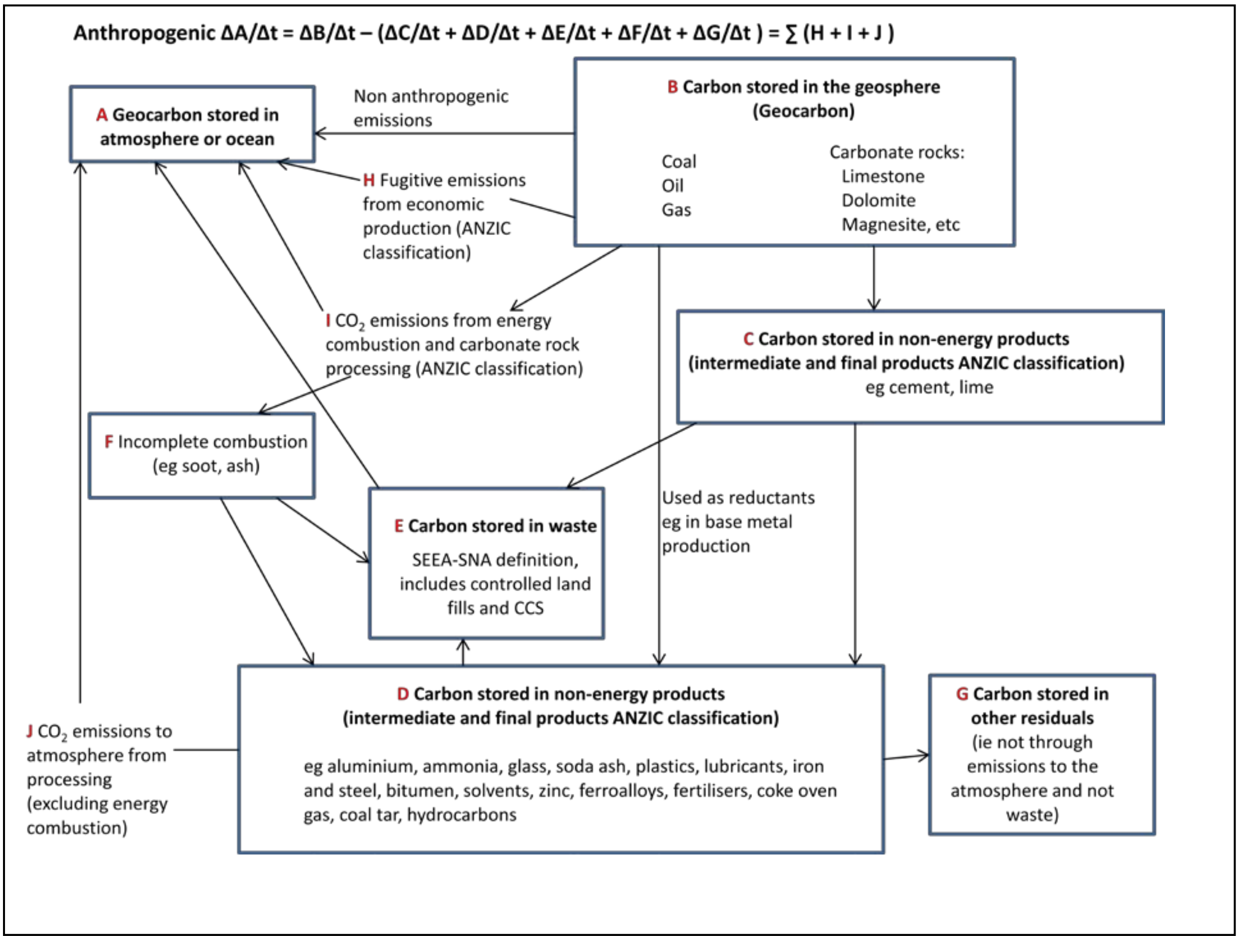
Such a mapping for the geocarbon stocks and flows at the highest level of aggregation is presented in Figure 5. It uses the ANZSIC industry classification (although IPCC Sectors could also be used) to emphasise the potential for linkage to ABS economic information including input-output tables. The accounting identity presented at the top of Figure 5 articulates the relationship between geocarbon stocks, stock changes and CO_2 emissions originating from human use of geocarbon stocks for a given time period:

Anthropogenic $\Delta A/\Delta t = \Delta B/\Delta t - (\Delta C/\Delta t + \Delta D/\Delta t + \Delta E/\Delta t + \Delta F/\Delta t + \Delta G/\Delta t) = \sum (H + I + J)$

> The change in carbon stocks in the atmosphere and oceans due to human use of geocarbon ($\Delta A/\Delta t$)
> = change in geocarbon stocks due to human use ($\Delta B/\Delta t$) minus the sum of all stock changes in economic products ($\Delta C/\Delta t + \Delta D/\Delta t + \Delta E/\Delta t$) and their associated non atmospheric residuals ($\Delta F/\Delta t + \Delta G/\Delta t$)
> = sum of all emissions to the atmosphere from economic activity (H + I + J).

Figure 5 is consistent with the national carbon balance approach DoE already uses as an emissions estimation quality control tool, given the substantial number of data inputs (around 15 000 per year) used to calculate Australia's energy-related emissions (Australian Government 2014c, pp 136-8). Figure 5 expands on the DoE approach to create the linkages into the economy as measured using the *SNA*.

Figure 5 Stock and flow mapping of geocarbon and linkages to the economy**.**



AGEIS can be used now to populate components of the stocks in C, D and F; namely stock changes and possibly stock levels if meaningful assumptions about product lifetimes can be made. Ongoing research by DoE to net off non-energy uses of coal, oil and gas will generate further data to populate the stock account. A common interest exists between DoE and its information needs for greenhouse gas reporting and *SEEA*. The stocks (in C, D and E) are the Accumulations in economy in the *SEEA EEA* carbon stock account. With *SNA* classifications, these stocks can be readily disaggregated into the *SNA* components: Fixed assets (e.g.

concrete in buildings, bitumen in roads); Inventories (e.g. petroleum products in storage); Consumer durables (e.g. wood and plastic products); and Waste.

34. Are there outstanding methodological and procedural issues in the ANZSIC and IPCC sector concordance tables?

35. Is the stock and flow mapping presented in Figure 5 a useful approach serving jointly the needs of DoE, the ABS and users of integrated information? What improvements can be made?

6.2 Waste

The IPCC defines greenhouse gas emissions from Waste as emissions from solid waste disposal on land, wastewater, waste incineration and any other waste management activity. CO_2 emissions from fossil-based products (incineration or decomposition) should be included. CO_2 emissions from organic waste handling and decay are considered to be from biomass sources and reported in Agriculture to avoid double counting (IPCC 1997). Waste emissions include those from:

> Solid waste disposal on land (mostly CH_4 but also CO_2 from inorganic waste sources) from both managed and unmanaged disposal sites;
> Waste water handling (CH_4 and N_2O from anaerobic decomposition of organic matter by bacteria in sewage facilities and from food processing and other industrial facilities); and
> Waste incineration (all non-CO_2 greenhouse gases from incineration and CO_2 from non-biological waste: emissions from waste to energy and burning of agricultural wastes are reported elsewhere).

Waste as defined for national greenhouse gas inventories is focussed largely to CH_4 and biodegradable material (not inert products like concrete).

The methods used to calculate Waste emissions in Australia's *National Inventory Report* are highly useful for calculating carbon stocks in waste as defined in the *SNA/SEEA Central Framework*. DoE uses a carbon stock and flow model to estimate greenhouse gas emissions from degradable landfill: keeping track of additions of carbon through waste disposal and losses due to decay with product specific decay functions. Models have been developed for:

> Solid wood products and paper, and
> Food, garden and other organic carbon (run using data from state and territory waste agencies covering 665 managed sites and facility level data from NGERS).

Distinguishing waste from residuals

Of key importance for the *SNA* double entry bookkeeping approach to its sequence of accounts in monetary units is maintaining clarity about what is in the economy: guided by principles for making boundary decisions. For waste, the *SNA* uses the word 'Residuals' and defines residuals as the unintended and undesired outputs from the economy which have zero price and may be recycled or discharged into the environment. Residuals cover solid waste, effluents (discharges to water) and emissions (discharges to air) (European Union *et al*. 2009, para 29.016). Further details are provided in the *SEEA Central Framework*, particularly about the distinction between monetary payments made by a generator of residuals to establishments that collect or treat residuals and the flows of residuals themselves, and also highlighting the boundary between the economy and the environment. Controlled and managed landfill sites, emission capture and storage facilities, treatment plants and other waste disposal sites are considered within the boundary of the economy. Residual stocks and flows (including their embodied carbon) into these facilities are regarded as part of the economy, but subsequent flows from these facilities may be either directly to the environment as residuals or lead to the creation of other products through for example recycling (European Commission *et al*. 2012, paras 3.73-3.82). The approach to carbon stock accounting within the *SEEA EEA* follows the *SNA/SEEA Central Framework*. Carbon stored in waste products or residuals in managed facilities (e.g. municipal tips, carbon capture and storage) is recorded as Accumulation in economy. Any subsequent release of carbon to the atmosphere is treated as a Residual flow with a reduction in Accumulation to economy and a corresponding increase in Residuals (i.e. emissions to the environment) (European Commission *et al.* 2013).

Despite their different purposes, Australia's methods to calculate greenhouse gas emissions under IPCC guidelines and to report economic activity/residuals to the environment under *SNA/SEEA* guidelines are largely in alignment. The aim of the *SNA/SEEA* is to report in physical and monetary units the stocks and flows of waste with clear boundaries between the economy and environment. For national greenhouse gas inventory purposes, stock/flow modelling is used to report emissions from human generated waste irrespective of the entity or location. Australia's capacity to report spatial information on landfill greenhouse gas emissions is under development with increased facility-level data collected via NGERS (Australian Government 2014c, p. 50).

36. Are there unrealised opportunities for work task and information sharing between the agencies for estimating waste and residual stocks and flows?

6.3 Land and marine sector

6.3.1 FullCAM

FullCAM (full carbon accounting model) underpins Australia's regularly reported carbon flow information resulting from land use/land management. It is a stock-based model generating annual (or sub-annual) information on carbon stocks for each relevant carbon pool (for e.g. above ground living biomass) in forest and agricultural ecosystems. Carbon flow information (emissions less removals) is calculated using estimates of annual stock changes. FullCAM therefore is highly applicable for populating an Australian carbon stock account for much of the land sector. DoE maintains an active work program to refine and extend Australia's coverage of land and marine sector emissions and removals. For details on FullCAM's evolving development, see Australian Government 2014b, Appendix 7B.

FullCAM's modules comprise:

> A physiological growth module (**3PG**) which uses leaf area information to estimate net primary productivity (NPP) of the defined area (for example, an ecosystem or land use). 3PG factors in fixed attributes of slope and aspect solar radiation to 250 m resolution under optimal growth conditions with adjustments made using information from monthly climate maps (rainfall, evaporation, min/max/average temperature, frost days) and combined with soil moisture and fertility mapping, elevation mapping and vegetation mapping to generate biomass productivity with a spatial scaling to 25m^2 (some cases 50m^2) (for details see Kesteven and Landsberg 2004 and Australian Government 2014b, Appendix 7.C). 3PG is currently being extended from forest lands to crop lands and grass lands.

- **CAMag** is used to estimate carbon flows associated with cropping and grazing under specified management regimes. Australia's signing of the Kyoto Protocol second commitment period has stimulated additional work to enable reporting under Article 3.4 (human-generated emissions and removals from forest management, cropland management, grazing land management and revegetation). The CAMag module is undergoing considerable upgrading and will cover:

    - Annual and perennial crops (combined)
    - Annual pastures
    - Perennial pastures

  Exogenous crop and pasture yield data will be replaced by data generated from 3PG's crop growth model with climate a variable at location. Australia's Kyoto Protocol commitment requires new work to model changes in crop and pasture management over time. DoE is planning for the developments for this module of FullCAM to be in place for the 2015 National Inventory Report.

- **Roth C** is FullCAM's soil carbon module. It disaggregates the mass of above ground litter estimated by **GENDEC** (general decomposition model) into 'resistant' plant material and decomposable plant material, the source of soil organic carbon (SOC). The turnover rates are determined by rainfall, temperature, ground cover and evaporation. DoE has engaged Jeff Baldock, Senior Principal Research Scientist CSIRO Land and Water, to assist develop FullCAM's capability to estimate the SOC effects of land use in Australia. This builds on earlier extensive soil sampling work (through the national Soil Carbon Research Program (SCaRP)), under Baldock's direction, commissioned by the Department of Agriculture, Fisheries and Forestry. SCaRP examined variations in SOC stocks and composition in the 0 to 30 cm layer of soil due to agricultural management practices in Australia. The program also collected land management histories at all sites along with other potential determinants of SOC content and composition such as climate, soil type and topography (CSIRO Data Access Portal; Sanderman *et al*. 2011; Baldock 2009). The SOC information is largely reported as stocks (t C/ha) and, with spatial referencing, can be used to populate the soil pools of a carbon stock account.

  DoE is working to link the four modules (3PG, CAMag, RothC and GENDEC).

- **CAMfor** is used to estimate the carbon flows in forests as defined in Australia's Kyoto Protocol commitment (an area greater than 0.2 hectares of trees with a potential height of at least two metres and crown cover of at least 20 per cent) and includes both native forests and plantations. 3PG is used to estimate the NPP of above ground living biomass in stands of trees with adjustments for forest management as specified by CAMfor. CAMfor is then used to disaggregate NPP into the debris pools. CAMfor was built without a soil carbon model: a gap subsequently filled by Roth C. Australia's Kyoto Protocol commitment which requires us to report greenhouse gas net emissions resulting from deforestation and reforestation has stimulated the production of substantial information on forest carbon stocks. Our signing up for the second commitment period has extended Australia's reporting coverage to all forest areas irrespective of land use.

The areas where FullCAM and associated information systems could be used to populate a carbon stock account are indicated in Table 7. Substantial areas are covered or will be by 2015.

Table 7 FullCAM carbon stock information.

Ecosystem type/land use	Biomass measured information	Biomass modelled information	Soil organic carbon measured information	Soil organic carbon modelled information
Natural and Semi natural ecosystems				
Native forests	**Yes**	**Yes**	**Yes** (from SCaRP as t C/ha)	**Yes**
Environmental plantings	**Yes**	**Yes**	**Yes** (from SCaRP as t C/ha)	**Yes**
Non-forested natural and semi-natural terrestrial ecosystems	**No**[1]	**No**[1]	Yes (from SCaRP as t C/ha)	**Yes**
Marine ecosystems	**No**[2]	**No**[2]	**No**[2]	**No**[2]
Agricultural ecosystems				
Crop lands	**Yes** (annual crop yields currently supplied by ABARES and CSIRO[3])	**Yes** (by 2015)	**Yes** (from SCaRP as t C/ha)	**Yes**
Grazing lands	**Partial** (annual and perennial pasture yields currently supplied by ABARES and CSIRO)	**Yes** (by 2015[4])	**Yes** (from SCaRP as t C/ha)	**Yes**
Horticulture	**No**	**?**[5]	**Yes** (from SCaRP as t C/ha)	**Yes**
Plantation wood	**Yes**	**Yes**	**Yes** (from SCaRP as t C/ha)	**Yes**
Settlements	**No**	**Yes**[6]	**No**	**No**

1. DoE currently researching <20 per cent canopy cover ecosystems.
2. DoE currently working to incorporate marine ecosystems in the national inventory.
3. Annual crop yields are stock figures with a scaling up factor required for non-merchantable biomass.
4. DoE working to disaggregate grazing lands into annual and perennial pastures for 2015 reporting.
5. DoE working to incorporate horticulture for 2015 reporting.
6. FullCAM can model biomass in urban trees and other vegetation but additional data required.

6.3.2 Native forests

With Australia's international reporting commitments, generating information on deforestation (largely low productivity native forests) and reforestation (largely plantations, with more recent attention to environmental plantings and biodiverse environmental plantings) was a priority. AGEIS has two components of direct relevance for reporting carbon stocks in native forests:

- estimates of the stocks of carbon in Kyoto Protocol defined forests before their first clearing event, and
- FullCAM itself: in its measured information used for both model calibration and the modelled information it generates.

6.3.2.1 Native forest carbon stocks before their first clearing event

DoE has developed a data set on carbon stocks in native forests pre-European settlement (for details on methods see, Australian Government 2014b, Appendix 7.D: Initial Forest Biomass). (This information is used to prepare estimates of net emissions from deforestation for Kyoto Protocol reporting. The first clearing action is run through FullCAM to enable separation of any continuing emissions or removals from those generated from deforestation since the 1990 Kyoto Protocol base year.) Where land has been cleared of forest (and is now cropland or grassland), its initial biomass is estimated spatially to 25 m^2 with areas of forest gaps excluded.

The approach taken to estimate native forest carbon stocks before their first clearing event could also be used to help build the picture of Australia's carbon carrying capacity (CCC). CCC is the mass of carbon able to be stored in an ecosystem under prevailing environmental conditions and natural disturbance regimes, but excluding disturbance by human activity (Gupta and Rao, 1994; Mackey *et al*. 2008). CCC is a dynamic equilibrium concept of particular relevance to natural or semi-natural ecosystems. Undisturbed by human activity or restored since this disturbance, their biomass or carbon stocks will fluctuate over the long term at a 'maximum range' as they recover from natural disturbances such as fire and pest attacks. The CCC of natural ecosystems is important stock information for climate change policy and research and informing land use trade-off decisions (discussed in Section 1.3).

37. **CCC information is highly relevant for research and policy making, but should it be generated through a one-off stock account reporting period, say 1750, or some other approach?**

38. **Is Australia's approach to estimating carbon stocks in native forests before the first clearing event useful for estimating CCC for natural and semi-natural ecosystems?**

6.3.2.2 CAMfor-generated native forest carbon stock information

With Australia signing up to a second Kyoto Protocol commitment period, our reporting of native forest emissions and removals has extended from native forests used for wood production (harvested native forests) to all native forests irrespective of use. FullCAM is used to generate non-spatially explicit information on annual net emissions from harvested native forests with account taken of stock changes due to:

- wood extraction (see Section 7.1 for further discussion on wood products)
- movement of residue material through the various pools
- forest growth.

Different forest types, age profiles and forest harvest and post-harvest management methods are accommodated in FullCAM's generation of net emission information for native forests currently or previously used for wood production (Australian Government 2014b pp. 25-30).

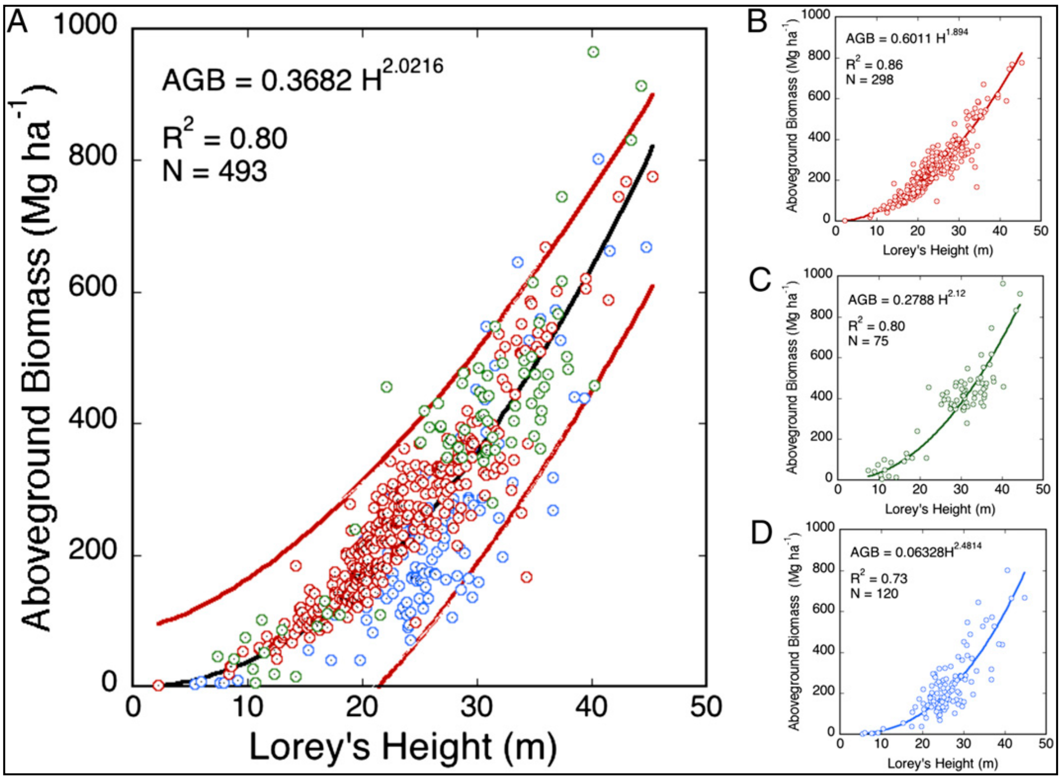
Other native forests (i.e. non harvested native forests) include State native forests that have not been used for wood production such as protected areas and extensive areas of private native forests not considered to be available for wood production in 1990 (see Australian Government 2014b, p. 25). The area of these forests and their carbon stocks fluctuate due to natural disturbance and climate variability. Australia's approach is to separately model the effects of ephemeral, intermittent changes in forest cover where some areas move in and out of the forest threshold definition (two metres in height and 20 per cent crown cover) from the effects of changes in leaf mass/area as a result of climate variability (see Australian Government 2014b, pp 42- 3). The effects of prescribed burning and wildfire are also modelled and reported (see Australian Government 2014b, pp. 43-4).

6.3.2.3 3PG and Lidar

The Reducing Emissions from Deforestation and Degradation (REDD) provisions in the UNFCCC stimulated research into information systems that could generate carbon stock and stock change data across large areas of forest, economically. The work of a collaboration of scientists published in Saatchi *et al.* 2011 is a major contribution: a mapping of the total carbon stock in above and below ground living biomass covering over 2.5 billion hectares of forests on three continents. They estimated the stocks of carbon in above ground living biomass using a combination of data from inventory plots and satellite light detection and ranging (Lidar) samples of forest structure to estimate biomass stocks, plus optical and microwave imagery (1 km resolution) to extrapolate over the landscape. Below ground living biomass was estimated as a function of above ground living biomass using Mokany *et al*. 2006 and carbon was calculated at 50 per cent of biomass. Spatially explicit uncertainties were estimated though error propagation spatial analysis and included errors associated with prediction of spatial modelling, and estimation of above and below ground biomass. Maps of the carbon stock estimates and associated uncertainties are available at <http://carbon.jpl.nasa.gov/index.cfm>.

For native forests, FullCAM and Saatchi *et al*. 2011 approach carbon stock estimation using a similar framework. Both first establish the relationship between above ground living biomass and forest productivity. Saatchi *et al*. 2011 use a simpler tree height measure (Figure 6). FullCAM uses 3PG to estimate forest productivity: a more refined estimation approach. The single variable tree height measure however may appeal to low income countries with limited data.

Figure 6 Allometric relations between forest height and above ground living biomass of calibration plots using in Saatchi *et al*. 2011.



Source: Saatchi *et al*. 2011, Figure 1.

(A) Combined relation from three continents, (B) from 298 plots in Latin America, (C) from 75 plots in sub-Saharan Africa including woodland savanna, (D) from 120 plots in Southeast Asia including plots in secondary and fragmented forests.

6.3.3 Environmental plantings

The methods for calculating carbon stocks in environmental plantings for non-wood production purposes have been approved under the Carbon Farming Initiative (Australian Government n.d.). The CSIRO was engaged to generate measured information covering 38 study sites in low to medium rainfall areas of the Goulburn-Broken and North Central catchments of Victoria. This included tree and shrub biomass stock data for mixed-species environmental plantings, remnant native forests and single-species farm forestry plantations. Growth relationships for predicting the above-ground biomass of tree and shrub species from measures of stem diameter were developed from biomass harvests. This information was used to help calibrate the 3PG module.

39. **Is additional measured information required for FullCAM's carbon stock estimates for environmental plantings, including biodiverse environmental plantings? If so, how can it be done cost effectively and what priority should it be given?**

6.3.4 Non-forested natural and semi-natural terrestrial ecosystems

Non or low-forested ecosystems dominate Australia's terrestrial area. Despite their relatively low carbon densities in biomass and soils, carbon stocks in these ecosystems in aggregate are significant (Table 2 on page 26). DoE is using satellite imagery to investigate carbon in woody vegetation in areas with canopy cover down to 6-8 per cent.

40. **What, if any, modelling refinements are required for FullCAM to estimate carbon stocks and stock changes in non-forested natural and semi-natural terrestrial ecosystems?**

41. **Is additional measured information necessary? If so, how can it be done cost effectively and what priority should it be given?**

42. **Should the NVIS defined Inland aquatic (freshwater, salt lakes and lagoons) be included as part of Natural ecosystems? What methods should be used to estimate their carbon stocks and stock changes, and allow for ephemeral changes?**

6.3.5 Marine ecosystems

NVIS provides information on the vegetated areas of Australia's coastal or tidally influenced marine ecosystems disaggregated into mangroves, seagrasses and estuaries. Changes in beach morphology should be factored into the accounting system and here a fixed area statistical unit (discussed in Section 2.2) has advantages.

DoE is currently working to incorporate marine ecosystems in the national inventory consistent with the IPCC's development of national reporting guidelines on wetlands to fill gaps in the 2006 *IPCC Guidelines*. The 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands is due for IPCC Panel adoption/acceptance in October 2013***.*** Guidance in reporting coastal marine ecosystem greenhouse gas emissions and removals will be included in the IPCC guidelines. Within Australia, the CSIRO Marine and Coastal Carbon Biogeochemistry Cluster (Coastal Carbon Cluster) lead by Andy Steven is researching methods to estimate carbon stocks in coastal areas: collating the limited existing Australian coastal carbon data and generating new data to enhance CSIRO's coastal carbon modelling capacity.

43. **What territory definition should be adopted to allow for tidal movements and to meet varying user needs?**

44. **Is the NVIS ecosystem classification complete, for example what about coral reefs?**

45. **What are the boundary issues between coastal marine ecosystems (such as mangroves, tidal salt marshes and seagrass meadows) and terrestrial ecosystems? What are the principles to develop boundary rules?**

46. **Does FullCAM require a new module for generating coastal marine ecosystem carbon stocks and stock changes? If so, how can the information to calibrate and run the module to be generated cost effectively?**

47. **Leaving aside the issue of extending the measuring of terrestrial SOC from depth 30 cm to 100cm, is there a special case for measuring and reporting marine ecosystem SOC to 100 cm?**

6.3.6 Crop lands, grazing lands and horticulture

With the main exception of trees used for wood, fibre and food, agricultural ecosystems work on an annual cycle. Stocks therefore can be estimated as an average yield over the year using FullCAM scaled up for non-merchantable above and below ground biomass. Soil organic carbon stocks are estimated using RothC. DoE is currently developing FullCAM's capacity to generate carbon stock and stock change information for horticulture.

48. **Are there new research findings or information that could improve FullCAM's carbon stock estimates for crop lands, grazing lands and horticulture?**

6.3.7 Plantations for wood

Planting Kyoto Protocol defined forests for wood production is reforestation/afforestation and therefore covered in Australia's national greenhouse gas inventory reporting. Substantial long-term research including site measured data is available for Australia's two million hectare softwood and hardwood plantation estate. Carbon stocks in plantation biomass and soil can be readily estimated using FullCAM.

49. **Are there new research findings or information that could improve FullCAM's carbon stock estimates for wood plantations?**

6.3.8 Settlements

This category covers biocarbon stocks in human settlements. Carbon in infrastructure such as bitumen roads and buildings is classified as Fixed assets and reported in Accumulations in economy. FullCAM can model biomass in urban trees and other vegetation but additional data may be required on urban tree density and non-tree vegetation. Carbon stocks in urban landscapes may prove to be more significant than generally thought (see Table 2 on page 26).

50. **What additional information is required to use FullCAM to estimate biocarbon stocks in human settlements?**

6.4 Carbon stock estimates for the land sector using data available to Australia's National Inventory System

FullCAM, despite being used predominately to generate flow information to meet Australia's reporting requirements under our international climate mitigation commitments, is highly suited to reporting stocks because it is a stock-based model. To assist in Australia's developing application of SEEA, DoE undertook an exercise in 2012 to investigate the potential to populate a carbon stock account for the land sector using data available to Australia's National Inventory System. The reporting year chosen was 2010 with estimates of stock changes from 2009 to 2010 for forests and agricultural land (Tables 8 and 9). The exercise identified substantial scope to populate the stock account for these land uses/ecosystem types although at the time there were gaps in the estimates, namely in:

- carbon in debris (coarse and fine woody debris) in native forests used for conservation and wood production
- soil organic carbon in all native forest areas
- soil organic carbon in pre 1990 plantations (approximately half the estate area)
- carbon in herbaceous plants and debris associated with agricultural land.

Table 8 Forest and agricultural land sector carbon stocks in 2010 estimated using data available to the National Inventory System.

Category	Sub-category	Carbon stock (million t C)	Area (million ha)
Forest land		**16,506**	**87**
	Native forests - production	2,057	9
	Native forests - conservation	1,200	5
	Plantations	113	2
	Native forests - extensive	13,127	70
Agricultural land		**5,090**	**471**
	Grassland	4,481	445
	Cropland	609	26
Forest and agricultural land		**21,595**	**557**

Source: DoE presentation to *Completing the Picture - Environmental Accounting in Practice* Conference hosted by the ABS, Melbourne 14-15 May 2012.

Table 9 Change in land sector carbon stocks between 2009 and 2010 estimated using data available to the National Inventory System.

Category	Sub-category	Carbon stock change (million t C)	Area (million ha)
Forest land		**13.7**	**0.12**
	Native forests – production	3.1	0.00
	Native forests - conservation	7.0	0.00
	Plantations	3.8	0.02
	Native forests - extensive	-0.3	0.10
Agricultural land		**-24.0**	**0.06**
	Grassland	-19.1	0.04
	Cropland	-5.0	0.02
Forest and agricultural land		**-10.4**	**0.18**

Source: DoE presentation to *Completing the Picture - Environmental Accounting in Practice* Conference hosted by the ABS, Melbourne 14-15 May 2012.

7 CARBON STOCKS IN THE ECONOMY AND LINKING CARBON AND ECONOMIC INFORMATION

7.1 Accumulation in economy

The carbon stock account presented in *SEEA EEA* includes carbon in products accumulated in the economy. Extraction of material from the primary reservoirs in the geosphere and biosphere is the original source of the carbon. Double counting is avoided in the *SEEA EEA* carbon stock account by recording all biomass carbon in the primary reservoir part of the classification. The category Accumulation in the economy comprises:

> Inventories (raw materials, work-in-process products and finished products not yet sold)
> Fixed assets
> Consumer durables
> Waste (discussed in Section 6.2).

Fixed assets and consumer durables align with *SNA* definitions and have a particular meaning of relevance for carbon stock accounting. They refer to products that are not consumed within the year but continue to be used in subsequent years as fixed assets or consumer durables. Accumulations in the economy therefore exclude the carbon in fossil fuels mined and combusted in the year. This carbon is recorded as a stock change in primary reservoirs. Similarly for the products extracted from agricultural systems operating on an annual cycle.

The models and information used by DoE to prepare Australia's *National Inventory Report* contain substantial data suitable for populating the Accumulation in economy component of the carbon stock account. This is set out in Table 10. The main tasks are:

> extending the AGEIS to further disaggregate coal, oil and gas used as non-energy feedstocks
> extending the AGEIS treatment of waste for inert products (e.g. cement)
> separating information on wood products including paper into their native forest (Natural ecosystems) and plantation (Agricultural ecosystems) sources.

Table 10 Scope for Australian greenhouse gas information and information systems to populate carbon stock account for Accumulation in economy**.**

	Accumulation in economy as presented in *SEEA EEA* carbon stock account			
Primary reservoir source of carbon	Inventories	Fixed assets	Consumer durables	Waste
Geocarbon				
Coal, oil and gas	C in uncombusted fossil fuels. **Yes** (AGEIS)	C in non-energy products e.g. plastic, rubber products. **Yes but limited** to annual production of products (derived in process of deducting from BREE energy production statistics non-energy uses of coal, oil and gas).		C in waste stored in managed sites, includes CCS. **Yes but limited** (AGEIS stock-flow modelling used for estimating waste emissions).
Carbonate rocks (e.g. limestone)	**No**			**No** (because cement is inert).
Biocarbon				
Natural and semi-natural ecosystems	C in products made using biomass from natural and semi-natural ecosystems i.e. largely wood products using native forests. Note: carbon stocks in natural ecosystems are reported in Primary reservoirs. **Yes** (for wood products if plantation wood products can be separated out).			C in waste stored in managed sites, mainly disposed wood products including paper. **Yes** (for wood products if plantation products can be separated).
Agricultural ecosystems				
	C in crops in storage. **Yes** (using CAMag and ABS information)	Carbon stocks are recorded in Primary reservoirs. Consumption usually occurs within the year and therefore is not part of Accumulation in economy.		
Pasture	Not relevant (with minor exceptions e.g. hay and silage).	Carbon stocks are recorded in Primary reservoirs.		
Horticulture	C in harvested crops in storage. **Yes** (using CAMag and ABS information).	Carbon stocks are recorded in Primary reservoirs. Consumption usually occurs within the year and therefore is not part of Accumulation in economy.		
Plantations for wood	C stored in wood products made from plantation grown wood. Carbon in plantations is recorded in Primary reservoirs. **Yes** (if plantation wood products can be separated from products made using native forest wood).			C in waste wood products including paper stored in managed sites. **Yes** (if plantation products can be separated from products made using native forest wood).

51. **What priority should be given to populating Accumulation to economy?**

52. **What priority should be given to separating plantation and native forest based wood products for consistency with the ecosystem classification?**

53. **Is there a particular *SNA*/economic analysis need to separate carbon stocks in fixed assets and consumer durables?**

7.2 Linking carbon and economic information

A major attraction of the carbon stock accounting framework presented in *SEEA EEA* is its consistency with the *SNA*. This was achieved through the purposeful consistency in accounting concepts, standards and classifications. It should be noted that the *SEEA EEA* carbon stock account reports information in physical units, not monetary units.

This consistency means that carbon information can be analysed together with economic information and other associated information, for example employment, to generate useful information for policy making. Generating the most value from linked carbon-economic information systems will be achieved if carbon stock accounts are integrated with the carbon flow accounts underpinning Australia's *National Inventory Report*. Guided by the *SNA*, the ABS generates stock and flow economic information because economic analysis requires both. Stock and flow information is also required for climate change policy and research. The research to prepare this discussion paper suggests that the information systems for the economy and climate change can be linked through common frameworks, classifications and concepts but it will require planning and time. Separately, DoE and the ABS have built a substantial platform for such an information system:

> Through the AGEIS, DoE collects and collates substantial carbon stock data and has built, maintains and refines carbon stock and flow models (mostly for biocarbon but also for estimating emissions from inorganic waste).

> The ABS, through its engagement with the UN Statistics Division, has participated in the development of *SEEA EEA* within the *SNA/SEEA Central Framework* and therefore helped generate an accounting framework that enables the linkage.

> Concordance tables between the IPCC sectors and the ANZSIC have been developed by the ABS and DoE.

54. **Do the information benefits of integrated carbon stock and flow accounts linked with the economic stock and flow accounts justify the necessary investment in time and resources to develop the framework, methods and information for such an account?**

8 STOCK CHANGE CLASSIFICATION

Reporting carbon stocks is relatively straight forward in that the item being measured or estimated is the element carbon (C). The processes that generate carbon stock changes entail the formation of many compounds, namely CO_2, CH_4, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs). These compounds are all relevant for DoE in its preparation of Australia's *National Inventory Report* with CO_2 and CH_4 reporting priorities.

55. Conceptually, is it best to develop a carbon stock and flow accounting framework comprehensively covering all carbon compounds and placing a priority on CO_2 in populating the account? Should a separate CH_4 stock and flow account be developed and linked with the carbon stock account?

8.1 Stock changes, flows and netting

The net flow to a stock (inflows less outflows) is the instantaneous rate of change of the stock: calculated using differential calculus. From the dynamics of the stock, we can deduce the behaviour of the net flows. Similarly, we can integrate the flow information to deduce the behaviour of the stocks. In practice however, we usually cannot measure stocks and flows instantly and so we set a time period – for e.g. hourly, daily, monthly, quarterly, annually – for measurement/estimation and calculate averages. As the length of the measurement interval shrinks, the reported average rate becomes a better approximation of the instantaneous rate. Whether the cost of finer time scaling is justified depends on the type of measurement, the purpose of the information and the nature of the systems being measured.

When stock changes are used to report flows, it means the flows are regarded as quantities: collections of individual items that cannot be divided into arbitrarily small units (Sterman 2000, p. 207). Sterman (2000) argues that whilst the instantaneous value of a flow cannot be measured, most flows at some stage are discrete quantities. In other words stock changes, integral equations and differential equations present the same information.

Irrespective of whether stock change or flow data are used to populate the carbon stock account, it is important to separate additions to carbon stocks from reductions to carbon stocks and minimise the reporting of net flow/stock changes. Netting eliminates information about the different processes affecting stock levels, thereby reducing the usefulness of reported information for policy, research and public understanding. Exceptions exist, for example aggregation will not result in loss of information in systems where the different flows are determined by the same processes and have the same lifetimes in the individual stocks.

For ecosystems, reporting emissions and removals separately at appropriate time scales is problematic because of concurrent photosynthesis, respiration and decomposition processes. The essence of the problem is that the flows of gross primary production (GPP = annual amount of carbon uptake by photosynthesis) and net primary production (NPP = GPP less plant respiration i.e. carbon available to produce new biomass) can move at different rates for different ecosystems and environmental conditions (Keeling and Phillips 2007; Keith *et al*. 2009). A spatially fixed statistical unit (see Section 2.2) is a potential way forward. One of the sets of information that could be pinned to each unit is an estimate of the ratio of NPP:GPP (proportion of carbon uptake used for biomass production) using site specific information. NPP could then be estimated spatially by multiplying GPP for each statistical unit by the NPP:GPP ratio estimated for that statistical unit.

8.2 Stock change classification

The *SEEA EEA* carbon stock account adopts the *SEEA Central Framework* classifications for additions and reductions to the stock measured in physical units (European Commission *et al*. 2012, para 5.48 – 5.49). These in turn are crafted on the *SNA* with its long history of refinement to enhance the usefulness of the data, particularly for time series applications, by separating system process effects on stocks from changes due to statistical methods (e.g. reclassifications) and data quality improvements (e.g. reappraisals).

The row entries in the *SEEA EEA* account comprise opening stock, additions, reductions and closing stock. Additions to and Reductions in stock have been split between managed and natural expansion. Additional rows for imports and exports have been included, thus making the table a stock account, as distinct from an asset account.

There are six types of additions in the carbon stock account.

Natural expansion: These additions reflect increases in the stock of carbon over an accounting period due to natural growth. This will be effectively only for biocarbon and may arise from climatic variation, ecological factors such as reduction in grazing pressure, and indirect human impacts such as the CO_2 fertilisation effect (where higher atmospheric CO_2 concentrations cause faster plant growth).

Managed expansion: These additions reflect increases in the stock of carbon over an accounting period due to human-managed growth. This will be for biocarbon in ecosystems and Accumulations in economy, in inventories, consumer durables, fixed assets and waste stored in controlled land fill sites including the injection of greenhouse gases into the earth.

Discoveries of new stock: These additions concern the arrival of new resources to a stock and commonly arise through exploration and evaluation. This applies mainly, perhaps exclusively, to geocarbon.

Upwards reappraisals: These additions reflect changes due to the use of updated information that permits a reassessment of the physical size of the stock. The use of updated information may require the revision of estimates for previous periods to ensure a continuity of time series.

Reclassifications: Reclassifications of carbon assets will generally occur in situations in which another environmental asset is used for a different purpose, for example increases in carbon in Semi-natural ecosystems by the establishment of a national park on an area used for agriculture would be equalised by an equivalent decrease in Agricultural ecosystems. Here, it is only the land use that has changed; that is, reclassifications may have no impact on the total physical quantity of carbon.

Imports: A line for imports is shown to enable accounting for imports of produced goods (e.g. petroleum products).

There are five types of reductions in the carbon stock account.

Natural contraction: These reductions reflect natural, including episodic, losses of stock during the course of an accounting period. They may be due to changing distribution of ecosystems (e.g. a contraction of Natural ecosystems) or biocarbon losses that might reasonably be expected to occur based on past experience. Natural contraction includes losses from episodic events including drought, some fires and floods, and pest and disease attacks. Natural contraction also includes losses due to volcanic eruptions, tidal waves and hurricanes.

Managed contraction: These are reductions in stock due to human activities and include the removal or harvest of carbon through a process of production. This includes mining of fossil fuels and felling of timber. Extraction from ecosystems includes both those quantities that continue to flow through the economy as products (including waste products) and those quantities of stock that are immediately returned to the environment after extraction because they are unwanted, for example, discarded timber residues. Managed contraction also includes losses as a result of a war, riots and other political events; and technological accidents such as major toxic releases.

Downwards reappraisals: These reductions reflect changes due to the use of updated information that permits a reassessment of the physical size of the stock. The reassessments may also relate to changes in the assessed quality or grade of the natural resource. The use of updated information may require the revision of estimates for previous periods to ensure a continuity of time series.

Reclassifications: Reclassifications of carbon assets will generally occur in situations in which another environmental asset is used for a different purpose, for example decreases in carbon in Ecosystems agriculture by the establishment of a national park on an area used for agriculture would be equalised by an equivalent increase in Semi-natural ecosystems. Here it is only the land use that has changed; that is, reclassifications have no impact on the total physical quantity of carbon.

Exports: A line for exports is shown to enable accounting for exports of produced goods (e.g. petroleum products).

8.3 Using AGEIS to report stock changes

Australia's *National Inventory Report* reports flow information under IPCC guidelines, however the information systems used to prepare the report are highly relevant for populating a carbon stock account. In the geocarbon area, DoE has developed accounting methods and information systems which incorporate stock information; in the biocarbon area, DoE uses a stock-based model to estimate the flows of carbon generated by human activities and increasingly for natural processes. A decision to link carbon stock and flow accounts and report this information is sensible but the linkage is a project in its own right and requires decisions about accounting system mapping, classifications and stock change components for each carbon reservoir.

56. **Should Australia develop an integrated carbon stock and flow accounting framework?**

57. **Is the *SEEA EEA* stock change classification system useful?**

Anthropogenic and non-anthropogenic activities

A feature of Australia's *National Inventory Report* is the focus on human-induced greenhouse gas flows. Separating human-induced from natural effects is a challenge, particularly for the land sector. The IPCC and *SEEA* take different approaches, reflecting their different purposes, histories and experiences. Australia's *National Inventory Report* includes two sets of accounts: one compiled using the rules for reporting to the UNFCCC and the other to rules applicable to the Kyoto Protocol. In UNFCCC inventories, the land sector is divided into six land use categories with countries reporting net emissions from managed lands, considered to be due to anthropogenic activities. In the Kyoto Protocol, the land sector is divided on the basis of activities as well as land use categories. In both cases, emissions and removals from unmanaged lands are deemed natural and therefore not reported. What constitutes managed and unmanaged land and the on-going changes to negotiated agreements bring accounting challenges particularly for time-series information systems that have not evolved from the principle of comprehensive coverage.

The *SEEA EEA* with its institutional linkage to the *SNA* is strong on comprehensiveness in the initial framing of the accounts: priorities for populating the accounts are another matter. This approach therefore more readily accommodates institutional and other changes with limited disruption to aggregated time series data. From this base, the *SEEA EEA* allows for the separation of anthropogenic from non-anthropogenic generated stock changes with entries for Natural expansion/contraction and Managed expansion/contraction. However, it does not provide guidance on how to do the separation.

A related issue is the *SNA* treatment of catastrophic losses and maintaining linkage between economic statistics and the carbon stock account. The *SEEA EEA* splits catastrophic losses, as defined in the *SNA*, between Managed contraction and Natural contraction. Managed contraction includes fires deliberately lit to reduce the risk of uncontrolled wild fires. Also for the purposes of accounting, human accidents, such as rupture of oil wells, would also be included under Managed contraction. Catastrophic losses could, however, be separately identified in the table or a related table to facilitate linkage to *SNA* generated information.

Like the ABS, DoE reports quarterly emissions information in its original form and seasonally adjusted. Since 2012, DoE has extended the format of its time series data to include a weather normalised series. This series adjusts the seasonally adjusted and trend estimates to correct for the effects of variations around average seasonal temperatures (Australian Government 2013a, p. 35). This approach may have potential to help in the separation of anthropogenic from non-anthropogenic emissions and removals in a carbon accounting system covering all terrestrial and marine ecosystems irrespective of land use.

58. What approaches, including those currently used for UNFCCC and Kyoto Protocol accounts, should be investigated for separating anthropogenic from non-anthropogenic factors?

APPENDIX A – GLOSSARY

This glossary applies to key words used in the paper. References are provided where definitions are sourced externally, including those amended but without change in meaning. Some words are excluded from the glossary because, as discussed in the text, they have multiple meanings and require further consideration, for example 'waste' and 'Australian territory'.

Account
A set of data recording stocks and flows for a given region generated from a comprehensive and consistent framework.

Agricultural ecosystems
Human designed, engineered and maintained systems on agricultural lands that grow animals and crops mainly for food, wood and fibre and as feedstocks for biofuels and other materials. Plantations of trees for timber, fruit or biomass production are included in the agricultural ecosystem.

Biocarbon
Carbon stored in the biosphere, in living and dead biomass and soils in terrestrial and marine vegetated ecosystems.

Biodiversity
Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (1).

Biosphere
The part of the Earth system comprising all ecosystems and living organisms in the atmosphere, on land (terrestrial biosphere), or in the oceans (marine biosphere), including derived dead organic matter such as litter, soil organic matter, and oceanic detritus (2). Soils are included.

Carbon carrying capacity
The mass of carbon able to be stored in an ecosystem under prevailing environmental conditions and natural disturbance regimes, but excluding anthropogenic disturbance (3, 4).

Carbon density
The mass of carbon stored per unit area in a given ecosystem or landscape at a specified time.

Carbon stock
The quantity of carbon in a reservoir.

Ecosystem
A system of interacting living organisms together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth (2). In this paper ecosystems are categorised as Natural ecosystems, Semi-natural ecosystems, Agricultural ecosystems, and Other ecosystems.

Emissions
The release of greenhouse gases and/or their precursors into the atmosphere over a period of time: a flow (6).

Flow
Inflows and outflows that increase or decrease the amount of stocks. A flow is measured over a specified time period (e.g. a year).

Fossil carbon
Carbon compounds formed from the concentrated remains of prehistoric plants and animals, e.g. coal, oil, gas and unconventional oil and gas deposits (not including peat).

Geocarbon
Carbon stored in the geosphere, in fossil fuel deposits including coal, oil and gas, shale oil, sedimentary rocks including limestone, deep ocean sediments and methane clathrates, and the Earth's crust.

Geosphere
The solid parts of earth, as distinct from the atmosphere, hydrosphere and biosphere.

Gg
A gigagram is equal to 1,000,000,000 grams (1.0 x 10^9 grams) or 1,000 tonnes. UNFCCC inventories report in Gg CO_2-e.

GHG inventory
National greenhouse gas inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases prepared according to UNFCCC or Kyoto accounting provisions (5).

Greenhouse gas (GHG)
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent – but very powerful – greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (7).

Gross primary production
In carbon terms, the gross primary production of a defined ecosystem or area is the carbon uptake in biomass from photosynthesis over a period of time (see also net primary production).

Intergovernmental Panel on Climate Change (IPCC)
Scientific body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) to review and assess scientific, technical and socio-economic information about climate change and its consequences.

Kyoto Protocol
Intergovernmental agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC) which sets binding emission reduction targets for developed economies for the commitment period 2008-2012.

Natural ecosystems
These terrestrial and marine ecosystems are largely the product of natural and ongoing evolutionary, ecological and biological processes. The key mechanism of 'management' in natural ecosystems is natural selection operating on populations of species which has the effect over time of optimising system level properties and the traits of component species. System-level properties which are naturally optimised with respect to, among other things, environmental conditions include canopy density, energy use, nutrient cycling, resilience, and adaptive capacity. Natural processes dominate natural ecosystems within which human cultural and traditional uses also occur.

Net primary production
In carbon terms, the net primary production of an ecosystem or area is the gross primary production minus plant (autotrophic) respiration over a defined period. The carbon stock change over the period is the net primary production less turnover (emissions from mortality of plants or parts of plants through for example leaf fall, fine root death and harvesting of crops) and less soil microbial (heterotrophic) respiration (see also gross primary production).

Other ecosystems
Ecosystems other than natural, semi-natural and agricultural, including settlements and land with infrastructure.

Pg
A petagram is equal to 1,000,000,000,000,000 grams (1.0 x 10^{15} grams) or 1 billion tonnes.

Pool
A component of a reservoir.

Removal
Removal of greenhouse gases from the atmosphere (e.g. the sequestration of CO_2 through habitat restoration) over a period of time (a flow). Removals can occur from anthropogenic or non-anthropogenic processes (6).

Report
Information extracted from an Account to meet a user need, for example to support research, the policy process or public understanding.

Reservoir
A component or components of the climate system where a GHG or its precursor is stored (7). In this paper, 'primary reservoirs' are the reservoirs in the geosphere and biosphere; the release of carbon by human activity from 'primary reservoirs' is the primary cause of global warming.

Resilience
The capacity of a system to absorb disturbance and still retain its basic function and structure (8).

Restoration time
The time needed to restore the carbon density of an ecosystem to its pre-existing level after degradation or disturbance.

Semi-natural ecosystems
Human modified natural ecosystems where natural processes, including regenerative processes, are still in operation to varying degrees. However, the system is often prevented from reaching ecological maturity or is maintained in a degraded state due to human disturbance and land use. Thus, the vegetation structure may not reflect natural optima, and the taxonomic composition may be depauperate.

Sequestration
The process of increasing the carbon content of a biosphere or anthropogenic reservoir. Biological approaches to sequestration include removal of CO_2 from the atmosphere through for example, habitat restoration, reforestation and practices that enhance soil carbon in agriculture. Geosequestration is the storage of CO_2 in geological formations, creating an anthropogenic carbon stock. 'Sequestration' is used as a verb (a flow) or a noun (a stock) and users of the word should clarify what they mean when appropriate.

Sink
Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere. Forests and other vegetation are considered sinks because they remove CO_2 through photosynthesis (7).

Soil
The layer of fine material covering the Earth's land surface influenced by and influencing plants and soil organisms. It is composed of minerals from decomposition of rocks (over geological time) and organic matter, and contains two main types of carbon. Inorganic carbon is derived from weathering of parent material (lithogenic) or formed by chemical processes of dissolution of CO_2 and precipitation of carbonates within the soil. Organic carbon is derived from biomass; it is

the below ground carbon component of decomposed or partially decomposed fragments of plants, including roots and root exudates, and animals including soil microbes.

Source
A process, activity or mechanism that causes emissions of CO_2 and other greenhouse gases into the atmosphere.

Stock
Stocks are accumulations altered by inflows and outflows. Stock measurements relate to a quantity existing at a point in time.

System of Environmental –Economic Accounting (SEEA)
Handbook providing a common framework for economic and environmental information, permitting a consistent analysis of the contribution of the environment to the economy and of the impact of the economy on the environment (9).

System of National Accounts (SNA)
Statistical framework that provides a comprehensive, consistent and flexible set of macroeconomic accounts for policymaking, analysis and research purposes (10).

United Nations Framework Convention on Climate Change (the Convention)
Intergovernmental agreement to reduce global warming and adapt to the consequences of unavoidable climate change (11).

References for glossary

1. Convention on Biological Diversity. http://www.cbd.int/convention/articles/?a=cbd-02
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APPENDIX B – SCHEDULE OF UNITS AND CONVERSION FACTORS

Factor	Number	SI prefix	SI symbol	Common language
1,0E+15	1,000,000,000,000,000	peta-	P	
1,0E+12	1,000,000,000,000	tera-	T	
1,0E+9	1,000,000,000	giga-	G	billion
1,0E+6	1,000,000	mega-	M	million
1,0E+3	1,000	kilo-	k	thousand
1,0E+2	100	hecto-	h	hundred
1,0E+1	10	deca-	da	ten
1,0E-1	0.1	deci-	d	
1,0E-2	0.01	centi-	c	
1,0E-3	0.001	milli-	m	
1,0E-6	0.000 001	micro-	µ	
1,0E-9	0.000 000 001	nano-	n	

Converting C to CO_2	1 g C = 0.083 mole CO_2 = 3.664 g CO_2
Converting ppm to tonnes of C	1 ppm by volume of atmosphere CO_2 = 2.13 Gt C (Uses atmospheric mass (M_a) = 5.137×10^{18} kg)

Source: Carbon Dioxide Information Analysis Centre n.d

APPENDIX C – BIOCARBON STOCKS AUSTRALIA: INFORMATION SOURCES AND METHODS

This Appendix should be read in conjunction with the text (Sections 3.3 and 4.3).

Table A1 Disaggregation of Australian biocarbon stocks by ecosystem type: information sources and methods. Estimates generated for illustrative purposes to assist discussion about methods and information sources for regularly reporting carbon stocks.

Ecosystem	Area (million ha)[1]	Biocarbon stock (million t C)	Biomass carbon density (t C/ha)	Soil organic carbon density (t C/ha)[2]	Information sources and methods
NATURAL ECOSYSTEMS					
Rangelands - terrestrial					Regions are modified Grazing Land Management Zones (GLMZ) based on IBRA subregions as presented in Fisher *et al*. 2004 and adjusted using ALUM V 6.[3] GLMZ 10 (Highly modified rangelands) was allocated to Semi-natural ecosystems.
Arnhem Land and Tiwi Islands	10.1	606.2	25	35	Average biomass and soil carbon densities for each GLMZ were derived using Fisher *et al*. 2004; Hunt *et al.* 2013; Hunt pers. comm.; Murphy *et al*. 2003.
Tropical Savannas	115.6	4,622.0	20	20	As above
Mitchell Grass Downs	33.6	604.8	3	15	As above
Einasleigh and Desert Uplands, North Qld	18.9	1,136.4	35	25	As above
Arid Deserts	166.2	1,661.5	5	5	As above
Central Australia Cattle Grazing	54.3	814.1	5	10	As above
Pilbara: Extensive Cattle Grazing in Tussock and Hummock Grasslands	17.9	716.0	30	10	As above
South Australia Sheep and Cattle Grazing	128.9	1,289.0	5	5	As above
Extensive Sheep grazing	50.9	1,527.0	15	15	As above
Total rangelands - terrestrial	596.3	12,977			
Non rangelands - terrestrial					Area for each vegetation type derived using selected ALUCM V. 6 land use categories (Conservation and Natural Environments and Production from Relatively Natural Environments) outside of the GLMZ by area of NVIS4.1 present vegetation cover.

Eucalypt native forest					
Eucalypt Low Open Forests	0.4	186	280	225	Biomass carbon density derived using Mackey *et al*. 2008 estimate of carbon carrying capacity (CCC) in south east Australia's 14.5 million ha of eucalypt native forests (p. 28) and adjusted down to allow for stock losses from logging (p. 37). Guided by the findings of Rab 1994, 1999 & 2004 and Diochon *et al*. 2009 that soil carbon reductions from logging was not permanent but lasted for a few decades and assuming current land use arrangements, soil carbon density was assumed to be at 80 per cent of CCC reported in Mackey *et al*. 2008 p. 28.
Eucalypt Open Forests	13.1	6,612	280	225	Biomass carbon density derived using Mackey *et al*. 2008 estimate of carbon carrying capacity (CCC) in south east Australia's 14.5 million ha of eucalypt native forests (p. 28) and adjusted down to allow for stock losses from logging (p. 37). Soil carbon density was assumed to be at 80 per cent of CCC reported in Mackey *et al*. 2008 p. 28.
Eucalypt Tall Open Forests	3.2	1,626	280	225	Biomass carbon density derived using Mackey *et al.* 2008 estimate of carbon carrying capacity (CCC) in south east Australia's 14.5 million ha of eucalypt native forests (p. 28) and adjusted down to allow for stock losses from logging (p. 37). Soil carbon density was assumed to be at 80 per cent of CCC reported in Mackey *et al*. 2008 p. 28.
Total eucalypt native forest	16.7	8,424	280	225	
Shrublands & woodlands					
Acacia Forests and Woodlands	0.1	4	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Acacia Open Woodlands	0.0	0	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Acacia Shrublands	0.3	16	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Callitris Forests and Woodlands	0.4	17	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Casuarina Forests and Woodlands	0.1	4	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Chenopod Shrublands, Samphire Shrublands and Forblands	0.1	4	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Eucalypt Open Woodlands	0.4	29	40	40	Biomass carbon density calculated using Berry *et al*. 2010 average for uncleared Myall woodland, Coolabah and BimbleBox woodland. Soil carbon density sourced from Berry *et al*. 2010, pp. 79 - 81.
Eucalypt Woodlands	6.8	545	40	40	Biomass carbon density calculated using Berry *et al*. 2010 average for uncleared Myall woodland, Coolabah and BimbleBox woodland. Soil carbon density sourced from Berry *et al*. 2010, pp. 79 - 81.

Low Closed Forests and Tall Closed Shrublands	0.5	204	300	150	Carbon densities based on forest and rainforest densities.
Mallee Open Woodlands and Sparse Mallee Shrublands	0.2	10	80	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Mallee Woodlands and Shrublands	4.1	198	80	40	Carbon densities reported in Berry *et al.* 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Melaleuca Forests and Woodlands	0.2	17	40	40	Biomass carbon density calculated using Berry *et al*. 2010 average for uncleared Myall woodland, Coolabah and BimbleBox woodland. Soil carbon density sourced from Berry *et al*. 2010, pp. 79 - 81.
Other Forests and Woodlands	0.5	36	40	40	Biomass carbon density calculated using Berry *et al*. 2010 average for uncleared Myall woodland, Coolabah and BimbleBox woodland. Soil carbon density sourced from Berry *et al*. 2010, pp. 79 - 81.
Other Open Woodlands	0.1	4	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Other Shrublands	1.0	47	8	40	Carbon densities reported in Berry *et al*. 2010 p. 11 Table 4.2 total biomass and soil in shrublands and non eucalypt dominated woodlands.
Total shrublands & woodlands	14.7	1,137			
Grass, shrub & heathlands					
Heathlands	0.5	23	30	15	Biomass carbon density based on the average living AGB and BGB of 37 t C/ha for studies presented in Berry *et al*. 2010 (p. 75). This figure was increased to 40 t C/ha to allow for dead biomass. Soil carbon density is an informed guess.
Hummock Grasslands	0.0	0	20	15	Carbon densities based on amended figures for heathlands.
Other Grasslands, Herblands, Sedgelands and Rushlands	0.9	54	20	40	Biomass carbon density is a guess assuming it will be less than heathland. Soil carbon density is based on native grass land used for agriculture (Chan *et al*. 2010, table 1).
Tussock Grasslands	0.2	11	20	40	Applied carbon densities used for Other Grasslands, Herblands, Sedgelands and Rushlands.
Total Grass, shrub & heathlands	1.6	87			
Rainforests & vine thickets					
Queensland, NSW & Vic	1.6	894	475	80	Carbon densities in AGB in Queensland upland and lowland wet tropics were sourced from Bradford *et al*. 2013 and Liddell *et al*. 2007 and scaled up using Matt Bradford pers. comm. To include course woody debris and understory species. Carbon density in BGB estimated using Lima *et al*. 2012. Soil carbon densities for Queensland rainforest areas were sourced from Webb 2002. Biomass carbon density for NSW and Victoria assumed to match those of Queensland.

Tasmania	0.7	583	636	170	Biomass and soil carbon density for Tasmanian rainforests are the average of those reported in May *et al*. 2013 and include a 5 per cent scaling up factor for non woody understory. (Note: May *et al.* 2013 includes higher density eucalypt trees in rainforest ecosystems.)
Total Rainforests & vine thickets	2.3	1,477			
Other terrestrial					
Naturally bare - sand, rock, claypan, mudflat	0.2	1	0	5	Soil carbon density based on arid desert ecosystem.
Regrowth, modified native vegetation	0.3	27	40	40	A guess.
Unclassified native vegetation	0.2	4	40	40	A guess.
Total Other terrestrial	0.7	32			
Freshwater ecosystems					
Inland aquatic - freshwater, salt lakes, lagoons	9.9[4]	11	20	40	A guess. Ephemeralness will affect the estimate significantly, eg how carbon dense red gums are classified (woodlands or freshwater ecosystems) will depend on water levels. Density figures were applied to vegetated area not water surface area.
Marine ecosystems					
Mangroves		439	80	300	Carbon densities are global averages for biomass and soil presented in Laffoley and Grimsditch 2009 and Steven 2011. NVIS area data used.
Sea and estuaries		759	3	111	Carbon densities are global averages for biomass and soil presented in Laffoley and Grimsditch 2009 and Steven 2011. NVIS area data used.
Total Marine ecosystems	1.8[4]	1,198	139	154	
Total Natural ecosystems	641.7	25,343			
SEMI-NATURAL ECOSYSTEMS					
Highly Modified Rangelands	50.0	2,250	15	30	Average biomass and soil carbon densities were derived using Fisher *et al*. 2004; Hunt 2013; Leigh Hunt pers. comm.; Murphy *et al*. 2003.
Grazing in modified pastures (outside Rangelands GLMZ)	32.9	1,447	4	40	Carbon densities based on Chan *et al*. 2010; Helen King pers. comm.
Total Semi-natural ecosystems	82.9	3,697			
AGRICULTURAL ECOSYSTEMS					Land use and area data derived from ALUM V. 6. Includes Rangeland areas used for agriculture as specified in footnote 3. Excludes Semi-natural ecosystems (see above).

Cropping					
Cropping	25.5	1,124	4	40	Cropping biomass average 10t/ha AGB (dry) (Conyers 2012); average root to shoot ratio at maturity of 0.4 (Siddique *et al*. 1990); dry biomass is 50% C; divide by 2 to give C density in middle of crop cycle. Soil carbon density derived from Baldock 2009.
Irrigated agriculture					
Irrigated cropping	1.3	57	4	40	Carbon densities as for cropping.
Irrigated modified pastures	0.9	41	4	40	Carbon densities as for cropping.
Irrigated perennial horticulture	0.3	15	8	40	Carbon densities as for Intensive horticulture.
Irrigated seasonal horticulture	0.1	4	8	40	Carbon densities as for Intensive horticulture.
Total Irrigated agriculture	2.6	117			
Plantation forestry					
Irrigated plantation forestry	0.0	0.2			See Plantation forestry.
Plantation forestry	2.4	296			See footnote 5.
Total plantation forestry	2.4	296			
Other agriculture					
Intensive animal production	0.3	2	0	5	A guess.
Intensive horticulture	0.0	0.2	8	40	Assumed biomass carbon density was twice that for cropping.
Perennial horticulture	0.1	5	8	40	Carbon densities as for Intensive horticulture.
Seasonal horticulture	0.0	0.4	8	40	Carbon densities as for Intensive horticulture.
Cleared, non-native vegetation, buildings	5.9	356	20	40	A guess.
Reservoirs and dams	0.6[4]	7	2	10	A guess.
Total Other agriculture	6.9	370			
Total Agricultural ecosystems	37.4	1,907			
SETTLEMENTS					Area data sourced from ALUM V. 6.
Manufacturing and industrial	0.1		0	0	Carbon stocks in buildings and infrastructure reported in Accumulation in economy, ie not classified as biocarbon.

Residential	2.0		15	40	Biomass carbon density of 15 t C/ha was applied based on Killey *et al*. 2009 who reported an average density of 12 t C/ha for urban Canberra comprising trees in public streetscapes and mown parks and reserves and excluding vegetation in residential or other gardens in 2008. Kirkpatrick 2011 reported an average 85 trees/ha in south eastern Australia suburban gardens.
Services	0.3		0	0	Carbon stocks in buildings and infrastructure reported in Accumulation in economy, ie not classified as biocarbon.
Transport and communication	0.1		0	0	Carbon stocks in buildings and infrastructure reported in Accumulation in economy, ie not classified as biocarbon.
Utilities	0.0		0	0	Carbon stocks in buildings and infrastructure reported in Accumulation in economy, ie not classified as biocarbon.
Waste treatment and disposal	0.0		0	0	Carbon stocks in buildings and infrastructure reported in Accumulation in economy, ie not classified as biocarbon.
Total Settlements	2.6	108			
OTHER					
Mining	0.2	6	0	40	A guess.
Unknown/no data	0.3	20	20	40	A guess.
Total Other	0.5	26			
AUSTRALIA TOTAL BIOCARBON	767.4	31,081			

1. Reported to one decimal place: 0.0 entries do not imply there is no vegetation cover or carbon stock. Figures may not add precisely due to rounding.
2. Soil organic carbon to 30 cm depth except for marine ecosystems where the estimate was taken to 100 cm depth.
3. Areas deducted and incorporated in other ecosystems comprise Cropping, Estuary/coastal waters, Intensive animal production, Intensive horticulture, Irrigated cropping, Irrigated modified pastures, Irrigated perennial horticulture, Irrigated plantation forestry, Irrigated seasonal horticulture, Lake, Manufacturing and industrial, Marsh/wetland, Mining, Perennial horticulture, Plantation forestry, Reservoir/dam, Residential, River, Seasonal horticulture, Services, Transport and communication, Utilities, Waste treatment and disposal, Blank (no data).
4. Surface area using ALUM V. 6, ie not vegetated area which was used to estimate carbon stocks and stock density.
5. Carbon density of plantation biomass calculated as follows:
   - Australian estate is 50:50 softwood:hardwood species.
   - Softwood now managed as even aged plantation over rotations of 30 years; average MAI (commercial) = 16m^3/ha/yr (Ajani 1995); 1 t = 1 m^3; stem: residual AGB+BGB = 1:0.7 (Polglase *et al*. 2000); dry biomass is half green biomass by weight; dry biomass is 50 per cent carbon by weight; divide by 2 to derive average biomass carbon in middle of crop cycle.
   - Hardwood managed over rotations of 12 years; average MAI (commercial) = 18m^3/ha/yr; 1 t = 1 m^3; residual AGB+BGB = 1:0.7 (Polglase *et al*. 2000); dry biomass is half green biomass by weight; dry biomass is 50 per cent carbon by weight; divide by 2 to derive average biomass carbon in middle of crop cycle.
   - Average softwood and hardwood plantation soil carbon density (50 t C/ha) was derived using Chee 1999; Polglase *et al*. 2000 and May *et al*. 2013.

APPENDIX D – MAIN INFORMATION PROVIDERS/SOURCES FOR AUSTRALIAN GREENHOUSE GAS REPORTING

Information	Data providers*
Fuel combustion	National Greenhouse and Energy Reporting System (NGERS) Bureau of Resource and Energy Economics (BREE) Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian Bureau of Statistics (ABS)
Fugitive emissions	NGERS BREE Australian Petroleum Production and Exploration Association (APPEA) Department of Employment, Economic Development and Innovation, Queensland (DEEDI) Coal Services Pty Ltd Energy Supply Association of Australia (ESAA)
Industrial processing	NGERS DoE ABARES ABS
Agriculture and forestry	ABS Stage agriculture and forestry agencies ABARES and National Forest Inventory Commonwealth Scientific and Industrial Research Organisation (CSIRO) Bureau of Meteorology (BoM) Geoscience Australia
Waste	NGERS State waste management agencies ABARES ABS

*Less significant industry information sources are detailed throughout the inventory.
Source: Australian Government 2013a, pp 5-6.

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